

حل مراجعة نهائية وفق الهيكل الوزاري منهج انسابير



تم تحميل هذا الملف من موقع المناهج الإماراتية

موقع المناهج ← المناهج الإماراتية ← الصف العاشر المتقدم ← كيمياء ← الفصل الثالث ← ملفات متنوعة ← الملف

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المزيد من مادة
كيمياء:

إعداد: Diab Ahmed

التواصل الاجتماعي بحسب الصف العاشر المتقدم



صفحة المناهج
الإماراتية على
فيسبوك

الرياضيات

اللغة الانجليزية

اللغة العربية

التربية الاسلامية

المواد على تلغرام

المزيد من الملفات بحسب الصف العاشر المتقدم والمادة كيمياء في الفصل الثالث

حل تجميعية مراجعة عامة وفق الهيكل الوزاري

1

تجميعية صفحات الكتاب وفق الهيكل الوزاري منهج بريدج

2

تجميعية تدريبات صفحات الكتاب وفق الهيكل الوزاري منهج بريدج

3

تجميعية أسئلة شاملة وفق الهيكل الوزاري باللغتين العربية والانجليزية

4

مراجعة امتحانية شاملة وفق الهيكل الوزاري

5

Academic Year	2024/2025
العام الدراسي	
Term	3
الفصل	
Subject	Chemistry /Inspire
المادة	الكيمياء / إنسباير
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الصف	
Stream	Advanced
المسار	
Number of MCQ عدد الأسئلة الموضوعية	25
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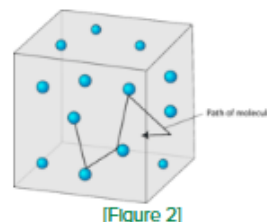
Prepared By
Mr. Ahmed Diab

The Kinetic-Molecular Theory

The **kinetic-molecular theory** is a **theory** that explains the **states of matter** and is based on the idea that matter is composed of tiny particles that are always in motion. The theory helps explain observable properties and behaviors of solids, **liquids**, and **gases**. However, the theory is most easily understood as it applies to gases and it is with gases that we will begin our detailed study. The theory applies specifically to a model of a gas called an **ideal gas**. An ideal gas is an imaginary gas whose behavior perfectly fits all the assumptions of the kinetic-molecular theory. In reality, gases are not ideal, but are very close to being so under most everyday conditions.

The kinetic-molecular theory as it applies to gases has five basic assumptions.

- 1. Gases consist of very large numbers of tiny spherical particles that are far apart from one another compared to their size.** The particles of a gas may be either atoms or molecules. The distance between the particles of a gas is much, much greater than the distances between the particles of a liquid or a solid. Most of the volume of a gas, therefore, is composed of the empty space between the particles. In fact, the volume of the particles themselves is considered to be insignificant compared to the volume of the empty space.
- 2. Gas particles are in constant rapid motion in random directions.** The fast motion of gas particles gives them a relatively large amount of **kinetic energy**. Recall that kinetic energy is the **energy** that an object possesses because of its motion. The particles of a gas move in straight-line motion until they collide with another particle or with one of the walls of its container.
- 3. Collisions between gas particles and between particles and the container walls are elastic collisions.** An elastic collision is one in which there is no overall loss of kinetic energy. Kinetic energy may be transferred from one particle to another during an elastic collision, but there is no change in the total energy of the colliding particles.
- 4. There are no forces of attraction or repulsion between gas particles.** Attractive forces are responsible for particles of a **real gas** condensing together to form a liquid. It is assumed that the particles of an ideal gas have no such attractive forces. The motion of each particle is completely independent of the motion of all other particles.
- 5. The average kinetic energy of gas particles is dependent upon the temperature of the gas.** As the temperature of a sample of gas is increased, the speeds of the particles are increased. This results in an increase in the kinetic energy of the particles. Not all particles of gas in a sample have the same speed and so they do not have the same kinetic energy. The temperature of a gas is proportional to the average kinetic energy of the gas particles.



Gas particles are in random straight-line motion according to the kinetic-molecular theory. The space between particles is very large compared to the particle size.

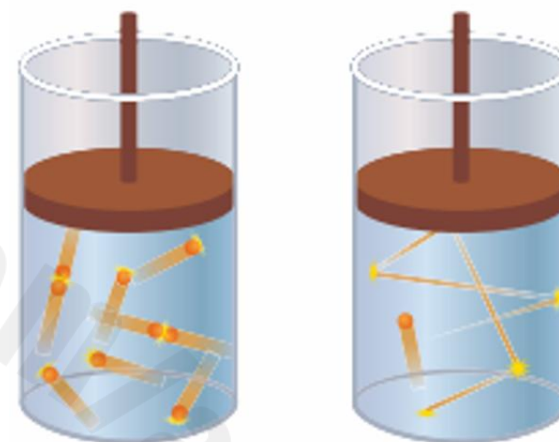


Figure 2 Kinetic energy can be transferred between gas particles during an elastic collision. Between collisions, the particles move in straight lines.

Explain the influence that gas particles have on each other, both in terms of collisions and what happens to particles between collisions.

Greek word meaning *to move*. Objects in motion have energy called kinetic energy. The **kinetic-molecular theory** describes the behavior of matter in terms of particles in motion. The model makes several assumptions about the size, motion, and energy of gas particles.

Two factors determine the kinetic energy of a particle: mass and velocity. The kinetic energy of a particle can be represented by the following equation.

$$KE = \frac{1}{2} mv^2$$

gases effused into a vacuum—space containing no matter. He discovered an inverse relationship between effusion rates and molar mass. **Graham's law of effusion** states that the rate of effusion for a gas is inversely proportional to the square root of its molar mass.

Graham's Law

$$\text{Rate of effusion} \propto \frac{1}{\sqrt{\text{molar mass}}}$$

The rate of diffusion or effusion of a gas is inversely proportional to the square root of its molar mass.

$$\frac{\text{Rate}_A}{\text{Rate}_B} = \sqrt{\frac{\text{molar mass}_B}{\text{molar mass}_A}}$$

EXAMPLE Problem 1

GRAHAM'S LAW Ammonia has a molar mass of 17.0 g/mol; hydrogen chloride has a molar mass of 36.5 g/mol. What is the ratio of their diffusion rates?

$$= \sqrt{\frac{36.5 \text{ g/mol}}{17.0 \text{ g/mol}}} = 1.47$$

Substitute molar mass_{HCl} = 36.5 g/mol and molar mass_{NH₃} = 17.0 g/mol.

The ratio of diffusion rates is 1.47.

PRACTICE Problems



1. Calculate the ratio of effusion rates for nitrogen (N₂) and neon (Ne).
2. Calculate the ratio of diffusion rates for carbon monoxide and carbon dioxide.
3. **CHALLENGE** What is the rate of effusion for a gas that has a molar mass twice that of a gas that effuses at a rate of 3.6 mol/min?

1. احسب نسبة معدلات التدفق للنيتروجين (N₂) والنيون (Ne).

المعطيات :

الغاز الأول N₂ كتلته المولية = 28 = 14 × 2
الغاز الثاني Ne كتلته المولية = 20

المطلوب :

نسبة معدل التدفق = ؟

$$\sqrt{\frac{\text{الكتلة المولية B}}{\text{الكتلة المولية A}}} = \frac{\text{المعدل A}}{\text{المعدل B}}$$

2. احسب نسبة معدلات الانتشار لأول أكسيد الكربون وثاني أكسيد الكربون.

المعطيات :

الغاز الأول CO كتلته المولية = 28 = 12 + 16
الغاز الثاني CO₂ كتلته المولية = 44 = 12 + 2(16)

المطلوب :

نسبة معدل التدفق = ؟

$$\sqrt{\frac{\text{الكتلة المولية B}}{\text{الكتلة المولية A}}} = \frac{\text{المعدل A}}{\text{المعدل B}}$$

Neon
10
Ne
20.180

Nitrogen
7
N
14.007

الحل :

$$\frac{\text{معدل تدفق لـ } N_2}{\text{معدل تدفق لـ } Ne} = \frac{\text{الكتلة المولية لـ } Ne}{\text{الكتلة المولية لـ } N_2}$$

$$\frac{\text{معدل تدفق لـ } N_2}{\text{معدل تدفق لـ } Ne} = \frac{20}{28}$$

$$= 0.845$$

Carbon
6
C
12.011

Oxygen
8
O
15.999

الحل :

$$\frac{\text{معدل تدفق لـ } CO}{\text{معدل تدفق لـ } CO_2} = \frac{\text{الكتلة المولية لـ } CO_2}{\text{الكتلة المولية لـ } CO}$$

$$\frac{\text{معدل تدفق لـ } CO}{\text{معدل تدفق لـ } CO_2} = \frac{44}{28}$$

$$= 1.254$$

3. Challenge What is the rate of effusion for a gas that has a molar mass twice that of a gas that effuses at a rate of 3.6 mol/min?

3. تحدي ما هو معدل التدفق للغاز الذي تكون كتلته المولية ضعفي كتلة غاز يتدفق بمعدل 3.6 mol/min ؟

الحل

المعطيات :

الكتلة المولية للغاز الأول = 2

الكتلة المولية للغاز الثاني = 1

معدل التدفق للغاز الثاني = 3.6 mol/min

المطلوب :

معدل التدفق للغاز الأول = ؟

$$\sqrt{\frac{\text{الكتلة المولية B}}{\text{الكتلة المولية A}}} = \frac{\text{المعدل A}}{\text{المعدل B}}$$

$$\sqrt{\frac{1}{2}} = \frac{\text{معدل التدفق للغاز الأول}}{3.6}$$

$$3.6 \times \sqrt{\frac{1}{2}} = \text{معدل التدفق للغاز الأول}$$

$$\text{معدل التدفق للغاز الأول} = 2.5 \text{ mol/min}$$

احسب نسبة معدلات الانتشار لأول أكسيد الكربون وثاني أكسيد الكربون.

(Molar masses: CO = 28.01 g/mol, CO₂ = 44.01 g/mol)

a. 1.25

b. 1.15

c. 1.47

d. 1.95

Four identical balloons were filled with different gases to the same volume.
Which balloon does the gas effuse the fastest from it?

أربع بالونات متطابقة تم ملؤها بنفس الحجم من غازات مختلفة.
أي البالونات سيتدفق الغاز منه بشكل أسرع؟

CCl ₄	Cl ₂	N ₂	CO ₂	الكتلة المولية Molar Mass (g/mol)
154	71	28	44	

The Least M. Wt
The Fastest

CO₂

CCl₄

N₂

Cl₂

Neon (Ne) has a molar mass of 20.0 g/mol;

غاز النيون له كتلة مولية 20.0 g/mol، وغاز كلوريد الهيدروجين له

and Hydrogen Chloride (HCl) has a molar mass of 36.5 g/mol.

كتلة مولية 36.5 g/mol.

What is the ratio of their diffusion rates?

ما هي نسبة معدلات انتشارها؟

0.54

$$\frac{r_{\text{Ne}}}{r_{\text{HCl}}} = \sqrt{\frac{36.5}{20.0}} = \sqrt{1.825} \approx 1.35$$

0.77

$$\frac{r_{\text{Ne}}}{r_{\text{HCl}}} \approx 1.35$$

1.35

1.83

An unknown gas diffuses 1.25 times faster than
N₂O₄ gas. What is the molar mass of unknown gas?
(molar mass of carbon dioxide gas N₂O₄= 92.0 g/mol)

غاز مجهول يتدفق أسرع بـ 1.25 مرات من غاز N₂O₄.
ما الكتلة المولية للغاز المجهول؟
(الكتلة المولية لغاز ثاني أكسيد الكربون N₂O₄ = 92.0 g/mol)

$$1.25 = \sqrt{\frac{92.0}{M_1}}$$

$$1.5625 = \frac{92.0}{M_1}$$

$$M_1 = \frac{92.0}{1.5625} \approx 58.9 \text{ g/mol}$$

36.2 g/mol

58.9 g/mol

7.7 g/mol

18.6 g/mol

☐

☐

☐

☐

Units of pressure

The SI unit of pressure is the pascal (Pa). It is named for Blaise Pascal (1623–1662), a French mathematician and philosopher. The pascal is derived from the SI unit of force, the newton (N). One **pascal** is equal to a force of one newton per square meter: 1 Pa equals 1 N/m².

At sea level, the average air pressure is 101.3 kPa when the temperature is 0°C. Air pressure is often reported in a unit called an atmosphere (atm). One **atmosphere** is equal to 760 mmHg or 760 torr or 101.3 kilopascals (kPa). **Table 1** compares different units of pressure. Because the units 1 atm, 760 mmHg, and 760 torr are defined units,

Table 1 Comparison of Pressure Units

Unit	Number Equivalent to 1 atm	Number Equivalent to 1 kPa
Kilopascal (kPa)	101.3 kPa	—
Atmosphere (atm)	—	0.009869 atm
Millimeters of mercury (mmHg)	760 mmHg	7.501 mmHg
Torr	760 torr	7.501 torr
Pounds per square inch (psi or lb/in ²)	14.7 psi	0.145 psi
Bar	1.01 bar	0.01 bar

<http://www.ilpi.com/msds/ref/pressureunits.html>

Dalton's law of partial pressures

When Dalton studied the properties of gases, he found that each gas in a mixture exerts pressure independently of the other gases present. Illustrated in **Figure 7, Dalton's law of partial pressures** states that the total pressure of a mixture of gases is equal to the sum of the pressures of all the gases in the mixture. The portion of the total pressure contributed by a single gas is called its partial pressure. The partial pressure of a gas depends on the number of moles of gas, the size of the container, and the temperature of the mixture. It does not depend on the identity of the gas. At a given temperature and pressure, the partial pressure of 1 mol of any gas is the same.

$$P_{\text{total}} = P_1 + P_2 + P_3 + \dots P_n$$

يعتمد الضغط الجزئي للغاز على :

- عدد مولاته .
- حجم الوعاء .
- درجة حرارته .

ولا يعتمد الضغط الجزئي للغاز على نوعه .

EXAMPLE Problem 2

THE PARTIAL PRESSURE OF A GAS A mixture of oxygen (O_2), carbon dioxide (CO_2), and nitrogen (N_2) has a total pressure of 0.97 atm. What is the partial pressure of O_2 if the partial pressure of CO_2 is 0.70 atm and the partial pressure of N_2 is 0.12 atm?

$$P_{\text{total}} = P_{\text{N}_2} + P_{\text{CO}_2} + P_{\text{O}_2}$$

$$P_{\text{O}_2} = P_{\text{total}} - P_{\text{CO}_2} - P_{\text{N}_2}$$

$$P_{\text{O}_2} = 0.97 \text{ atm} - 0.70 \text{ atm} - 0.12 \text{ atm}$$

$$P_{\text{O}_2} = 0.15 \text{ atm}$$

PRACTICE Problems

ADDITIONAL PRACTICE

- What is the partial pressure of hydrogen gas in a mixture of hydrogen and helium if the total pressure is 600 mmHg and the partial pressure of helium is 439 mmHg?
- Find the total pressure for a mixture that contains four gases with partial pressures of 5.00 kPa, 4.56 kPa, 3.02 kPa, and 1.20 kPa.
- Find the partial pressure of carbon dioxide in a gas mixture with a total pressure of 30.4 kPa if the partial pressures of the other two gases in the mixture are 16.5 kPa and 3.7 kPa.
- CHALLENGE** Air is a mixture of gases. By percentage, it is roughly 78 percent nitrogen, 21 percent oxygen, and 1 percent argon. (There are trace amounts of many other gases in air.) If the atmospheric pressure is 760 mmHg, what are the partial pressures of nitrogen, oxygen, and argon in the atmosphere?

4. ما هو الضغط الجزئي لغاز الهيدروجين في خليط من الهيدروجين والهيليوم إذا كان الضغط الكلي هو 600 mmHg والضغط الجزئي لغاز الهيليوم هو 439 mmHg؟

المعطيات :

$$P_{He} = 439 \text{ mmHg}$$

$$P_{total} = 600 \text{ mmHg}$$

المطلوب :

$$P_{H_2} = ?$$

الحل :

$$P_{total} = P_{H_2} + P_{He}$$

$$600 = P_{H_2} + 439 \text{ mmHg}$$

$$P_{H_2} = 161 \text{ mmHg}$$

6. احسب الضغط الجزئي لثاني أكسيد الكربون في خليط من الغازات ذو ضغط كلي يساوي 30.4 kPa إذا كان الضغطان الجزئيان لاثنتين من الغازات الأخرى في الخليط هما 16.5 kPa و 3.7 kPa .

المعطيات :

$$P_{total} = 30.4 \text{ KPa}$$

$$P_2 = 16.5 \text{ kPa}$$

$$P_3 = 3.7 \text{ kPa}$$

المطلوب :

$$P_{CO_2} = ?$$

الحل :

$$P_{total} = P_{CO_2} + P_2 + P_3$$

$$30.4 = P_{CO_2} + 16.5 + 3.7$$

$$P_{CO_2} = 10.2 \text{ KPa}$$

5. ما الضغط الكلي لخليط يحتوي على أربع غازات ضغطها الجزئية كالتالي 5.00 kPa ، 4.56 kPa ، 3.02 kPa و 1.20 kPa .

المعطيات :

$$P_1 = 5.00 \text{ kPa}$$

$$P_2 = 4.56 \text{ kPa}$$

$$P_3 = 3.02 \text{ kPa}$$

$$P_4 = 1.20 \text{ kPa}$$

المطلوب :

$$P_{total} = ?$$

الحل :

$$P_{total} = 5.00 + 4.56 + 3.02 + 1.20$$

$$P_{total} = 13.78 \text{ kPa}$$

7. تحدي الهواء هو خليط من الغازات، يتكون من نحو 78% من النيتروجين 21% أكسجين و 1% أرجون. (هناك كميات ضئيلة من غازات عديدة أخرى في الهواء.) إذا كان الضغط الجوي هو 760 mmHg، ما الضغوط الجزئية للنيتروجين والأكسجين والأرجون في الغلاف الجوي؟

الضغط الجزئي للغاز = الضغط الكلي × النسبة المئوية للغاز

الضغط الجزئي للنيتروجين

$$\text{الضغط الجزئي} = 78\% \times 760$$

$$\text{الضغط الجزئي} = 592.8 \text{ mmHg}$$

What is the partial pressure

What is the total pressure for a mixture that contains three gases with partial pressures of 1.35 kPa, 3.81 kPa, and 5.22 kPa?

ما الضغط الكلي لخليط يحتوي على ثلاث غازات ضغوطها الجزئية كالتالي 5.22 kPa ، 3.81 kPa ، 1.35 kPa ؟

What is the partial pressure of carbon dioxide in a gas mixture with a total pressure of 40.8 kPa ,if the partial pressures of the other two gases in the mixture are 18.4 kPa and 7.50 kPa.



a. 8.50

b. 10.2

c. 5.20

d. 14.9

7.68 kPa

10.38 kPa

12.76 kPa

6.57 kPa

$$P_3 = P_{\text{total}} - (P_1 + P_2) = 40.8 - (18.4 + 7.5) = 14.9 \text{ kPa}$$

$$P_{\text{total}} = 1.35 + 3.81 + 5.22 = 10.38 \text{ kPa}$$

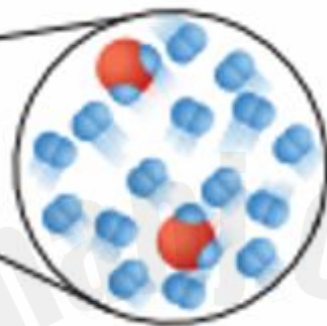


Figure 8 In the flask, sulfuric acid (H_2SO_4) reacts with zinc to produce hydrogen gas. The hydrogen is collected at 20°C .

Calculate the partial pressure of hydrogen at 20°C if the total pressure of the hydrogen and water vapor mixture is 100.0 kPa .

As the gas collects, it displaces the water. The gas collected in the container will be a mixture of hydrogen and water vapor. Therefore, the total pressure inside the container will be the sum of the partial pressures of hydrogen and water vapor.

As you will read later, knowing the pressure, volume, and temperature of a gas allows you to calculate the number of moles of the gas. Temperature and volume can be measured during an experiment. Once the temperature is known, the partial pressure of water vapor is used to calculate the pressure of the gas. The known values for volume, temperature, and pressure are then used to find the number of moles.

Boyle's Law

$$P_1 V_1 = P_2 V_2$$

Boyle's law states that the volume of a fixed amount of gas held at a constant temperature varies inversely with the pressure. Look at the graph in Figure 1, on the previous page, in which volume versus pressure is plotted for a gas. The plot of an inversely proportional relationship results in a downward curve.

temperature and the amount of gas are constant, doubling the pressure decreases the volume by one-half. On the other hand, reducing the pressure by one-half doubles the volume. A relationship in which one variable increases proportionally as the other variable decreases is known as an inversely proportional relationship.

EXAMPLE Problem 1

BOYLE'S LAW A diver blows a 0.75-L air bubble 10 m under water. As it rises to the surface, the pressure goes from 2.25 atm to 1.03 atm. What will be the volume of air in the bubble at the surface?

Known

$$V_1 = 0.75 \text{ L}$$

$$P_1 = 2.25 \text{ atm}$$

$$P_2 = 1.03 \text{ atm}$$

Unknown

$$V_2 = ? \text{ L}$$

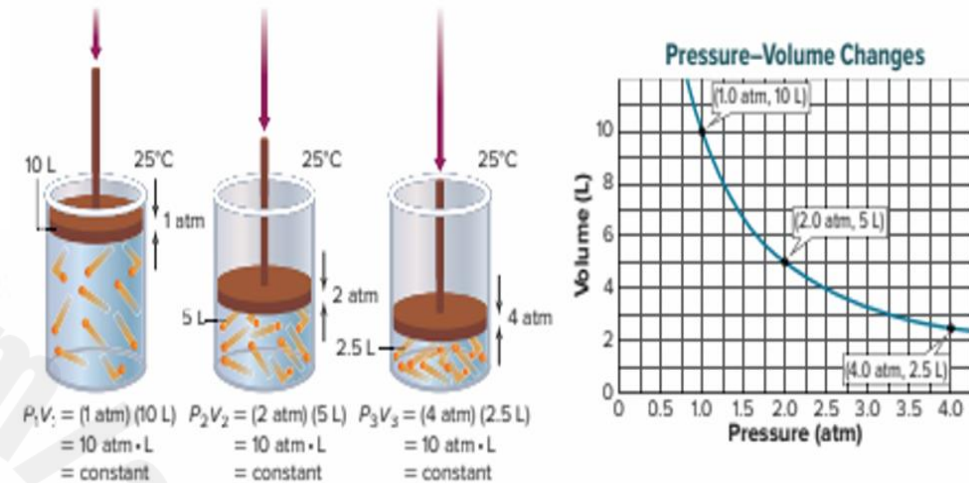


Figure 1 As the external pressure on the cylinder's piston increases, the volume inside the cylinder decreases. The graph shows the inverse relationship between pressure and volume.

$$P_1 V_1 = P_2 V_2$$

$$V_2 = V_1 \left(\frac{P_1}{P_2} \right)$$

$$V_2 = 0.75 \text{ L} \left(\frac{2.25 \text{ atm}}{1.03 \text{ atm}} \right)$$

$$V_2 = 0.75 \text{ L} \left(\frac{2.25 \cancel{\text{ atm}}}{1.03 \cancel{\text{ atm}}} \right) = 1.6 \text{ L}$$



Assume that the temperature and the amount of gas are constant in the following problems.

1. The volume of a gas at 99.0 kPa is 300.0 mL. If the pressure is increased to 188 kPa, what will be the new volume?
2. The pressure of a sample of helium in a 1.00-L container is 0.988 atm. What is the new pressure if the sample is placed in a 2.00-L container?
3. **CHALLENGE** Air trapped in a cylinder fitted with a piston occupies 145.7 mL at 1.08 atm pressure. What is the new volume when the piston is depressed, increasing the pressure by 25%?

1. إذا كان حجم غاز عند ضغط 99.0 kPa هو 300 mL. وأصبح الضغط 188 kPa فما الحجم الجديد؟
2. إذا كان ضغط عينة من غاز الهيليوم في إناء حجمه 1.00 L هو 0.988 atm، فما مقدار ضغط هذه العينة إذا نُقِلَتْ إلى وعاء حجمه 2.00 L؟
3. تحفيز إذا كان مقدار حجم غاز محصور تحت مكبس أسطوانة 145.7 mL، و ضغطه 1.08 atm، فما حجمه الجديد عندما يزداد الضغط بمقدار 25%؟

$$V_1 P_1 = V_2 P_2 \Rightarrow V_2 = \frac{V_1 P_1}{P_2}$$

$$V_2 = \frac{(300.0 \text{ mL})(99.0 \text{ kPa})}{188 \text{ kPa}} = 158 \text{ mL}$$

$$V_1 P_1 = V_2 P_2 \Rightarrow P_2 = \frac{P_1 V_1}{V_2}$$

$$P_2 = \frac{(0.988 \text{ atm})(1.00 \text{ L})}{2.00 \text{ L}} = 0.494 \text{ atm}$$

$$P_2 = (1.08 \text{ atm}) + (25\% \times 1.08 \text{ atm}) = 1.35 \text{ atm}$$

$$V_1 P_1 = V_2 P_2 \Rightarrow V_2 = \frac{V_1 P_1}{P_2}$$

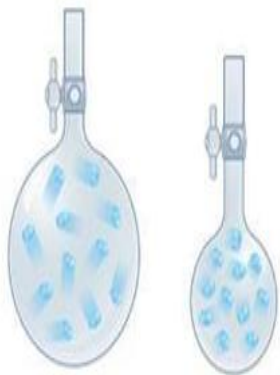
$$V_2 = \frac{(145.7 \text{ mL})(1.08 \text{ atm})}{1.35 \text{ atm}} = 117 \text{ mL}$$

The pressure of a sample of helium in a 1.0 L container is 0.857 atm. What is the pressure if the same sample is placed in a 0.50 L container?
(Assume that the temperature is constant.)

ضغط عينة من الهيليوم في حاوية سعة 1.0 L هو 0.857 atm
ما الضغط إذا تم وضع نفس العينة في حاوية سعة 0.50L؟
(افترض أن درجة الحرارة ثابتة)

Increasing the pressure on the balloon's gas shown in the figure below, how that would affect the balloon's volume at constant temperature?

عند ازدياد الضغط على الغاز في البالون الموضح بالشكل أدناه،
ما تأثير ذلك على حجم البالون عند ثبات درجة الحرارة؟



Boyle's Law

$$P_1 V_1 = P_2 V_2$$



doubling the pressure decreases the volume by one-half.

0.44 atm

It will increase

سوف يزداد

1.4 atm

It will decrease

سوف يقل

1.7 atm

It will stay the same

سيبقى كما هو

0.14 atm

It will increase triple times

يزداد ثلاثة أضعاف

The volume of a gas is 400.0 mL, and the pressure is 1.00 atm.
When the volume of the gas is 2.0 L, what is the pressure,
if the temperature remains the same?

حجم غاز 400.0 ml وعند ضغط 1.00 atm
إذا أصبح حجم الغاز 2.0 L ، ما ضغط الغاز عند
نفس درجة الحرارة؟

Boyle's Law

$$P_1 V_1 = P_2 V_2$$

0.20 atm

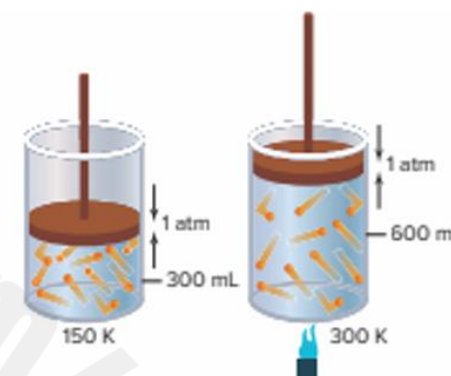
0.5 atm

5.0 atm

0.80 atm

As you can see in **Figure 2**, the volume occupied by a gas at 1 atm increases as the temperature in the cylinder increases. The distance the piston moves is a measure of the increase in volume of the gas as it is heated. This behavior is explained by the kinetic-molecular theory: as temperature increases, gas particles move faster, striking the walls of their container more frequently and with greater force. Because pressure depends on the frequency and force with which gas particles strike the walls of their container, this would increase the pressure. For the pressure to stay constant, volume must increase so that the particles have farther to travel before striking the walls. Having to travel farther decreases the frequency with which the particles strike the walls of the container.

does show a direct proportion. A temperature of 0 K corresponds to 0 mL, and doubling the temperature doubles the volume. Zero on the Kelvin scale is also known as **absolute zero**. Absolute zero represents the lowest possible theoretical temperature. At absolute zero, the atoms are all in the lowest possible energy state.



$$\frac{V_1}{T_1} = \frac{300 \text{ mL}}{150 \text{ K}} = 2 \text{ mL/K} = \text{constant}$$

$$\frac{V_2}{T_2} = \frac{600 \text{ mL}}{300 \text{ K}} = 2 \text{ mL/K} = \text{constant}$$

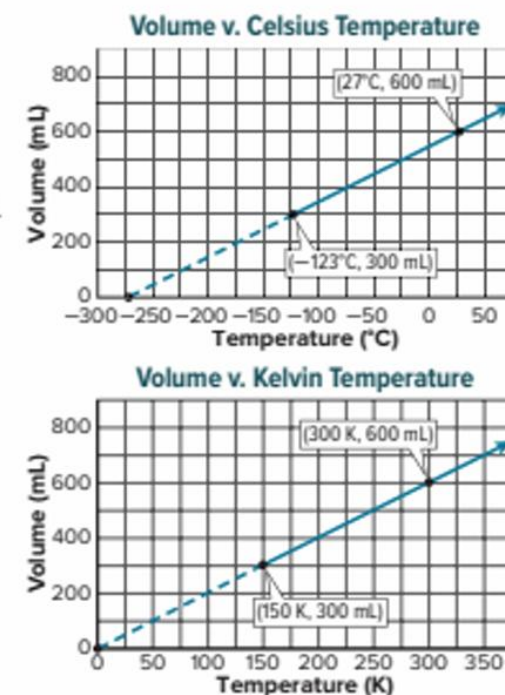


Figure 2 When the cylinder is heated, the kinetic energy of the gas particles increases, causing them to push the piston outward. The graphs show the relationship of volume to Celsius and Kelvin temperatures.

Charles's law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$T_K = 273 + T_C$$

EXAMPLE Problem 2

CHARLES'S LAW A helium balloon in a closed car occupies a volume of 2.32 L at 40.0°C. If the car is parked on a hot day and the temperature inside rises to 75.0°C, what is the new volume of the balloon, assuming the pressure remains constant?

Convert degrees Celsius to kelvin.

$$T_k = 273 + T_c$$

$$T_1 = 273 + 40.0^\circ\text{C} = 313.0 \text{ K}$$

$$T_2 = 273 + 75.0^\circ\text{C} = 348.0 \text{ K}$$

Use Charles's law. Solve for V_2 .

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$V_2 = V_1 \left(\frac{T_2}{T_1} \right)$$

$$V_2 = 2.32 \text{ L} \left(\frac{348.0 \text{ K}}{313.0 \text{ K}} \right)$$

$$V_2 = 2.32 \text{ L} \left(\frac{348.0 \text{ K}}{313.0 \text{ K}} \right) = 2.58 \text{ L}$$

PRACTICE Problems

Assume that the pressure and the amount of gas remain constant in the following problems.

- What volume will the gas in the balloon at right occupy at 250 K?
- A gas at 89°C occupies a volume of 0.67 L. At what Celsius temperature will the volume increase to 1.12 L?
- The Celsius temperature of a 3.00-L sample of gas is lowered from 80.0°C to 30.0°C. What will be the resulting volume of this gas?
- CHALLENGE** A gas occupies 0.67 L at 350 K. What temperature is required to reduce the volume by 45%?



ADDITIONAL PRACTICE



5. A gas at 89°C occupies a volume of 0.67 L. At what Celsius temperature will the volume increase to 1.12 L?

5. شَغَلَ غازٌ عند درجة حرارة 89 °C حجمًا مقداره (0.67 L). عند أيّ درجة سيليزية سيزيد الحجم ليصل 1.12 L؟

$$T_1 = 89^{\circ}\text{C} + 273 = 362\text{ K}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow T_2 = \frac{T_1 V_2}{V_1}$$

$$T_2 = \frac{(362\text{ K})(1.12\text{ L})}{0.67\text{ L}} = 605\text{ K}$$

$$605\text{ K} - 273\text{ K} = 332^{\circ}\text{C}$$

4. What volume will the gas in the balloon at right occupy at 250 K?

4. ما الحجم الذي يشغله الغاز في البالون الموجود أدناه عند درجة 250 K؟



$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow V_2 = \frac{V_1 T_2}{T_1}$$

$$V_2 = \frac{(4.3\text{ L})(250\text{ K})}{350\text{ K}} = 3.1\text{ L}$$

6. The Celsius temperature of a 3.00-L sample of gas is lowered from 80.0°C to 30.0°C. What will be the resulting volume of this gas?

6. إذا انخفضت درجة الحرارة السيليزية لعينة من الغاز حجمها 3.0 L من 80 °C إلى 30 °C. فما الحجم الجديد للغاز؟

$$T_1 = 80\text{ }^{\circ}\text{C} + 273 = 353\text{ K}$$

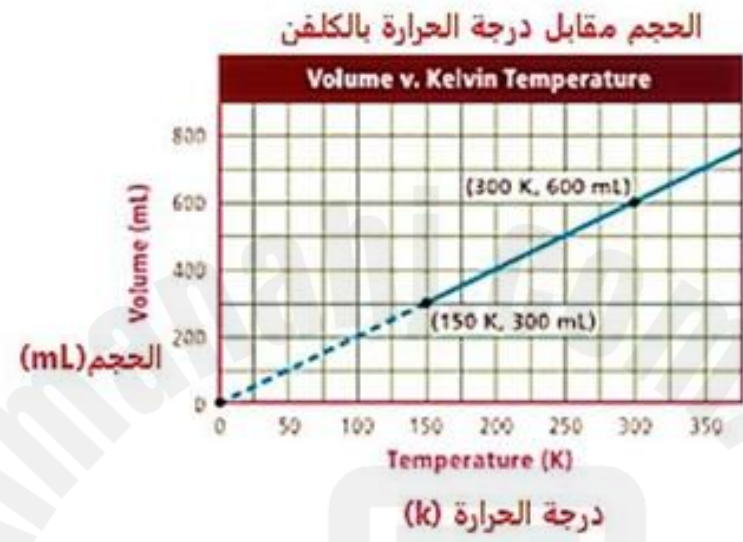
$$T_2 = 30\text{ }^{\circ}\text{C} + 273 = 303\text{ K}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow V_2 = \frac{V_1 T_2}{T_1}$$

$$V_2 = \frac{(3.00\text{ L})(303\text{ K})}{353\text{ K}} = 2.58\text{ L}$$

According to the graph below, which of the following statement is **NOT correct**?

أي العبارات التالية **غير صحيحة** فيما يتعلق بالرسم البياني أدناه؟



Doubling the temperature doubles the volume

عندما تتضاعف درجة الحرارة يتضاعف الحجم

Doubling the temperature does not double the volume

تضاعف درجة الحرارة لا يُسبب تضاعف الحجم

The graph shows a linear relationship.

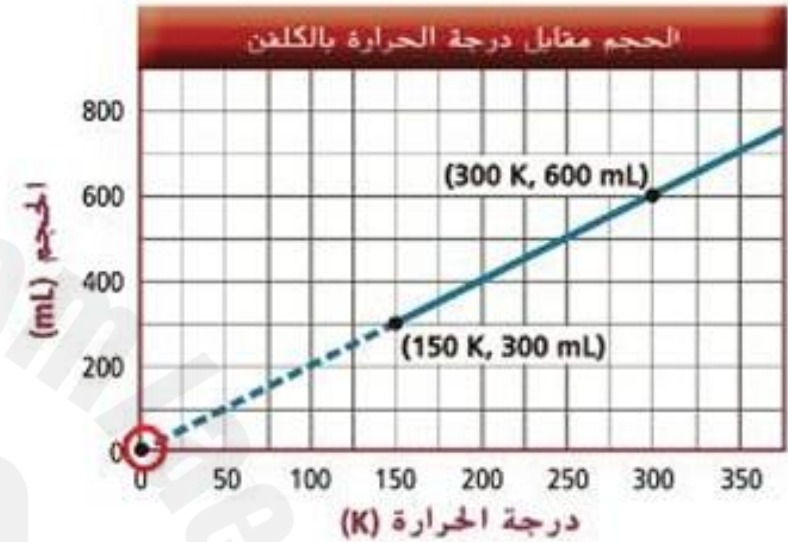
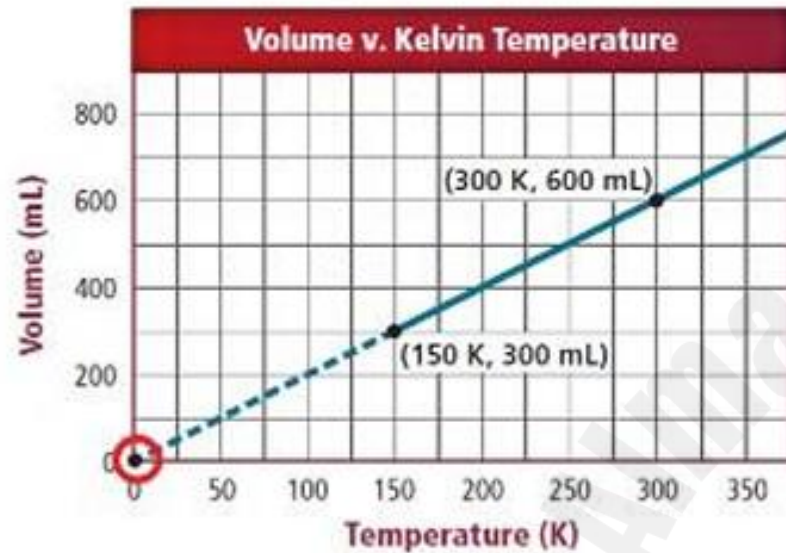
يُمثل الرسم علاقة خطية

The graph shows a directly proportional relationship

يُمثل الرسم علاقة تناسب طردي

What is the point marked in red on the following graph called?

ماذا تُسمى النقطة المميزة بالدائرة الحمراء عليها في المنحني التالي؟



Absolute zero

الصفء المطلق

Boiling point

درجة الغليان

Triple point

النقطة الثلاثية

Critical point

النقطة الحرجة

What is the volume for the gas in the below balloon when temperature changes to 348 K?

ما حجم الغاز الموجود في البالون أدناه عندما تتغير درجة الحرارة إلى 348 K ؟

Charles's law

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$



$$\frac{3.45 \text{ L}}{313.0 \text{ K}} = \frac{V_2}{348 \text{ K}}$$

4.01 L

3.84 L

2.73 L

2.31 L

Joseph Gay-Lussac (1778–1850) found that a direct proportion exists between Kelvin temperature and pressure, as illustrated in Figure 3. **Gay-Lussac's law** states that the pressure of a fixed amount of gas varies directly with the Kelvin temperature when the volume remains constant. It can be expressed mathematically as follows.

Gay-Lussac's Law

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

EXAMPLE Problem 3

GAY-LUSSAC'S LAW The pressure of the oxygen gas inside a canister is 5.00 atm at 25.0°C. The canister is located at a camp high on Mount Everest. If the temperature there falls to −10.0°C, what is the new pressure inside the canister?

Known

$$P_1 = 5.00 \text{ atm}$$

$$T_1 = 25.0^\circ\text{C}$$

$$T_2 = -10.0^\circ\text{C}$$

Convert degrees Celsius to kelvin.

$$T_k = 273 + T_c$$

$$T_1 = 273 + 25.0^\circ\text{C} = 298.0 \text{ K}$$

$$T_2 = 273 + (-10.0^\circ\text{C}) = 263.0 \text{ K}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$P_2 = P_1 \left(\frac{T_2}{T_1} \right)$$

$$P_2 = 5.00 \text{ atm} \left(\frac{263.0 \text{ K}}{298.0 \text{ K}} \right)$$

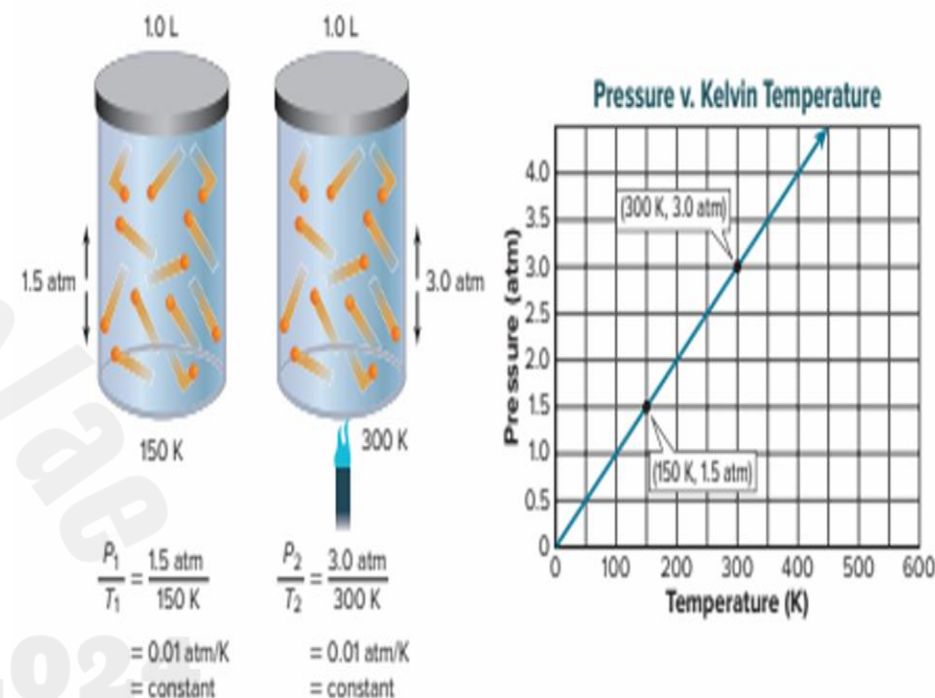


Figure 3 When the cylinder is heated, the kinetic energy of the particles increases, increasing both the frequency and energy of the collisions with the container wall. The volume of the cylinder is fixed, so the pressure exerted by the gas increases.

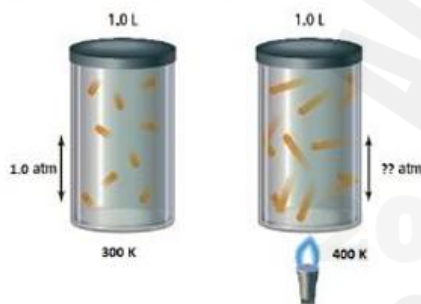
$$P_2 = 5.00 \text{ atm} \left(\frac{263.0 \text{ K}}{298.0 \text{ K}} \right) = 4.41 \text{ atm}$$

Assume that the volume and the amount of gas are constant in the following problems.

8. The pressure in an automobile tire is 1.88 atm at 25.0°C. What will be the pressure if the temperature increases to 37.0°C?
9. Helium gas in a 2.00-L cylinder is under 1.12 atm pressure. At 36.5°C, that same gas sample has a pressure of 2.56 atm. What was the initial temperature in degrees Celsius of the gas in the cylinder?
10. **CHALLENGE** If a gas sample has a pressure of 30.7 kPa at 0.00°C, by how many degrees Celsius does the temperature have to increase to cause the pressure to double?

The pressure for a gas in a cylinder is 1.00 atm at 300 K.

What will be the pressure if the temperature increases to 400 K?



الضغط لغاز في أسطوانة 1.00 atm عند 300 K.

كم سيصبح الضغط إذا زادت درجة الحرارة إلى 400 K؟

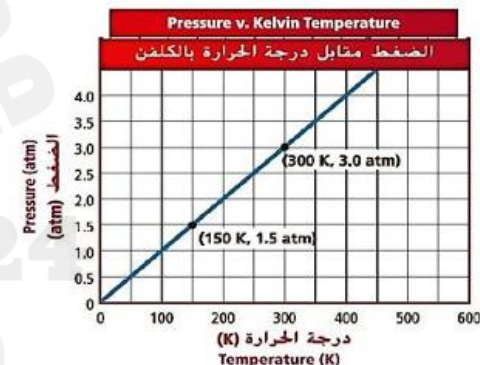
0.75 atm

2.67 atm

2.44 atm

1.30 atm

Which law is represented by the graph below?



ما القانون الذي يُمثله الرسم البياني أدناه؟

Charles's law

قانون شارل

Gay-Lussac's law

قانون جاي لوساك

Henry's Law

قانون هنري

Boyle's Law

قانون بويل

The Combined Gas Law

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Using the combined gas law

The combined gas law enables you to solve problems involving changes in more than one variable. It also provides a way for you to remember the other three laws without memorizing each equation. If you can write out the combined gas law equation, equations for the other laws can be derived from it by remembering which variable is held constant in each case.

Table 1 The Gas Laws

Law	Boyle's	Charles's	Gay-Lussac's	Combined
Formula	$P_1 V_1 = P_2 V_2$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$	$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$
What is constant?	amount of gas, temperature	amount of gas, pressure	amount of gas, volume	amount of gas
Graphic organizer				

EXAMPLE Problem 4

THE COMBINED GAS LAW A gas at 110 kPa and 30.0°C fills a flexible container with an initial volume of 2.00 L. If the temperature is raised to 80.0°C and the pressure increases to 440 kPa, what is the new volume?

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

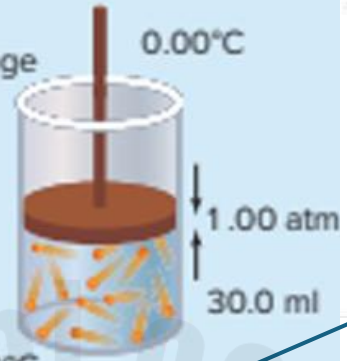
$$V_2 = V_1 \left(\frac{P_1}{P_2} \right) \left(\frac{T_2}{T_1} \right)$$

$$V_2 = 2.00 \text{ L} \left(\frac{110 \text{ kPa}}{440 \text{ kPa}} \right) \left(\frac{353.0 \text{ K}}{303.0 \text{ K}} \right)$$

$$V_2 = 2.00 \text{ L} \left(\frac{110 \text{ kPa}}{440 \text{ kPa}} \right) \left(\frac{353.0 \text{ K}}{303.0 \text{ K}} \right) = 0.58 \text{ L}$$

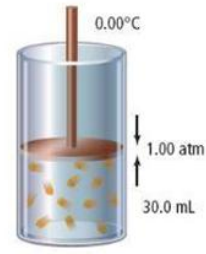
Assume that the amount of gas is constant in the following problems.

- 11. A sample of air in a syringe exerts a pressure of 1.02 atm at 22.0°C. The syringe is placed in a boiling-water bath at 100.0°C. The pressure is increased to 1.23 atm by pushing the plunger in, which reduces the volume to 0.224 mL. What was the initial volume?
- 12. A balloon contains 146.0 mL of gas confined at a pressure of 1.30 atm and a temperature of 5.0°C. If the pressure doubles and the temperature decreases to 2.0°C, what will be the volume of gas in the balloon?
- 13. **CHALLENGE** If the temperature in the gas cylinder at right increases to 30.0°C and the pressure increases to 1.20 atm, will the cylinder's piston move up or down?



A sample of gas starts at 1.00 atm, 0.00° C, and 30.0 mL. What is the volume if the temperature increases to 27.0° C and the pressure increases to 2.00 atm?

عينة من الغاز بدأت عند 1.00 atm عند 0.00°C ، 30.0mL. ما الحجم إذا زادت درجة الحرارة إلى 27.0°C وزاد الضغط إلى 2.00 atm ؟



65.9 mL

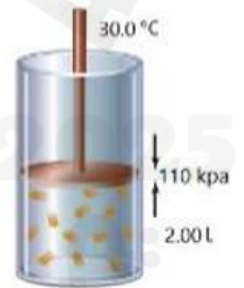
16.5 mL

54.6 mL

13.7 mL

A sample of gas starts at 110.0 kPa, 30.0° C, and 2.00 L. What is the volume in mL if the temperature increases to 80.0° C and the pressure increases to 440.0 kPa?

عينة من الغاز بدأت عند 110.0 kPa عند 30.0°C ، 2.00 L. ما الحجم إذا زادت درجة الحرارة إلى 80.0°C وزاد الضغط إلى 440.0 kPa ؟



18. **Calculate** A rigid plastic container holds 1.00 L of methane gas at 660 torr pressure when the temperature is 22.0°C. How much pressure will the gas exert if the temperature is raised to 44.6°C?

0.64 L

0.58 L

1.3 L

8.1 L

The volume of a sample of gas measured at 25.0°C and 1.00 atm is 5.00 L. If the gas was pressed to 3.00 atm and the volume became 2.00 L what is the final temperature?

حجم عينة من الغاز على درجة حرارة 25°C وضغط 1.00 atm هو 5.00 L. إذا تم ضغط الغاز لـ 3.00 atm وأصبح الحجم 2.00 L فما درجة الحرارة النهائية للغاز؟



$$\begin{aligned} V_1 &= 5.00 \text{ L} \\ P_1 &= 1.00 \text{ atm} \\ T_1 &= 25.0^\circ\text{C} \end{aligned}$$

$$\begin{aligned} V_2 &= 2.00 \text{ L} \\ P_2 &= 3.00 \text{ atm} \end{aligned}$$

$$98.2^\circ\text{C}$$

$$30.0^\circ\text{C}$$

$$84.6^\circ\text{C}$$

$$20.3^\circ\text{C}$$

this idea in 1811. **Avogadro's principle** states that equal volumes of gases at the same temperature and pressure contain equal numbers of particles. **Figure 5** shows equal volumes of carbon dioxide, helium, and oxygen.

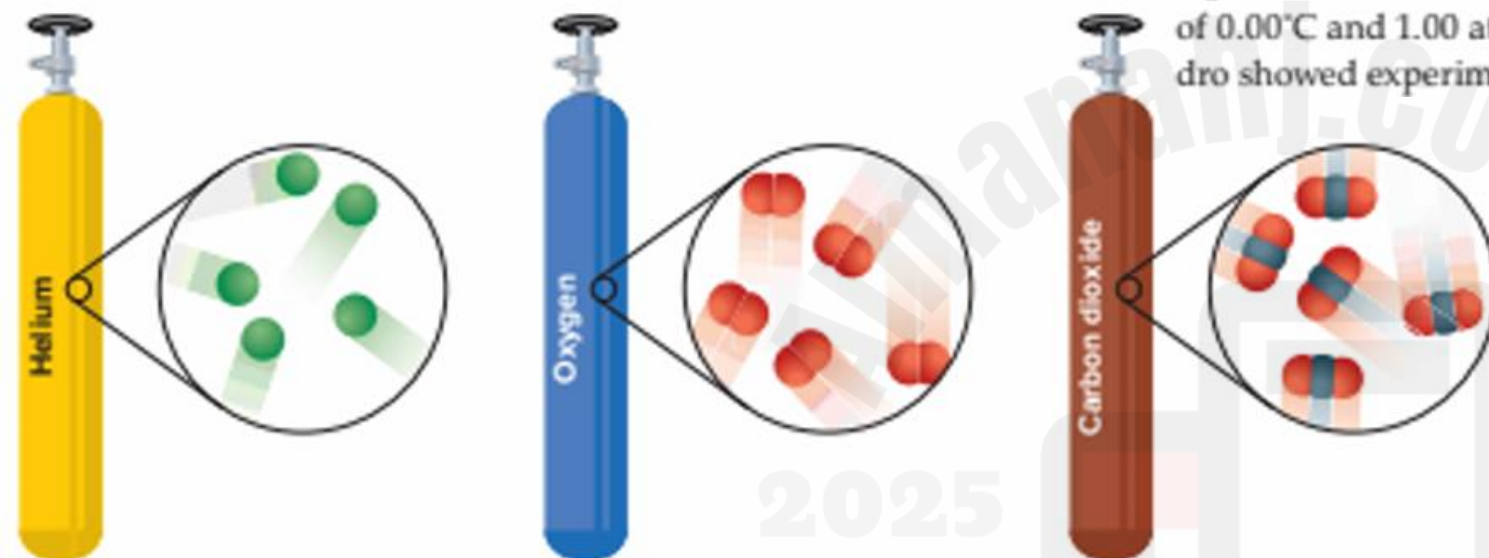


Figure 5 Gas tanks of equal volume that are at the same pressure and temperature contain equal numbers of gas particles, regardless of which gas they contain.

Infer Why doesn't Avogadro's principle apply to liquids and solids?

a gas is the volume that 1 mol occupies at 0.00°C and 1.00 atm pressure. The conditions of 0.00°C and 1.00 atm are known as **standard temperature and pressure (STP)**. Avogadro showed experimentally that 1 mol of any gas occupies a volume of 22.4 L at STP.

Determine the molar mass for methane.

$$\begin{aligned} M &= 1 \text{ C atom} \left(\frac{12.01 \text{ amu}}{1 \text{ C atom}} \right) + 4 \text{ H atoms} \left(\frac{1.01 \text{ amu}}{1 \text{ H atom}} \right) \\ &= 12.01 \text{ amu} + 4.04 \text{ amu} = 16.05 \text{ amu} \\ &= 16.05 \text{ g/mol} \end{aligned}$$

$$2.00 \text{ kg} \left(\frac{1000 \text{ g}}{1 \text{ kg}} \right) = 2.00 \times 10^3 \text{ g}$$

$$\frac{m}{M} = \frac{2.00 \times 10^3 \text{ g}}{16.05 \text{ g/mol}} = 125 \text{ mol}$$

$$V = 125 \text{ mol} \times \frac{22.4 \text{ L}}{1 \text{ mol}} = 2.80 \times 10^3 \text{ L}$$

EXAMPLE Problem 5

MOLAR VOLUME The main component of natural gas used for home heating and cooking is methane (CH_4). Calculate the volume that 2.00 kg of methane gas will occupy at STP.

20. What size container do you need to hold 0.0459 mol of N_2 gas at STP?
21. How much carbon dioxide gas, in grams, is in a 1.0-L balloon at STP?
22. What volume in milliliters will 0.00922 g of H_2 gas occupy at STP?
23. What volume will 0.416 g of krypton gas occupy at STP?
24. Calculate the volume that 4.5 kg of ethylene gas (C_2H_4) will occupy at STP.
25. **CHALLENGE** A flexible plastic container contains 0.860 g of helium gas in a volume of 19.2 L. If 0.205 g of helium is removed at constant pressure and temperature, what will be the new volume?

What is the volume of 7.85 mol sample of gas

at (STP)? (the molar volume is 22.4 L at STP)

A – 1.43 L

B – 2.90 L

C – 88.0 L

D - 176 L

According to Avogadro's principle, 1 mol of any gas
at STP occupies a volume of _____.

رارة

22.4 L

3.72 L

1.00 L

6.02 L

$$\frac{PV}{nT} = \text{constant}$$

Experiments using known values of P , T , V , and n have determined the value of this constant. It is called the **ideal gas constant**, and it is represented by the symbol R .

EXAMPLE Problem 6

THE IDEAL GAS LAW Calculate the number of moles of ammonia gas (NH_3) contained in a 3.0-L vessel at $3.00 \times 10^2 \text{ K}$ with a pressure of 1.50 atm.

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

$$n = \frac{(1.50 \text{ atm})(3.0 \text{ L})}{\left(0.0821 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}\right) (3.00 \times 10^2 \text{ K})}$$

$$n = \frac{(1.50 \text{ atm})(3.0 \text{ L})}{\left(0.0821 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}\right) (3.00 \times 10^2 \text{ K})} = 0.18 \text{ mol}$$

The Ideal Gas Law

$$PV = nRT$$

PRACTICE Problems



ADDITIONAL PRACTICE

26. Determine the Celsius temperature of 2.49 mol of a gas contained in a 1.00-L vessel at a pressure of 143 kPa.
27. Calculate the volume of a 0.323-mol sample of a gas at 265 K and 0.900 atm.
28. What is the pressure, in atmospheres, of a 0.108-mol sample of helium gas at a temperature of 20.0°C if its volume is 0.505 L?
29. If the pressure exerted by a gas at 25°C in a volume of 0.044 L is 3.81 atm, how many moles of gas are present?
30. **CHALLENGE** An ideal gas has a volume of 3.0 L. If the number of moles of gas and the temperature are doubled, while the pressure remains constant, what is the new volume?

$$PV = nRT$$

substitute $n = \frac{m}{M}$

$$PV = \frac{mRT}{M}$$

$$M = \frac{mRT}{PV}$$

substitute $\frac{m}{V} = D$

$$M = \frac{DRT}{P}$$

You can rearrange the new equation to solve for the molar mass.

$$M = \frac{mRT}{PV}$$

You can rearrange the new equation to solve for density.

$$D = \frac{MP}{RT}$$

PROBLEM-SOLVING STRATEGY

Deriving Gas Laws

If you master the following strategy, you will need to remember only one gas law—the ideal gas law. Consider the example of a fixed amount of gas held at constant pressure. You need Charles's law to solve problems involving volume and temperature.

1. Use the ideal gas law to write two equations that describe the gas sample at two different volumes and temperatures. (Quantities that do not change are shown in **red**.)
2. Isolate volume and temperature—the two conditions that vary—on the same side of each equation.
3. Because n , R , and P are constant under these conditions, you can set the volume and temperature conditions equal, deriving Charles's law.

$$PV_1 = nRT_1$$

$$\frac{V_1}{T_1} = \frac{nR}{P}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$PV_2 = nRT_2$$

$$\frac{V_2}{T_2} = \frac{nR}{P}$$

In reality, **no gas is truly ideal**. All gas particles have some volume, however small, and are subject to intermolecular interactions. Also, the collisions that particles make with each other and with the container are not perfectly elastic. Despite that, **most gases behave like ideal gases at a wide range of temperatures and pressures**. Calculations made using the ideal gas law often closely approximate experimental measurements.

When is the ideal gas law not likely to work for a real gas? **Real gases deviate most from ideal gas behavior at high pressures and low temperatures**. The nitrogen gas shown in **Figure 8 (left)** behaves as a real gas. **Lowering the temperature of nitrogen gas** results in less kinetic energy of the gas particles, which means their intermolecular attractive (electric) forces are strong enough to affect their behavior. When the temperature is low enough, **this real gas condenses to form a liquid**.

The propane gas in the tanks shown in **Figure 8 (right)** also behaves as a real gas. **Increasing the pressure** on a gas forces the gas particles closer together until the volume occupied by the gas particles themselves is no longer negligible. Real gases such as propane will **liquefy** if enough pressure is applied.

When does a real gas behave like an ideal gas?

- a. When the particles are far apart and attractive forces decreases
- b. When the particles are closer together and attractive forces increases
- c. At high pressure and low temperature
- d. When the gas is liquefied if enough pressure is applied

When does a real gas behave like an ideal gas?

متى يسلك الغاز الحقيقي مثل الغاز المثالي؟

Which of the following is a characteristic of the ideal gas?

أي مما يلي من خصائص الغاز المثالي؟

At high pressure and low temperature

عند الضغط العالي ودرجة الحرارة المنخفضة

When high pressure is applied and the gas changes to the liquid phase

عندما تتحول حالة الغاز إلى سائل، عند التأثير عليه بضغط مرتفع

When the particles are close to each other, and attractive forces are high

عندما تقرب الجزيئات عن بعضها البعض وتزداد قوى التجاذب

When the particles are far apart, and the attractive forces are low

عندما تبتعد الجزيئات عن بعضها البعض وتقل قوى التجاذب

When real gases deviate most from ideal gas behavior?

- A – At high pressures and low temperatures
- B – At low pressures and high temperatures
- C – At high pressures and high temperatures
- D - At low pressures and low temperatures

Its particles move at variable velocities and on winding (zigzag) lines

تتحرك جسيماته بسرعات متغيرة وبمسارات متعرجة

Its particles take up space and measured in volume units (L)

تتخذ جسيماته حيزاً من الفراغ ويعبر عنها بوحدة الحجم (L)

Its particles collide with each other or with the wall surface in perfectly elastic way

تتصادم جسيماته ببعضها أو مع جدران الوعاء تصادمات مرنة بشكل مثالي

Its particles experience intermolecular attractive forces

تتعرض جسيماته لقوى تجاذب بينها

Suspensions, Colloids, and Solutions

	Particle size	Particles settle?	Tyndall effect?
Suspensions	Large (wide variation)	Yes	Yes
Colloids	1 nm–1000 nm	No	Yes
Solutions	Atomic scale (atoms, ions, and molecules)	No	No

out? One reason is that the dispersed particles of liquid colloids make jerky, random movements. This erratic movement of colloid particles is called **Brownian motion** and

Tyndall effect Concentrated colloids are often cloudy or opaque. Dilute colloids sometimes appear as clear as solutions. Dilute colloids appear to be homogeneous solutions because their dispersed particles are so small. However, dispersed colloid particles scatter light, a phenomenon known as the Tyndall effect. In Figure 3, a beam of light is shone through two unknown mixtures. You can observe that dispersed colloid particles scatter the light, unlike particles in the solution. Suspensions also exhibit the Tyndall effect, but solutions never exhibit the Tyndall effect. You have observed the

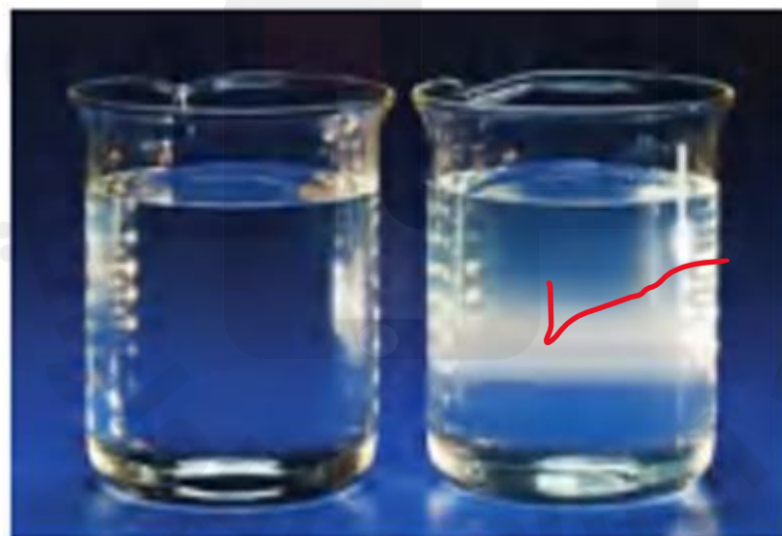


Figure 3 Particles in a colloid scatter light, unlike particles in a solution. Called the Tyndall effect, the beam of light is visible in the colloid because of light scattering.

Determine which mixture is a colloid.

solute: a substance dissolved in a solution

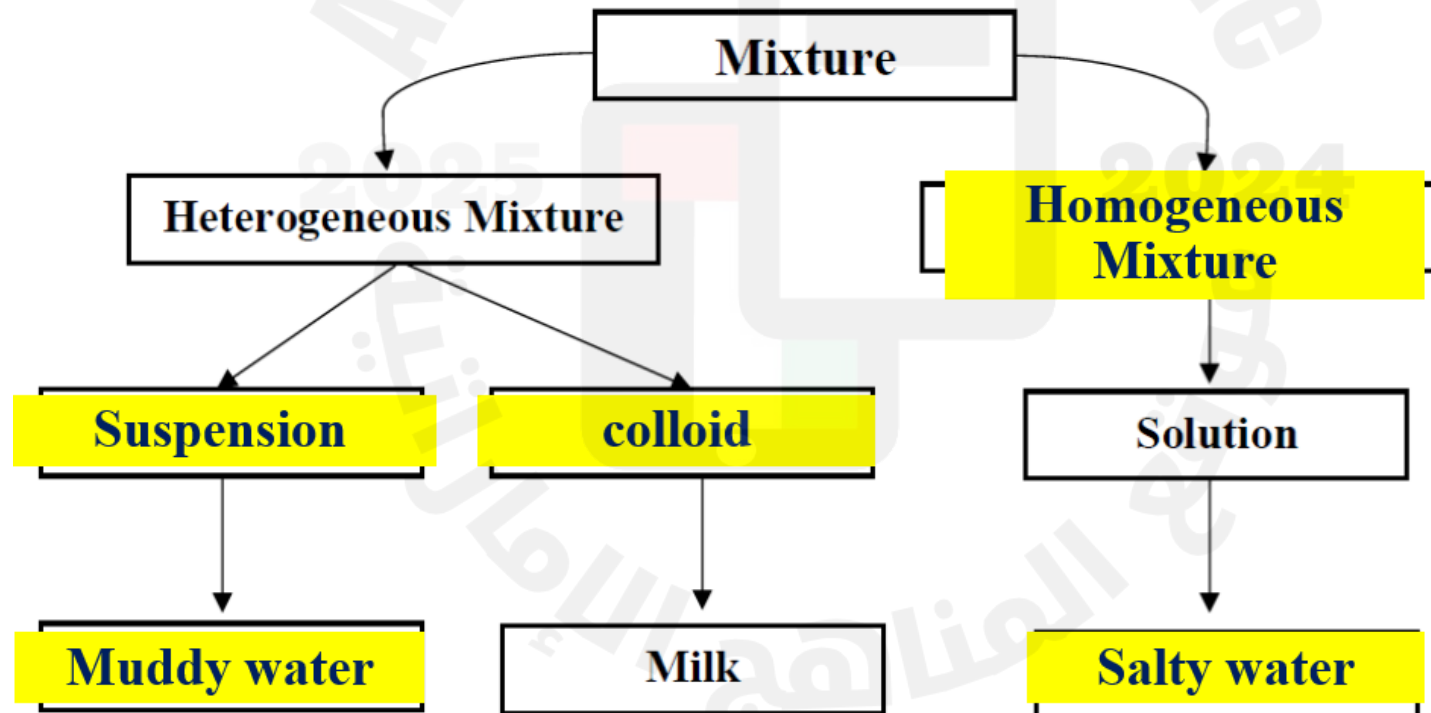
solvent: the substance that dissolves a solute to form a solution

Table 2 Types and Examples of Solutions

Type of Solution	Example	Solvent	Solute
Gas	air	nitrogen (gas)	oxygen (gas)
Liquid	carbonated water	water (liquid)	carbon dioxide (gas)
	ocean water	water (liquid)	oxygen gas (gas)
	antifreeze	water (liquid)	ethylene glycol (liquid)
	vinegar	water (liquid)	acetic acid (liquid)
	ocean water	water (liquid)	sodium chloride (solid)
Solid	dental amalgam	silver (solid)	mercury (liquid)
	steel	iron (solid)	carbon (solid)

Cell solutions, ocean water, and steel might appear dissimilar, but they share certain characteristics. You learned earlier that solutions are homogeneous mixtures that contain two or more substances called the solute and the solvent. The solute is the substance that dissolves. The solvent is the dissolving medium. When you look at a solution, it is not possible to distinguish the solute from the solvent.

Recall that a mixture is a combination of two or more pure substances in which each pure substance retains its individual chemical properties. Homogeneous mixtures are called solutions, where the particles are evenly distributed or blended. Particles in a solution are very small, and occur on an atomic-scale. Heterogeneous mixtures, however, do not blend smoothly throughout, and the individual substances remain distinct. Two types of heterogeneous mixtures are suspensions and colloids.



Percent by Mass

$$\text{percent by mass} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100$$

EXAMPLE Problem 1

CALCULATE PERCENT BY MASS In order to maintain a sodium chloride (NaCl) concentration similar to ocean water, an aquarium must contain 3.6 g NaCl per 100.0 g of water. What is the percent by mass of NaCl in the solution?

mass of solution = grams of solute + grams of solvent

$$\text{mass of solution} = 3.6 \text{ g} + 100.0 \text{ g} = 103.6 \text{ g}$$

Calculate the percent by mass.

$$\text{percent by mass} = \frac{\text{mass of solute}}{\text{mass of solution}} \times 100$$

$$\text{percent by mass} = \frac{3.6 \text{ g}}{103.6 \text{ g}} \times 100 = 3.5\%$$



9. What is the percent by mass of NaHCO_3 in a solution containing 20.0 g of NaHCO_3 dissolved in 600.0 mL of H_2O ?
10. You have 1500.0 g of a bleach solution. The percent by mass of the solute sodium hypochlorite (NaOCl) is 3.62%. How many grams of NaOCl are in the solution?
11. In Question 10, how many grams of solvent are in the solution?
12. **CHALLENGE** The percent by mass of calcium chloride in a solution is found to be 2.65%. If 50.0 g of calcium chloride is used, what is the mass of the solution?

9. What is the percent by mass of NaHCO_3 in a solution containing 20.0 g NaHCO_3 dissolved in 600.0 mL H_2O ?

$$600.0 \text{ mL H}_2\text{O} \times 1.0 \text{ g/mL} = 600.0 \text{ g H}_2\text{O}$$

$$\frac{20 \text{ g NaHCO}_3}{600 \text{ g H}_2\text{O} + 20 \text{ g NaHCO}_3} \times 100 = 3\%$$

10. You have 1500.0 g of a bleach solution. The percent by mass of the solute sodium hypochlorite, NaOCl , is 3.62%. How many grams of NaOCl are in the solution?

$$3.62\% = 100 \times \frac{\text{mass NaOCl}}{1500.0 \text{ g}}$$

$$\text{mass NaOCl} = 54.3 \text{ g}$$

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11. In question 10, how many grams of solvent are in the solution?

$$1500.0 \text{ g} - 54.3 \text{ g} = 1445.7 \text{ g solvent}$$

12. **Challenge** The percent by mass of calcium chloride in a solution is found to be 2.65%. If 50.0 grams of calcium chloride is used, what is the mass of the solution?

$$2.65\% = \frac{100 \times 50 \text{ g CaCl}_2}{\text{mass of solution}}$$

$$\text{mass of solution} = 1886.79 \text{ g}$$

Molarity is the measure of concentration that you will likely use most in your studies of chemistry. The molarity of a solution tells you the amount of solute present in a solution, and this is the information that is important to know when you are planning and analyzing reactions in solution. Knowing the amounts of different solutes in solution allows you to predict how they will react based on a balanced chemical equation.

EXAMPLE Problem 2

CALCULATING MOLARITY A 100.5-mL intravenous (IV) solution contains 5.10 g of glucose ($C_6H_{12}O_6$). What is the molarity of this solution? The molar mass of glucose is 180.16 g/mol.

$$\text{molarity (M)} = \frac{\text{moles of solute}}{\text{liters of solution}}$$

Calculate the number of moles of $C_6H_{12}O_6$.

$$(5.10 \text{ g } C_6H_{12}O_6) \left(\frac{1 \text{ mol } C_6H_{12}O_6}{180.16 \text{ g } C_6H_{12}O_6} \right) = 0.0283 \text{ mol } C_6H_{12}O_6$$

Convert the volume of H_2O to liters.

$$(100.5 \text{ mL solution}) \left(\frac{1 \text{ L}}{1000 \text{ mL}} \right) = 0.1005 \text{ L solution}$$

Solve for the molarity.

$$M = \frac{\text{moles of solute}}{\text{liters of solutions}}$$

$$M = \left(\frac{0.0283 \text{ mol } C_6H_{12}O_6}{0.1005 \text{ L solution}} \right)$$

$$M = \left(\frac{0.0282 \text{ mol } C_6H_{12}O_6}{1 \text{ L solution}} \right) = 0.282M$$

- 16.** What is the molarity of an aqueous solution containing 40.0 g of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) in 1.5 L of solution?

$$\text{mol C}_6\text{H}_{12}\text{O}_6 = 40.0 \text{ g} \times \frac{1 \text{ mol}}{180.16 \text{ g}} = 0.222 \text{ mol}$$

$$\text{molarity} = \frac{\text{mol C}_6\text{H}_{12}\text{O}_6}{1.5 \text{ L solution}} = \frac{0.222 \text{ mol}}{1.5 \text{ L}} = 0.15M$$

- 17.** Calculate the molarity of 1.60 L of a solution containing 1.55 g of dissolved KBr.

$$\text{mol KBr} = 1.55 \text{ g} \times \frac{1 \text{ mol}}{119.0 \text{ g}} = 0.0130 \text{ mol KBr}$$

$$\begin{aligned} \text{molarity} &= \frac{\text{mol KBr}}{1.60 \text{ L solution}} = \frac{0.0130 \text{ mol}}{1.60 \text{ L}} \\ &= 8.13 \times 10^{-3}M \end{aligned}$$

- 18.** What is the molarity of a bleach solution containing 9.5 g of NaOCl per liter of bleach?

$$\text{mol NaOCl} = 9.5 \text{ g} \times \frac{1 \text{ mol}}{74.44 \text{ g}} = 0.13 \text{ mol}$$

$$\begin{aligned} \text{molarity} &= \frac{\text{mol NaOCl}}{1.00 \text{ L solution}} = \frac{0.128 \text{ mol}}{1.00 \text{ L}} \\ &= 0.13M \end{aligned}$$

- 19. Challenge** How much calcium hydroxide ($\text{Ca}(\text{OH})_2$), in grams, is needed to produce 1.5 L of a 0.25M solution?

$$0.25M = \frac{x \text{ mol Ca}(\text{OH})_2}{1.5 \text{ L solution}}$$

$$x = 0.38 \text{ mol Ca}(\text{OH})_2$$

$$0.38 \text{ mol Ca}(\text{OH})_2 \times \frac{74.08 \text{ g}}{\text{mol}} = 28 \text{ g Ca}(\text{OH})_2$$

Molality

The volume of a solution changes with temperature as it expands or contracts. This change in volume alters the molarity of the solution. Masses, however, do not change with temperature. It is sometimes more useful to describe solutions in terms of how many moles of solute are dissolved in a specific mass of solvent. Such a description is called **molality**—the ratio of the number of moles of solute dissolved in 1 kg of solvent. The unit *m* is read as molal. A solution containing 1 mol of solute per kilogram of solvent is a one-molal solution.

EXAMPLE Problem 4

CALCULATING MOLALITY In the lab, a student adds 4.5 g of sodium chloride (NaCl) to 100.0 g of water. Calculate the molality of the solution.

$$4.5 \text{ g NaCl} \times \frac{1 \text{ mol NaCl}}{58.44 \text{ g NaCl}} = 0.077 \text{ mol NaCl}$$

$$100.0 \text{ g H}_2\text{O} \times \frac{1 \text{ kg H}_2\text{O}}{1000 \text{ g H}_2\text{O}} = 0.1000 \text{ kg H}_2\text{O}$$

$$m = \frac{\text{moles of solute}}{\text{kilograms of solvent}}$$

$$m = \frac{0.077 \text{ mol NaCl}}{0.1000 \text{ kg H}_2\text{O}} = \mathbf{0.77 \text{ mol/kg}}$$

$$\text{molality (m)} = \frac{\text{moles of solute}}{\text{kg of solvent}}$$

- 27.** What is the molality of a solution containing 10.0 g Na₂SO₄ dissolved in 1000.0 g of water?

$$\begin{aligned} \text{mol Na}_2\text{SO}_4 &= 10.0 \text{ g Na}_2\text{SO}_4 \times \frac{1 \text{ mol}}{142.04 \text{ g}} \\ &= 0.0704 \text{ mol Na}_2\text{SO}_4 \end{aligned}$$

$$\text{molality} = \frac{0.0704 \text{ mol Na}_2\text{SO}_4}{1.0000 \text{ Kg H}_2\text{O}} = 0.0704 \text{ m}$$

- 28. Challenge** How much (Ba(OH)₂), in grams, is needed to make a 1.00*m* aqueous solution?

$$\text{mol Ba(OH)}_2 = \frac{1 \text{ mol}}{1 \text{ kg solvent}}$$

$$\text{molar mass of Ba(OH)}_2 = \frac{171 \text{ g Ba(OH)}_2}{1 \text{ mol}}$$

$$\text{mass of Ba(OH)}_2 = 171 \text{ g}$$

Mole fraction

If you know the number of moles of solute and solvent, you can also express the concentration of a solution as a **mole fraction**—the ratio of the number of moles of solute or solvent in solution to the total number of moles of solute and solvent, as shown in **Figure 10**. The symbol X is commonly used for mole fraction, with a subscript to indicate the solvent or solute.

Mole Fraction

$$X_A = \frac{n_A}{n_A + n_B}$$

$$X_B = \frac{n_B}{n_A + n_B}$$

- 29.** What is the mole fraction of NaOH in an aqueous solution that contains 22.8% NaOH by mass?

Assume 100.0 g sample.

Then, mass NaOH = 22.8 g

mass H₂O = 100.0 g – (mass NaOH) = 77.2 g

$$\text{mol NaOH} = 22.8 \text{ g} \times \frac{1 \text{ mol}}{40.00 \text{ g}} = 0.570 \text{ mol NaOH}$$

$$\text{mol H}_2\text{O} = 77.2 \text{ g} \times \frac{1 \text{ mol}}{18.02 \text{ g}} = 4.28 \text{ mol H}_2\text{O}$$

$$\text{mol fraction NaOH} = \frac{\text{mol NaOH}}{\text{mol NaOH} + \text{mol H}_2\text{O}}$$

$$= \frac{0.570 \text{ mol NaOH}}{0.570 \text{ mol NaOH} + 4.28 \text{ mol H}_2\text{O}} = \frac{0.570}{4.85}$$

$$= 0.118$$

The mole fraction of NaOH is 0.118.

- 30. Challenge** If the mole fraction of sulfuric acid (H₂SO₄) in an aqueous solution is 0.125, what is the percent by mass of H₂SO₄?

$$0.125 = \text{mole fraction of H}_2\text{SO}_4$$

$$1 - 0.125 = 0.875 \text{ mole fraction of water}$$

Assume a sample of the solution totals 100.0 moles. By definition there would be 87.5 moles of water and 12.5 moles of sulfuric acid in the sample.

$$87.5 \text{ mol of H}_2\text{O} \times \frac{18.02 \text{ g}}{1 \text{ mol}} = 1580 \text{ g H}_2\text{O}$$

$$12.5 \text{ mol H}_2\text{SO}_4 \times \frac{98.08 \text{ g}}{1 \text{ mol}} = 1230 \text{ g H}_2\text{SO}_4$$

$$\text{percent by mass H}_2\text{SO}_4$$

$$= \frac{1230 \text{ g H}_2\text{SO}_4}{(1580 + 1230) \text{ g solution}} \times 100$$

$$= 43.8\% \text{ H}_2\text{SO}_4 \text{ by mass}$$

Henry's law states that at a given temperature, the solubility (S) of a gas in a liquid is directly proportional to the pressure (P) of the gas above the liquid. When the bottle of soda is closed, as illustrated in **Figure 19**, the pressure above the solution keeps carbon dioxide from escaping the solution.

Henry's Law

$$\frac{S_1}{P_1} = \frac{S_2}{P_2}$$

EXAMPLE Problem 5

HENRY'S LAW If 0.85 g of a gas at 4.0 atm of pressure dissolves in 1.0 L of water at 25°C, how much will dissolve in 1.0 L of water at 1.0 atm of pressure and the same temperature?

$$\frac{S_1}{P_1} = \frac{S_2}{P_2}$$

$$S_2 = S_1 \left(\frac{P_2}{P_1} \right)$$

$$S_2 = \left(\frac{0.85 \text{ g}}{1.0 \text{ L}} \right) \left(\frac{1.0 \text{ atm}}{4.0 \text{ atm}} \right) = 0.21 \text{ g/L}$$

36. If 0.55 g of a gas dissolves in 1.0 L of water at 20.0 kPa of pressure, how much will dissolve at 110.0 kPa of pressure?

$$S_1 = \frac{0.55 \text{ g}}{1.0 \text{ L}} = 0.55 \text{ g/L}$$

$$S_2 = S_1 \times \frac{P_2}{P_1} = 0.55 \text{ g/L} \times \frac{110.0 \text{ kPa}}{20.0 \text{ kPa}} = 3.0 \text{ g/L}$$

37. A gas has a solubility of 0.66 g/L at 10.0 atm of pressure. What is the pressure on a 1.0-L sample that contains 1.5 g of gas?

$$S_2 = \frac{1.5 \text{ g}}{1.0 \text{ L}} = 1.5 \text{ g/L}$$

$$P_2 = P_1 \times \frac{S_2}{S_1} = 10.0 \text{ atm} \times \frac{1.5 \text{ g/L}}{0.66 \text{ g/L}} = 23 \text{ atm}$$

38. Challenge The solubility of a gas at 7.0 atm of pressure is 0.52 g/L. How many grams of the gas would be dissolved per 1 L if the pressure increased 40.0 percent?

$$\begin{aligned} P_2 &= P_1 + (P_1)(0.400) \\ &= (7.0 \text{ atm}) + (7.0 \text{ atm})(0.400) \\ &= 9.8 \text{ atm} \end{aligned}$$

$$S_2 = S_1 \times \frac{P_2}{P_1}$$

$$S_2 = (0.52 \text{ g/L}) \times \frac{9.8 \text{ atm}}{7.0 \text{ atm}}$$

$$S_2 = 0.73 \text{ g/L}$$

Temperature and supersaturated solutions

Solubility is affected by raising the temperature of the solvent because the kinetic energy of its particles is increased, resulting in more-frequent collisions and collisions with greater energy than those that occur at lower temperatures. The fact that many substances are more soluble at high temperatures is demonstrated in Figure 16. For example, calcium chloride (CaCl_2) has a solubility of about 64 g CaCl_2 per 100 g H_2O at 10°C. Increasing the temperature to approximately 27°C increases the solubility by almost 50%, to 100 g CaCl_2 per 100 g H_2O . For other substances, such as cerium sulfate, $\text{Ce}_2(\text{SO}_4)_3$, solubility initially decreases rapidly as temperature increases, but then levels off and remains constant.

The effect of temperature on solubility is also illustrated by the data in Table 4. Notice in Table 4 that at 20°C, 203.9 g of sucrose ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$) dissolves in 100 g of water. At 100°C, 487.2 g of sucrose dissolves in 100 g of water, a nearly 140% increase in solubility.

Solubilities as a Function of Temperature

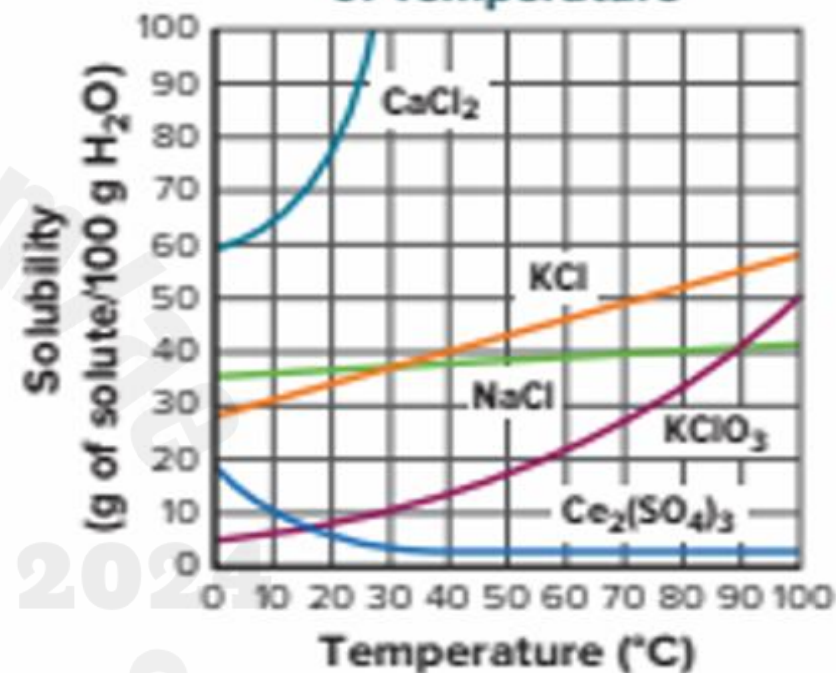


Figure 16 The solubilities of several substances as a function of temperature are shown in this graph.

Solubility increases by increasing Temperature

The Solvation Process

- **Solvation** is the process of surrounding solute particles with solvent particles to form a solution.
- Solvation in water is called hydration.
- The attraction between dipoles of a water molecule and the ions of a crystal are greater than the attraction among ions of a crystal.

Gypsum is insoluble in water because the attractive forces between the ions in gypsum are so strong that they cannot be overcome by the attractive forces of the water molecules.

Calcium carbonate is insoluble in water, found in nature as limestone, in eggshells,

Aqueous solutions of ionic compounds

Recall that water molecules are polar molecules and are in constant motion, as described by the kinetic-molecular theory. When a crystal of an ionic compound, such as sodium chloride (NaCl), is placed in water, the water molecules collide with the surface of the crystal. The charged ends of the water molecules attract the positive sodium ions and negative chloride ions. This attraction between the dipoles and the ions is greater than the attraction among the ions in the crystal, so the ions break away from the surface. The water molecules surround the ions—in other words, the ions become solvated. The solvated ions move into the solution, as shown in Figure 12,

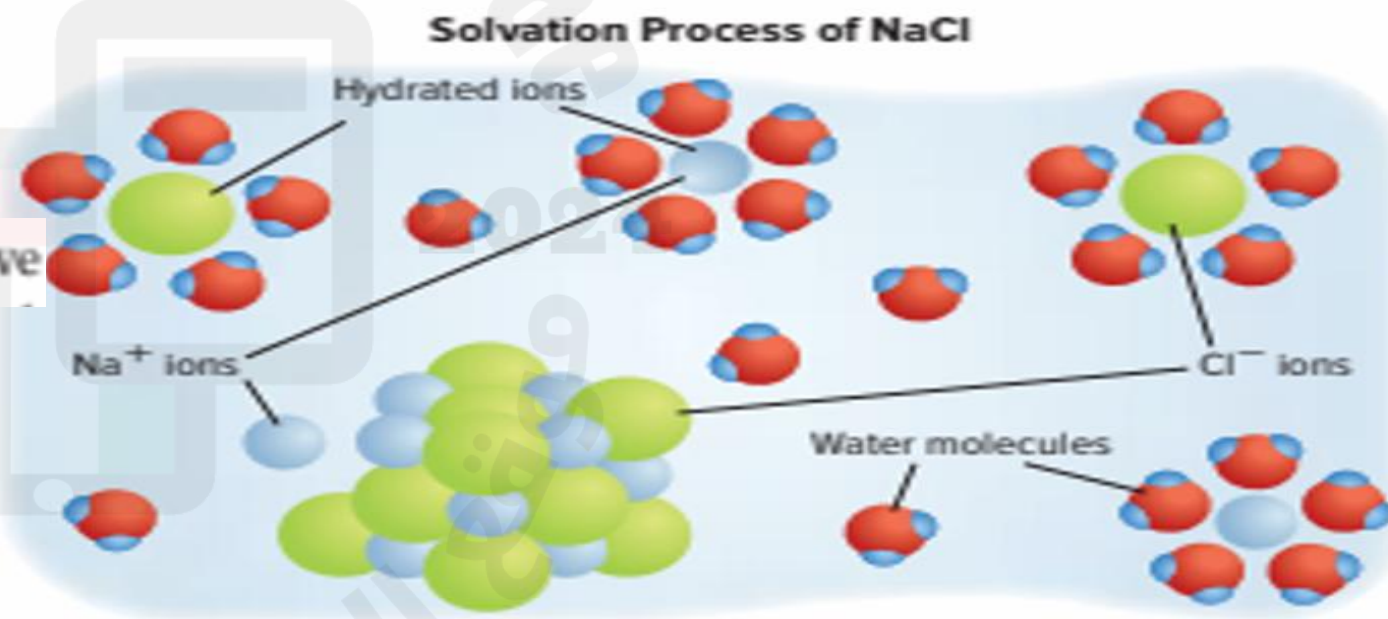


Figure 12 Sodium chloride dissolves in water as the water molecules surround the sodium and chloride ions. Note how the polar water molecules orient themselves differently around the positive and negative ion.

The Solvation Process (cont.)

- Sucrose molecules have several O–H bonds, which become sites for hydrogen bonding with water molecules.
- Oil does not form a solution with water because there is little attraction between polar water molecules and nonpolar oil molecules.
- During solvation, the solute must separate into particles and move apart, which requires energy.
- The overall energy change that occurs during solution formation is called the **heat of solution**.

