

Simple Step-by-Step
Guides to Solving
Chemistry Problems

Moles & Gases



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MOLES & GASES

Introduction

The same volume of gas contains the same number of particles. One mole of a gas occupies a volume of 22.4 litres (22.4 L; 22,400 cm³) at STP (standard temperature and pressure). This means: 2 g of hydrogen, H₂, occupies a volume of 22.4 litres, 28g of nitrogen, N₂ occupies a volume of 22.4 litres, 71 g of Cl₂ occupies a volume of 22.4 litres at STP.

A mole always contains the same number of formula units (particles) regardless of the substance, and a mole of gas always occupies the same volume STP. But, the mass of a mole differs from substance to substance, and is the formula mass expressed in grams.

The effect of this is to make calculations involving gas volumes much easier than you might expect.

ONE MOLE = M_r in grams = 6.02 x 10²³ particles = 22.4 litres of a gas at STP

Given that the relative formula mass of CO₂ = 44 (12 +16 +16):

44g of CO₂ contains 6 x 10²³ molecules of CO₂ which equals 1 mole and under STP occupies a volume of 22,400 cm³ (22.4 L)

Thus,

0.5 moles of CO₂ has a mass of 22g, contains 3 x 10²³ molecules of CO₂ and occupies a volume of 11,200 cm³ (11.2 litres) at STP

Under the same conditions of temperature and pressure, equal number of moles of gas occupies the same volume.

The molar volume (V_m) is the **volume occupied by one mole of a gas**.

The units used for the molar volume are L/mol (or cm³/mole).

Under standard temperature (0°C) and pressure (1 atmosphere) ONE mole of a gas occupies a volume of 22.4 L (22,400 cm³). Molar volume at room temperature and pressure (25°C, 1 atmosphere) is 24.0 L.

Molar Volume will vary with both temperature and pressure

Volume of gas = Number of moles x V_m

$$\text{Number of Moles} = \text{Volume of gas} / V_m$$

$$V_m = \text{Volume of Gas} / \text{Number of Moles}$$

Ensure that the volume units for V and V_m are the same, i.e. either L or cm^3 .

Moles to Volume

$$\text{Volume of gas} = \text{Number of moles} \times V_m$$

Example 1: What is the volume of 0.025 mole of hydrogen, when the molar volume is 24 L/mol? Give your answer in cm^3 .

Answer:

1 mole occupies a volume of 24 L

Volume of gas = Number of moles $\times V_m$

Thus 0.25 moles will occupy $0.025 \times 24 = 0.6 \text{ L} = 600 \text{ cm}^3$

Example 2: Determine the volume occupied by 0.5 moles of chlorine gas given that the molar volume is $23,000 \text{ cm}^3/\text{mol}$

Answer:

$V_m = 23,000 \text{ cm}^3$

Number of moles = 0.5

Volume of gas = Number of moles $\times V_m$

Thus 0.5 moles will occupy $0.5 \times 23 = 11.5 \text{ L}$



Practice Problems 1: In each case calculate the volume of the number of moles of gas stated at STP, given that 1 mole of gas has a volume of 22.4 L

- 2 moles of CH_4
- 0.3 moles of NH_3
- 1.6 moles of C_2H_4
- 3 moles of SO_2

- e. 0.26 moles of NO
- f. 5.7 moles of HBr
- g. 0.22 moles of Cl₂
- h. 0.020 moles of CO₂
- i. 15 moles of O₂
- j. 3.5×10^{-3} moles of H₂

Volume to Moles (and Mass)

$$\text{Number of moles} = \text{Volume} / V_m$$

$$\text{Mass} = \text{Number of moles} \times M_r$$

Example 3: Under certain conditions, the molar volume of carbon dioxide, CO₂, is 23 L/mol. How many moles of carbon dioxide are present in 250 cm³ of the gas?

Answer

$$V_m = 23 \text{ L} = 23,000 \text{ cm}^3$$

$$\text{Number of moles} = \text{Volume} / V_m$$

$$\text{Thus, number of moles present in } 250 \text{ cm}^3 = 250 / 23000 = 0.01087 \text{ moles}$$

Example 4: A sample of oxygen gas, O₂, occupies a volume of 5 litres at STP. What is the mass of the gas?

Answer

$$V_m (\text{at STP}) = 22.4 \text{ L} = 22,400 \text{ cm}^3$$

$$M_r[\text{O}_2] = 32$$

$$\text{Number of Moles} = \text{Volume} / V_m$$

$$\text{Number of moles present in } 5 \text{ L} = 5 / 22.4 = 0.223 \text{ moles}$$

$$\text{Mass of O}_2 = \text{number of moles} \times M_r$$

$$\text{Mass of O}_2 = 0.223 \times 32 = 37.14 \text{ g}$$



Exercise 2: Calculate the number of moles present in the volume of gases. Assume that all volumes are measured at room temperature and pressure and that 1 mol of gas has a volume of 24 dm³ (24 000 cm³) under these conditions.

- a. 200 cm³ of CH₄
- b. 10 cm³ of NH₃
- c. 3400 cm³ of C₂H₄
- d. 657 cm³ of SO₂
- e. 400 cm³ of NO
- f. 2500 cm³ of HBr
- g. 700 L of Cl₂
- h. 0.5 L of CO₂
- i. 9.5 x 10⁻³L of O₂
- j. 7.89L of H₂



Practice Problems 3: Calculate the mass of the volume of gases stated below. (Assume that all volumes are measured at room temperature and pressure, RTP and that 1 mole of gas has a volume of 24 L under these conditions).

- a. 200 cm³ of CH₄
- b. 10 cm³ of NH₃
- c. 3400 cm³ of C₂H₄
- d. 657 cm³ of SO₂
- e. 1400 cm³ of NO
- f. 2500 cm³ of HBr
- g. 760 cm³ of Cl₂
- h. 5 L of CO₂
- i. 9.5 L of O₂

j. 7.89 L of H₂

Relative Molecular Mass from Volume & Mass

Given the relationship between mass, the number of moles and the volume occupied by a gas, the relative molecular mass (M_r) of a gas can easily be determined from the volume occupied by a mass of gas under at a given set of temperature and pressure conditions

Example 5: Calculate the Relative Molecular Mass of a gas for which 100 cm³ of the gas at STP, has a mass of 0.1964 g

Answer:

This requires us to find the volume occupied by one mole of the gas, i.e. 22,400 cm³ (22.4 L)

Number of moles of the gas in 0.0667g = $100/22400 = 0.004464$ moles

Thus, the mass of 1 mole of the gas = $1/0.004464 \times 0.1964 = 44$ g

$M_r = 44$



Practice Problems 4: Calculate the Relative Molecular Mass of the gas from the given data. Assume that all volumes are measured at STP and that 1 mole of gas occupies a volume of 22,400 cm³ under these conditions.

a. 0.442 g of gas occupies 66 cm³

Answer

Number of moles in 66 cm³ of a gas at STP = $V/V_m = 66/22400 = 2.946 \times 10^{-3}$

Thus 2.946×10^{-3} moles has a mass of 0.442 g

$M_r = \text{mass} / \text{number of moles} = 0.442 / 2.946 \times 10^{-3} = \mathbf{150 \text{ g mol}^{-1}}$

b. 0.714 g of gas occupies 250 cm³

Answer

Number of moles in 250 cm³ of gas at STP = $V/V_m = 250/22400 = 0.1116$

Thus 0.1116 moles has a mass of 0.714 g

$M_r = \text{mass} / \text{number of moles} = 0.714 / 0.1116 = \mathbf{64 \text{ g mol}^{-1}}$

c. 0.402 g of gas occupies 100 cm³

Answer

Number of moles in 100 cm³ of a gas = $V/V_m = 100/22400 = 4.464 \times 10^{-3}$
Thus 4.464×10^{-3} moles of gas has a mass of 0.402 g
 $M_r = \text{mass} / \text{number of moles} = 0.402 / 4.464 \times 10^{-3} = \mathbf{90 \text{ g mol}^{-1}}$

d. 2.25 g of gas occupies 600 cm³

Answer

Number of moles of gas = $V/V_m = 600/22400 = 0.0268$
Thus 0.0268 moles of gas has a mass of 2.25 g
 $M_r = \text{mass} / \text{number of moles} = 2.25 / 0.0268 = \mathbf{84 \text{ g mol}^{-1}}$

e. 0.0893 g of gas occupies 1000 cm³

Answer

Number of moles of gas = $V/V_m = 1000/22400 = 0.0446$
Thus 0.0446 moles of gas has a mass of 0.0893 g
 $M_r = \text{mass} / \text{number of moles} = 0.0893 / 0.0446 = \mathbf{2 \text{ g mol}^{-1}}$

f. 0.1875 g of gas occupies 150 cm³

Answer

Number of moles of gas = $V/V_m = 150/22400 = 6.7 \times 10^{-3}$
Thus 6.7×10^{-3} moles of gas has a mass of 0.1875 g
 $M_r = \text{mass} / \text{number of moles} = 0.1875 / 6.7 \times 10^{-3} = \mathbf{28 \text{ g mol}^{-1}}$

g. 1.90 g of gas occupies 600 cm³

Answer

Number of moles of gas = $V/V_m = 600/22400 = 0.0268$
Thus 0.0268 moles of gas has a mass of 1.90 g
 $M_r = \text{mass} / \text{number of moles} = 1.90 / 0.0268 = \mathbf{71}$

h. 0.235 g of gas occupies 94 cm³

Answer

Number of moles of gas = $V/V_m = 94/22400 = 4.18 \times 10^{-3}$
Thus 4.18×10^{-3} moles of gas has a mass of 0.235 g
 $M_r = \text{mass} / \text{number of moles} = 0.235 / 4.18 \times 10^{-3} = \mathbf{56 \text{ g mol}^{-1}}$

- i. 4.286 g of gas occupies 1200 cm³

Answer

Number of moles of gas = $V/V_m = 1200/22400 = 0.0536$

Thus 0.0536 moles of gas has a mass of 4.286 g

$M_r = \text{mass} / \text{number of moles} = 4.286 / 0.0536 = \mathbf{80 \text{ g mol}^{-1}}$

- j. 2.143 g of gas occupies 1600 cm³

Answer

Number of moles of gas = $V/V_m = 1600/22400 = 0.0714$

Thus 0.0714 moles of gas has a mass of 2.143 g

$M_r = \text{mass} / \text{number of moles} = 2.143 / 0.0714 \times 2.143 = \mathbf{30 \text{ g mol}^{-1}}$

Molar Volume from Mass

Example 6: 976 cm³ of oxygen was found to have a mass of 1.3 g. Calculate the molar volume of oxygen, under these conditions.

Answer

$V_m = \text{Volume of Gas} / \text{Number of Moles}$

Volume of gas = 976 cm³

$M_r[\text{O}_2] = 32$

Number of moles in 1.3 g of O₂ = $\text{mass}/M_r = 1.3/32 = 0.0406$

$V_m = 976/0.0406 = 24,0246 \text{ cm}^3 = \mathbf{24.02 \text{ L}}$

Volume of one gas, from another gas

The examples below, involve the calculation of the volume of a product gas, from the volume of a reactant gas, and vice versa.

Example 7: What volume of propane, C₃H₈, must be burned in oxygen, to give 100 cm³ of carbon dioxide gas as a product (under the same conditions of temperature and pressure)?

Answer

Write a balanced chemical equation for the reaction and construct a mole calculation frame around it.

	C ₃ H ₈	+	5O ₂	→	3CO ₂	+	4H ₂ O
Volume (cm ³)	100/3 = 33.3		5/3 x 100 = 167		100		4/3 x 100 = 133
Reaction coefficients	1		5		3		4

Under the same conditions of temperature and pressure, equal number of moles of gas occupies the same volume.

Thus, according to the reaction coefficients in the balanced equation 1 volume C_3H_8 will be totally combusted by 5 volumes of O_2 to produce 3 volumes of CO_2 and 4 volumes of H_2O .

Therefore 100 cm^3 CO_2 will be produced from combustion of $100/3 = 33.3 \text{ cm}^3$ C_3H_8

Example 8: A mixture of hydrogen and oxygen is exploded to form water. Write a balanced equation for the reaction, then calculate the volume of oxygen needed to react with 123 cm^3 of hydrogen.

(3)

Answer

	$2H_{2(g)}$	+	$O_{2(g)}$	\rightarrow	$2H_2O_{(l)}$
Volume (cm^3)	123		62.5		246
Reaction coefficients	2		1		2

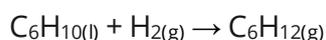
Under the same conditions of temperature and pressure, equal number of moles of gas occupies the same volume.

According to the reaction coefficients in the balanced equation 2 volumes of H_2 react with 1 volume of O_2 to produce 2 volumes H_2O .

Therefore 123 cm^3 H_2 will require $123/2 = 62.5 \text{ cm}^3$ O_2 to be totally combusted.

Equations, Moles and Volumes

Example 9: Under conditions in which the molar volume of hydrogen is 24.0 dm^{-3} , what volume of hydrogen would be required to produce 8.2 g of cyclohexane from cyclohexene?



Answer

	$C_6H_{10(l)}$	+	$H_{2(g)}$	\rightarrow	$C_6H_{12(l)}$
A_r/M_r	82		2		84
Mass	8.2				
No. of moles	$8.2/82 = 0.1$				
Volume (L)	$0.1 \times 24 = 2.4$				
Reaction coefficients	1		1		1

$$M_r [C_6H_{10}] = (6 \times 12) + (10 \times 1) = 82$$

Number of moles of C_6H_{10} in 8.2 g = $8.2/82 = 0.1$ moles

According to the reaction coefficients 1 mole of H_2 can hydrogenate 1 mole C_6H_{10}

Thus, 0.1 moles of H_2 are required to hydrogenate 0.1 moles C_6H_{10}

Volume occupied by 0.1 moles of H_2 = number of moles $\times V_m = 0.1 \times 24 = 2.4 \text{ L} = 2,400 \text{ cm}^3$

Example 10: Magnesium reacts with dilute sulfuric acid to produce hydrogen gas and a solution of magnesium sulphate. Calculate the volume of hydrogen produced at RTP when 12g of magnesium react completely with sulfuric acid.

Answer

	2Mg(s)	+	H ₂ SO ₄ (l)	→	MgSO ₄ (g)	+	H ₂ (g)
A _r /M _r	24		98		120		2
Mass (g)	12						0.5
Volume (L)							0.25 × 24 = 6
No. of moles	0.5		0.25		0.25		0.5/2 = 0.25
Reaction coefficients	2	:	1		1		1

$$V_m \text{ (at RTP)} = 24 \text{ L}$$

$$A_r [\text{Mg}] = 24 \text{ g mol}^{-1}$$

$$M_r [\text{H}_2] = 2 \text{ g mol}^{-1}$$

$$\text{Number of moles of Mg in 12 g} = \text{mass}/M_r = 12/24 = 0.5$$

According to the reaction coefficients 2 moles of Mg can produce 1 mole H₂

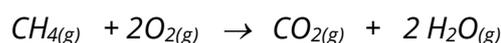
Thus 0.5 moles of Mg can produce $0.5/2 = 0.25$ moles H₂

$$\text{Volume occupied by 0.25 moles H}_2 = \text{number of moles} \times V_m = 0.25 \times 24 = \mathbf{6 \text{ L}}$$



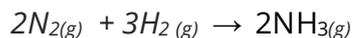
Practice Problems 5

- What is the volume of 0.25 mole of carbon dioxide, when the molar volume is 24.0 L mol⁻¹? Give your answer in litres.
- What amount in moles of oxygen is present in 20.0L of air at STP? Assume that air is 20% oxygen by volume.
- Calculate the molar volume given that 0.25 moles of a gas occupies a volume of 4,680 cm³.
- Methane burns completely to form carbon dioxide and water vapour:-

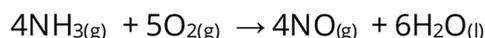


Calculate the volume of oxygen needed for the complete combustion of 125cm³ of methane and the volume of carbon dioxide which would be produced.

- What volume of propane, C₃H₈, must be burned in oxygen, to give 60 cm³ of carbon dioxide gas as a product (under the same conditions of temperature and pressure)?
- What volume of ammonia is made when 20L of hydrogen react with an excess of nitrogen (under the same conditions of temperature and pressure) according to the following equation:

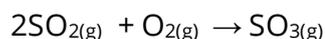


- g. What volume of O_2 is consumed when 25cm^3 of benzene is fully combusted oxygen (under the same conditions of temperature and pressure)?
- h. What volume of nitrogen dioxide would be produced from the complete combustion of 3 litres of nitrogen gas (under the same conditions of temperature and pressure)?
- i. In equation for the oxidation of ammonia to nitrogen monoxide is:



What volume of ammonia would be required to produce 10 L of nitrogen monoxide and what volume of air would be used in the conversion?

- j. In the production of sulphuric acid sulphur dioxide is converted to sulphur trioxide by reaction with the oxygen in the air.

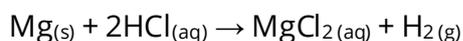


What volume of air (assume 20% of the air is oxygen) would be needed to produce 200 cm^3 of sulphur trioxide? Assume complete conversion of sulphur dioxide to sulphur trioxide.

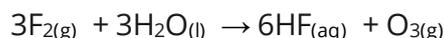


Practice Problems 6

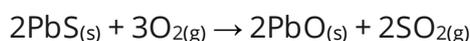
- a. What mass of magnesium would be required to generate 200cm^3 H_2 at STP?



- b. Under conditions in which the molar volume of ozone, O_3 , is 22.4 L, what volume of ozone would be produced by reacting 0.95 g of fluorine with excess steam?

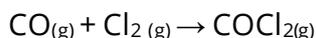


- c. Lead oxide is produced when lead sulphide is heated in oxygen.



What volume of oxygen (molar volume = 24L) would react exactly with 95.72 g of PbS ?

- d. Phosgene, used as a chemical weapon during world War I is produced industrially according to the following reaction:



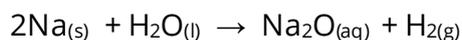
What volume of CO (at STP) is required to produce 10g of phosgene?

- e. What mass of ammonium chlorate is needed to decompose to give off 100 litres of oxygen at STP?

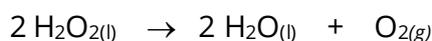


- f. Your car burns mostly octane, C₈H₁₈, as a fuel. How many litres of oxygen is needed to burn a kilogram of octane at RTP?

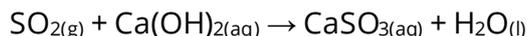
- g. How many grams of sodium do you have to put into water to make 30 litres of hydrogen at STP?



- h. A solution containing 1.7g of hydrogen peroxide decomposes to produce water and oxygen gas. Calculate the volume of oxygen produced at STP. The equation is: -

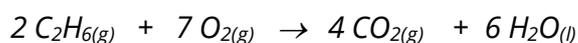


- i. Sulphur dioxide can be removed from the waste gases of a power station by passing it through a slurry of calcium hydroxide. The equation for this reaction is:



What mass of calcium hydroxide would be needed to deal with 1000 dm³ of sulphur dioxide at STP?

- k. The equation for the complete combustion of ethane is:



90g of ethane was completely burned in oxygen. Assuming air is 20% oxygen by volume, work out the volume of air needed to completely combust the ethane at STP.

Moles and Gases

Practice Problem Answers



Practice Problems 1: In each case calculate the volume of the number of moles of gas stated at STP, given that 1 mole of gas has a volume of 22.4 L

a. 2 moles of CH₄

Answer:

$$\begin{aligned}\text{Volume} &= \text{Number of Moles} \times V_m \\ &= 2 \times 22.4 \\ &= 44.8 \text{ L}\end{aligned}$$

b. 0.3 moles of NH₃

Answer:

$$\begin{aligned}\text{Volume} &= \text{Number of Moles} \times V_m \\ &= 0.3 \times 22.4 \\ &= 6.72 \text{ L}\end{aligned}$$

c. 1.6 moles of C₂H₄

Answer:

$$\begin{aligned}\text{Volume} &= \text{Number of Moles} \times V_m \\ &= 1.6 \times 22.4 \\ &= 35.84 \text{ L}\end{aligned}$$

d. 3 moles of SO₂

Answer:

$$\begin{aligned}\text{Volume} &= \text{Number of Moles} \times V_m \\ &= 3 \times 22.4 \\ &= 67.2 \text{ L}\end{aligned}$$

e. 0.26 moles of NO

Answer:

$$\begin{aligned}\text{Volume} &= \text{Number of Moles} \times V_m \\ &= 0.26 \times 22.4 \\ &= 5.82 \text{ L}\end{aligned}$$

f. 5.7 moles of HBr

Answer:

$$\begin{aligned}\text{Volume} &= \text{Number of Moles} \times V_m \\ &= 5.7 \times 22.4\end{aligned}$$

$$=127.68 \text{ L}$$

g. 0.22 moles of Cl_2

Answer:

$$\begin{aligned} \text{Volume} &= \text{Number of Moles} \times V_m \\ &= 0.22 \times 22.4 \\ &= 4.93 \text{ L} \end{aligned}$$

h. 0.020 moles of CO_2

Answer:

$$\begin{aligned} \text{Volume} &= \text{Number of Moles} \times V_m \\ &= 0.020 \times 22.4 \\ &= 0.448 \text{ L} \end{aligned}$$

i. 15 moles of O_2

Answer:

$$\begin{aligned} \text{Volume} &= \text{Number of Moles} \times V_m \\ &= 15 \times 22.4 \\ &= 336 \text{ L} \end{aligned}$$

j. 3.5×10^{-3} moles of H_2

Answer:

$$\begin{aligned} \text{Volume} &= \text{Number of Moles} \times V_m \\ &= 3.5 \times 10^{-3} \times 22.4 \\ &= 0.0784 \text{ L} \end{aligned}$$



Practice Problems 2 Answers:

It is essential that you use the same units for the volume of gas and V_m , i.e. either L or cm^3 .

a. 200 cm^3 of CH_4

Answer

$$\begin{aligned} \text{Number of moles} &= \text{Volume} / V_m \\ &= 200/24000 \\ &= \mathbf{8.33 \times 10^{-3}} \text{ OR} \end{aligned}$$

$$200\text{cm}^3 = 200/1000 = 0.2 \text{ L}$$

$$\text{Number of moles} = 0.2/24$$

$$= 8.33 \times 10^{-3}$$

b. 10 cm³ of NH₃

Answer

$$\begin{aligned}\text{Number of moles} &= \text{Volume} / V_m \\ &= 10/24000 \\ &= 4.17 \times 10^{-3}\end{aligned}$$

c. 3400 cm³ of C₂H₄

Answer

$$\begin{aligned}\text{Number of moles} &= \text{Volume} / V_m \\ &= 3400/24000 \\ &= \mathbf{0.142}\end{aligned}$$

d. 657 cm³ of SO₂

Answer

$$\begin{aligned}\text{Number of moles} &= \text{Volume} / V_m \\ &= 657/24000 \\ &= \mathbf{0.027}\end{aligned}$$

e. 400 cm³ of NO

Answer

$$\begin{aligned}\text{Number of moles} &= \text{Volume} / V_m \\ &= 400/24000 \\ &= \mathbf{0.017}\end{aligned}$$

f. 2500 cm³ of HBr

Answer

$$\begin{aligned}\text{Number of moles} &= \text{Volume} / V_m \\ &= 2500/24000 \\ &= \mathbf{0.1}\end{aligned}$$

g. 700 L of Cl₂

Answer

$$\begin{aligned}\text{Number of moles} &= \text{Volume} / V_m \\ &= 700/24 \\ &= \mathbf{29.2}\end{aligned}$$

h. 0.5 L of CO₂

Answer

$$\begin{aligned}\text{Number of moles} &= \text{Volume} / V_m \\ &= 0.5/24 \\ &= \mathbf{0.021}\end{aligned}$$

i. 9.5 L of O₂

Answer

$$\begin{aligned}\text{Number of moles} &= \text{Volume} / V_m \\ &= 9.5/24 \\ &= \mathbf{0.396}\end{aligned}$$

j. 7.89L^{of} H₂

Answer

$$\begin{aligned}\text{Number of moles} &= \text{Volume} / V_m \\ &= 7.89/24 \\ &= \mathbf{0.329}\end{aligned}$$



Practice Problems 3: Calculate the mass of the volume of gases stated below. (Assume that all volumes are measured at room temperature and pressure, RTP and that 1 mole of gas has a volume of 24 L under these conditions).

a. 200 cm³ of CH₄

Answer

$$\begin{aligned}M_r [\text{CH}_4] &= 16 \\ \text{Number of moles} &= V/V_m \\ \text{Number of moles} &= 200/24000 = 8.33 \times 10^{-3} \\ \text{Mass} &= \text{Number of moles} \times M_r \\ \text{Mass} &= 8.33 \times 10^{-3} \times 16 = \mathbf{0.13 \text{ g}}\end{aligned}$$

b. 10 cm³ of NH₃

Answer

$$\begin{aligned}M_r [\text{NH}_3] &= 17 \\ \text{Number of Moles} &= V/V_m \\ \text{Number of moles} &= 10/24000 = 4.17 \times 10^{-4} \\ \text{Mass} &= \text{Number of moles} \times M_r \\ \text{Mass} &= 4.17 \times 10^{-4} \times 17 = \mathbf{7.08 \times 10^{-3} \text{ g}}\end{aligned}$$

c. 3400 cm³ of C₂H₄

Answer

$M_r [\text{C}_2\text{H}_4] = 28$
Number of Moles = V/V_m
Number of moles = $3400/24000 = 0.142$
Mass = Number of moles $\times M_r$
Mass = $0.142 \times 28 = \mathbf{3.97 \text{ g}}$

d. 657 cm^3 of SO_2

Answer
 $M_r [\text{SO}_2] = 64$
Number of Moles = V/V_m
Number of moles = $657/24000 = 0.0273$
Mass = Number of moles $\times M_r$
Mass = $0.0273 \times 64 = \mathbf{1.752 \text{ g}}$

e. 1400 cm^3 of NO

Answer
 $M_r [\text{NO}] = 30$
Number of Moles = V/V_m
Number of moles = $1400/2400 = 0.058$
Mass = Number of moles $\times M_r$
Mass = $\mathbf{1.75 \text{ g}}$

f. 2500 cm^3 of HBr

Answer
 $M_r [\text{HBr}] = 81$
Number of Moles = V/V_m
Number of moles = $2500/24000 = 0.104$
Mass = Number of moles $\times M_r$
Mass = $0.104 \times 81 = \mathbf{8.44 \text{ g}}$

g. 760 cm^3 of Cl_2

Answer
 $M_r [\text{Cl}_2] = 71$
Number of Moles = V/V_m
Number of moles = $760/24000 = 0.0317$
Mass = Number of moles $\times M_r$
Mass = $0.03127 \times 71 = \mathbf{2.25 \text{ g}}$

h. 5 L of CO_2

Answer
 $M_r [\text{CO}_2] = 44$
Number of Moles = V/V_m
Number of moles = $5/24 = 0.208 \text{ g}$

Mass = Number of moles \times M_r
 Mass = $0.208 \times 44 = \mathbf{9.17 \text{ g}}$

i. 9.5 L of O_2

Answer

$M_r [O_2] = 32$
 Number of Moles = V/V_m
 Number of moles = $9.5/24 = 0.396$
 Mass = Number of moles \times M_r
 Mass = $0.396 \times 32 = \mathbf{12.7 \text{ g}}$

j. 7.89 L of H_2

Answer

$M_r [H_2] = 2$
 Number of Moles = V/V_m
 Number of moles = $7.89/24 = 0.329$
 Mass = Number of moles \times M_r
 Mass = $0.329 \times 2 = \mathbf{0.658 \text{ g}}$



Practice Problems 4: Calculate the Relative Molecular Mass of the gas from the given data. Assume that all volumes are measured at STP and that 1 mole of gas occupies a volume of $22,400 \text{ cm}^3$ under these conditions.

a. 0.442 g of gas occupies 66 cm^3

Answer

Number of moles in 66 cm^3 of a gas at STP = $V/V_m = 66/22400 = 2.946 \times 10^{-3}$
 Thus 2.946×10^{-3} moles has a mass of 0.442 g
 $M_r = \text{mass} / \text{number of moles} = 0.442 / 2.946 \times 10^{-3} = \mathbf{150}$

b. 0.714 g of gas occupies 250 cm^3

Answer

Number of moles in 250 cm^3 of gas at STP = $V/V_m = 250/22400 = 0.1116$
 Thus 0.1116 moles has a mass of 0.714 g
 $M_r = \text{mass} / \text{number of moles} = 0.714 / 0.1116 = \mathbf{64}$

c. 0.402 g of gas occupies 100 cm^3

Answer

Number of moles in 100 cm^3 of a gas = $V/V_m = 100/22400 = 4.464 \times 10^{-3}$
 Thus 4.464×10^{-3} moles of gas has a mass of 0.402 g
 $M_r = \text{mass} / \text{number of moles} = 0.402 / 4.464 \times 10^{-3} = \mathbf{90}$

d. 2.25 g of gas occupies 600 cm³

Answer

$$\text{Number of moles of gas} = V/V_m = 600/22400 = 0.0268$$

Thus 0.0268 moles of gas has a mass of 2.25 g

$$M_r = \text{mass} / \text{number of moles} = 2.25 / 0.0268 = 84$$

e. 0.0893 g of gas occupies 1000 cm³

Answer

$$\text{Number of moles of gas} = V/V_m = 1000/22400 = 0.0446$$

Thus 0.0446 moles of gas has a mass of 0.0893 g

$$M_r = \text{mass} / \text{number of moles} = 0.0893 / 0.0446 = 2$$

f. 0.1875 g of gas occupies 150 cm³

Answer

$$\text{Number of moles of gas} = V/V_m = 150/22400 = 6.7 \times 10^{-3}$$

Thus 6.7×10^{-3} moles of gas has a mass of 0.1875 g

$$M_r = \text{mass} / \text{number of moles} = 0.1875 / 6.7 \times 10^{-3} = 28$$

g. 1.90 g of gas occupies 600 cm³

Answer

$$\text{Number of moles of gas} = V/V_m = 600/22400 = 0.0268$$

Thus 0.0268 moles of gas has a mass of 1.90 g

$$M_r = \text{mass} / \text{number of moles} = 1.90 / 0.0268 = 71$$

h. 0.235 g of gas occupies 94 cm³

Answer

$$\text{Number of moles of gas} = V/V_m = 94/22400 = 4.18 \times 10^{-3}$$

Thus 4.18×10^{-3} moles of gas has a mass of 0.235 g

$$M_r = \text{mass} / \text{number of moles} = 0.235 / 4.18 \times 10^{-3} = 56$$

i. 4.286 g of gas occupies 1200 cm³

Answer

$$\text{Number of moles of gas} = V/V_m = 1200/22400 = 0.0536$$

Thus 0.0536 moles of gas has a mass of 4.286 g

$$M_r = \text{mass} / \text{number of moles} = 4.286 / 0.0536 = 80$$

j. 2.143 g of gas occupies 1600 cm³

Answer

Number of moles of gas = $V/V_m = 1600/22400 = 0.0714$

Thus 0.0714 moles of gas has a mass of 2.143 g

$M_r = \text{mass} / \text{number of moles} = 2.143 / 0.0714 \times 2.143 = 30$

**Practice Problems 5**

- a. What is the volume of 0.25 mole of carbon dioxide, when the molar volume is 24.0 L mol⁻¹? Give your answer in litres.

Answer:

One mole of CO₂ occupies 24 L

Therefore 0.25 moles CO₂ will occupy = number of moles × $V_m = 0.25 \times 24 = 6 \text{ L}$

- b. What amount in moles of oxygen is present in 20.0L of air at STP? Assume that air is 20% oxygen by volume.

Answer

Volume of O₂ in 20L of air = $20/100 \times 20 = 4\text{L}$

Number of moles of O₂ in 4L = $\text{volume}/V_m = 4/22.4 = 0.179$

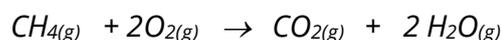
- c. Calculate the molar volume given that 0.25 moles of a gas occupies a volume of 4,680 cm³.

Answer

0.25 moles occupies a volume of 4680 cm³

$V_m = \text{Volume} / \text{Number of moles} = 4680 / 0.25 = 18,720 \text{ cm}^3 = 18.72 \text{ L}$

- d. Methane burns completely to form carbon dioxide and water vapour:-



Calculate the volume of oxygen needed for the complete combustion of 125cm³ of methane and the volume of carbon dioxide which would be produced.

Answer

	CH _{4(g)}	+	2O _{2(g)}	→	CO _{2(g)}	+	2H ₂ O _(g)
Volume (cm ³)	125		2 × 125 = 250		125		250
Reaction coefficients	1		2		1		2

Under the same conditions of temperature and pressure, equal numbers of moles of gas occupies the same volume.

According to the reaction coefficients in the balanced equation 1 volume of CH₄ reacts with 2 volumes of O₂ to produce 1 volume of CO₂ and 2 volumes of H₂O

Therefore 125 cm³ CH₄ will require 2 × 125 = **250 cm³** O₂ to be totally combusted

- e. What volume of propane, C_3H_8 , must be burned in oxygen, to give 60 cm^3 of carbon dioxide gas as a product (under the same conditions of temperature and pressure)?

Answer

	$C_3H_{8(l)}$	+	$5O_{2(g)}$	→	$3CO_{2(g)}$	+	$4H_2O_{(l)}$
Volume (cm^3)	$60/3 = 20$		$60/3 \times 5 = 100$		60		
Reaction coefficients	1		5		3		4

Under the same conditions of temperature and pressure, equal numbers of moles of gas occupies the same volume.

According to the reaction coefficients in the balanced equation 1 volumes of C_3H_8 reacts with 5 volumes of O_2 to produce 3 volumes of CO_2 and 4 volumes of H_2O

Therefore 60 cm^3 CO_2 will be produced from the combustion of $60/3 = 20\text{ cm}^3$ of C_3H_8

- f. What volume of ammonia is made when 20L of hydrogen react with an excess of nitrogen (under the same conditions of temperature and pressure) according to the following equation:



Answer

	$2N_{2(g)}$	+	$3H_2$	→	$2NH_{3(g)}$
Volume (L)	$20/3 \times 2 = 13.33$		20		$20/3 \times 2 = 13.33$
Reaction coefficients	2		3		2

Under the same conditions of temperature and pressure, equal numbers of moles of gas occupies the same volume.

According to the reaction coefficients in the balanced equation 2 volumes of N_2 will react with 3 volumes of H_2 to produce 2 volumes of NH_3

Therefore, 20 L N_2 will produce $20 \times 3/2 = 13.33\text{ L } NH_3$

- g. What volume of O_2 is consumed when 25 cm^3 of benzene is fully combusted oxygen (under the same conditions of temperature and pressure)?

Answer

	$2C_6H_{6(l)}$	+	$15O_{2(g)}$	→	$12CO_{2(g)}$	+	$6H_2O_{(g)}$
Volume (cm^3)	25		$25/2 \times 15 = 187.5$		$25/2 \times 12 = 150$		$25/2 \times 6 = 75$
Reaction coefficients	2		15		12		6

Under the same conditions of temperature and pressure, equal numbers of moles of gas occupies the same volume.

According to the reaction coefficients in the balanced equation 2 volumes of C_6H_6 react with 15 volumes of O_2 to produce 12 volumes of CO_2 and 6 volumes of H_2O

Therefore 60 cm^3 CO_2 will require produced from the combustion of $60/3 = 20\text{ cm}^3$ of C_3H_8

h. What volume of nitrogen dioxide would be produced from the complete combustion of 3 litres of nitrogen gas (under the same conditions of temperature and pressure)?

Answer

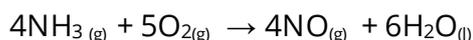
	$\text{N}_{2(\text{g})}$	+	$2\text{O}_{2(\text{g})}$	\rightarrow	$2\text{NO}_{2(\text{g})}$
Volume (L)	3		6		6
Reaction coefficients	1		2		2

Under the same conditions of temperature and pressure, equal number of moles of gas occupies the same volume.

According to the reaction coefficients in the balanced equation 1 volume of N_2 reacts with 2 volumes of O_2 to produce 2 volumes of NO_2

Therefore, total combustion of 3L N_2 will produce $3 \times 2 = 6 \text{ L}$ of NO_2

i. In equation for the oxidation of ammonia to nitrogen monoxide is:



What volume of ammonia would be required to produce 10 L of nitrogen monoxide and what volume of air would be used in the conversion?

Answer

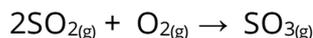
	$4\text{NH}_{3(\text{g})}$	+	$5\text{O}_{2(\text{g})}$	\rightarrow	$4\text{NO}(\text{g})$	+	$6\text{H}_2\text{O}(\text{l})$
Mr	17		32		30		18
Volume (L)	10		12.5		10		15
Reaction coefficients	4		5		4		6

Under the same conditions of temperature and pressure, equal numbers of moles of gas occupies the same volume.

According to the reaction coefficients in the balanced equation 4 volumes of NH_3 react with 5 volumes of O_2 to produce 4 volumes of NO and 6 volumes of H_2O

Therefore, the number volume of NH_3 required to generate 10 L of $\text{NO} = 10 \text{ L}$

j. In the production of sulphuric acid sulphur dioxide is converted to sulphur trioxide by reaction with the oxygen in the air.



What volume of air (assume 20% of the air is oxygen) would be needed to produce 200 cm^3 of sulphur trioxide? Assume complete conversion of sulphur dioxide to sulphur trioxide.

Answer

	$2\text{SO}_{2(\text{g})}$	+	$\text{O}_{2(\text{g})}$	\rightarrow	$2\text{SO}_{3(\text{g})}$
Volume (cm^3)	200		100		200
Reaction coefficients	2		1		2

Under the same conditions of temperature and pressure, equal numbers of moles of gas occupies the same volume.

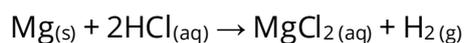
According to the reaction coefficients in the balanced equation 2 volumes of SO₂ react with 1 volume of O₂ to produce 2 volumes of 2SO₃

Therefore, the volume of O₂ required to produce 200 cm³ SO₃ = 100cm³

Volume of air required = 100/20 x 100 = 500 cm³

Practice Problems 6

a. What mass of magnesium would be required to generate 200cm³ H₂ at STP?



Answer

	Mg _(s)	+	2HCl _(aq)	→	MgCl _{2(aq)}	+	H _{2(g)}
A _r / M _r	24		36.5		95		2
Reaction Coefficients	1	:	2	:	1	:	1
Volume (cm ³)							200
Mass (g)	8.9 x 10 ⁻³ x 24						
	= 0.214						
Number of Moles	8.9 x 10 ⁻³		2 x 8.9 x 10 ⁻³		8.9 x 10 ⁻³		8.9 x 10 ⁻³

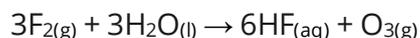
Number of moles of H₂ in 200cm³ = volume / V_m = 200/22400 = 8.9 x 10⁻³

According to the reaction coefficients 1 mole of H₂ is generated from 1 mole Mg

Therefore, 200cm³ H₂ will be generated from 8.9 x 10⁻³ moles Mg

Mass of 8.9 x 10⁻³ moles Mg = mass x M_r = 8.9 x 10⁻³ x 24 = **0.214 g**

b. Under conditions in which the molar volume of ozone, O₃, is 22.4 L, what volume of ozone would be produced by reacting 0.95 g of fluorine with excess steam?



Answer

	3F _{2(g)}	+	3H ₂ O _(l)	→	6HF _(aq)	+	O _{3(g)}
A _r / M _r	19		18		20		48
Reaction Coefficients	3	:	2	:	1	:	1
Volume (L)							373.3
Mass (g)	0.95						
No of moles	0.96/19 = 0.05						0.05/3 = 0.0167

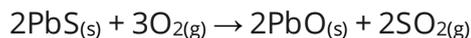
Number of moles in 0.95 g of F₂ = mass/M_r = 0.95/19 = 0.05

According to the reaction coefficients 3 moles of F₂ generate 1 mole of O₃

Therefore 0.05 moles F₂ will generate 0.05/3 = 0.0167 moles O₃

Volume of 0.0167 moles O₃ = number of moles x V_m = 0.0167 x 22400 = **373.3 cm³**

c. Lead oxide is produced when lead sulphide is heated in oxygen.



What volume of oxygen (molar volume = 24L) would react exactly with 95.72 g of PbS?

Answer

	$2\text{PbS}_{(s)}$	+	$3\text{O}_{2(g)}$	\rightarrow	$\text{PbO}_{(s)}$	+	$\text{SO}_{2(g)}$
Ar/ Mr	239		32		223		64
Reaction Coefficients	2	:	3	:	1	:	1
Volume (cm ³)			14,400				
Mass (g)	95.72						
Number of moles	0.4		0.6		0.2		0.2

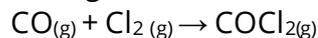
Number of moles in 95.72 g PbS = 95.72/239 = 0.4

According to the reaction coefficients, 1 mole PbS requires 1.5 (3/2) moles of O₂

Therefore, 0.4 moles of PbS requires 1.5 x 0.4 = 0.6 moles of O₂

Volume occupied by 0.6 moles O₂ = number of moles x V_m = 0.6 x 24 = 14.4 dm³ = **14,400 cm³**

d. Phosgene, used as a chemical weapon during world War I is produced industrially according to the following reaction:



What volume of CO (at STP) is required to produce 10g of phosgene?

Answer

	$\text{CO}_{(g)}$	+	$\text{Cl}_{2(g)}$	\rightarrow	$\text{COCl}_{2(g)}$
Ar/ Mr	28		71		99
Reaction Coefficients	1	:	1	:	1
Volume (cm ³)	2,262				
Mass (g)					10
No. of moles	0.101				0.101

Number of moles in 10g of COCl₂ = mass/ M_r = 10/99 = 0.101

According to the reaction coefficients, 1 mole of COCl₂ is produced from 1 mole CO

Therefore, the number of moles of CO required to generate 0.101 moles of COCl₂ = 0.101

Volume occupied by 0.101 moles of CO = number of moles x V_m = 0.101 x 22,400 = **2,262 cm³**

e. What mass of ammonium chlorate is needed to decompose to give off 100 litres of oxygen at STP?



Answer

	2KClO_3	\rightarrow	2KCl	+	3O_2
Ar/Mr	122.5		74.5		32
Reaction Coefficients	2		2		3
Mass (g)	122.5 x 2.98 =				
	364.6g				
Volume (L)					100
No. of moles	4.46 x 2/3 = 2.98		2.98		100/22.4 =
					4.46

Number of moles of O₂ in 100 L = volume / V_m = 100/22.4 = 4.46

According to the reaction coefficients 2 moles KClO_3 decompose to produce 3 moles O_2
 Therefore, the number of moles O_2 produced from decomposition of 4.46 moles $\text{KClO}_3 = 4.46 \times 2/3 = 2.98$
 Mass of 2.98 moles $\text{KClO}_3 = \text{number of moles} \times M_r = 2.98 \times 122.5 = 364.6$

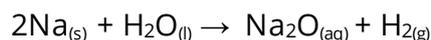
- f. Your car burns mostly octane, C_8H_{18} , as a fuel. How many litres of oxygen is needed to burn a kilogram of octane at RTP?

Answer

	$2\text{C}_8\text{H}_{18(aq)}$	$- 25\text{O}_{2(aq)}$	\rightarrow	$16\text{CO}_{2(g)}$	$+$	$18\text{H}_2\text{O}_{(l)}$
A_r/M_r	114	32		44		18
Reaction coefficients	2	25		4		6
Volume (L)		109.65×24				
		= 2631.6				
Mass	1,000					
Number of Moles	$1000/114 = 8.77$	$25/2 \times 8.77$				
		= 109.65				

Number of moles C_8H_{18} in 1 kg (1000 g) = $\text{mass}/M_r = 1000/114 = 8.77$
 According to the reaction coefficients 2 moles C_8H_{18} require 25 moles O_2 for total combustion
 Therefore 8.77 moles C_8H_{18} requires $25/2 \times 8.77 = 109.65$ moles O_2
 Volume of 109.65 moles O_2 at STP = $\text{number of moles} \times V_m = \text{L}$

- g. How many grams of sodium do you have to put into water to make 30 litres of hydrogen at STP?



Answer

	$2\text{Na}_{(s)}$	$+$	$\text{H}_2\text{O}_{(l)}$	\rightarrow	$\text{Na}_2\text{O}_{(aq)}$	$+$	$\text{H}_{2(g)}$
A_r/M_r	23		18		64		18
Reaction coefficients	2		1		1		1
Volume (L)							30
Mass	$2.68 \times 23 = 61.6$						
Number of Moles	$2 \times 1.34 = 2.68$						$30/22.4 = 1.34$

Number of moles in 30 L $\text{H}_2 = 30/22.4 = 1.34$
 According to the reaction coefficients 2 moles Na produce 1 mole H_2
 Therefore, number of moles of Na required to generate 1.34 moles $\text{H}_2 = 2 \times 1.34 = 2.68$
 Mass of 2.68 moles Na = $\text{number of moles} \times A_r = 2.68 \times 23 = 61.6 \text{ g}$

- h. A solution containing 1.7g of hydrogen peroxide decomposes to produce water and oxygen gas. Calculate the volume of oxygen produced at STP. The equation is: -



Answer

	$2\text{H}_2\text{O}_{20}$	\rightarrow	$2\text{H}_2\text{O}_{(l)}$	$+$	$\text{O}_{2(g)}$
A_r/M_r	34		18		32
Reaction Coefficients	2		2		1
Mass (g)	1.7				0.8
Volume (L)					$0.025 \times 22.4 = 0.56$
No. of moles	$1.7/34 = 0.05$				$0.05/2 = 0.025$

$$M_r[\text{H}_2\text{O}_2] = 34$$

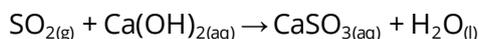
$$\text{Number of moles in 1.7 g H}_2\text{O}_2 = \text{mass}/M_r = 1.7/34 = 0.05$$

According to the reaction coefficients 2 moles H_2O_2 will decompose to produce 1 mole O_2

Therefore, 0.05 moles of H_2O_2 will produce $0.5 \times 0.05 = 0.025$ moles O_2

$$\text{Volume occupied by 0.025 moles O}_2 = \text{number of moles} \times V_m = 0.025 \times 22.4 = \mathbf{0.56 \text{ L}}$$

- i. Sulphur dioxide can be removed from the waste gases of a power station by passing it through a slurry of calcium hydroxide. The equation for this reaction is:



What mass of calcium hydroxide would be needed to deal with 1000 dm^3 of sulphur dioxide at STP?

Answer

	$\text{SO}_2(\text{g})$	+	$\text{Ca}(\text{OH})_2(\text{aq})$	\rightarrow	$\text{CaSO}_3(\text{aq})$	+	$\text{H}_2\text{O}(\text{l})$
A_r/M_r	64		74		120		18
Reaction coefficients	1		1		1		1
Volume (dm^3)	1000						
Mass			$4.64 \times 74 = 3303.6$				
Number of Moles	$1000/22.4$		4.64				
	$4 = 4.64$						

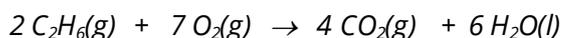
$$\text{Number of moles in } 1000 \text{ dm}^3 \text{ SO}_2 = \text{Volume}/V_m = 1000/22.4 = 4.64$$

According to the reaction coefficients, 1 mole SO_2 is removed by 1 mole of $\text{Ca}(\text{OH})_2$

Thus 4.64 moles of $\text{Ca}(\text{OH})_2$ can remove 4.64 moles of SO_2

$$\text{Mass of 4.64 moles Ca}(\text{OH})_2 = \text{number of moles} \times M_r = 4.64 \times 74 = \mathbf{3303.6 \text{ g}}$$

- j. The equation for the complete combustion of ethane is:



90g of ethane was completely burned in oxygen. Assuming air is 20% oxygen by volume, work out the volume of air needed to completely combust the ethane at STP.

Answer

	$2\text{C}_2\text{H}_6$	+	7O_2	\rightarrow	4CO_2	+	$6\text{H}_2\text{O}$
Mr	30		32		44		18
Reaction coefficients	2		7		4		6
Volume (L)			$22.4 \times 10.5 =$				
			235.2				
Mass (g)	90		336				
Number of Moles	$90/30 = 3$		$7/2 \times 3 = 10.5$				

$$M_r[\text{C}_2\text{H}_6] = 30$$

$$\text{Number of moles in 90 g of ethane} = m/M_r = 90/30 = 3$$

According to the reaction coefficients 2 moles of C_2H_6 are totally combusted by 7 moles O_2

Therefore 3 moles of C_2H_6 requires $3 \times 7/2 = 10.5$ moles of O_2 for total combustion

$$\text{Volume of 10.5 moles O}_2 = \text{number of moles} \times V_m = 10.5 \times 22.4 = \mathbf{235.2 \text{ L}}$$