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 cm^3) at STP (standard temperature and pressure). This means: 2 g of hydrogen, H_2, occupies a volume of 22.4 litres, 28g of nitrogen, N_2 occupies a volume of 22.4 litres, 71 g of Cl_2 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 = 6.02×10^{23} particles = 22.4 litres of a gas at STP

Given that the relative formula mass of CO_2 = 44 (12 +16 +16):

44g of CO_2 contains 6×10^{23} molecules of CO_2 which equals 1 mole and under STP occupies a volume of 22,400 cm^3 (22.4 L)

Thus,

0.5 moles of CO_2 has a mass of 22g, contains 3×10^{23} molecules of CO_2 and occupies a volume of 11,200 cm^3 (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 cm^3/mole).

Under standard temperature (0°C) and pressure (1 atmosphere) ONE mole of a gas occupies a volume of 22.4 L (22,400 cm^3). Molar volume at room temperature and pressure (25°C, 1 atmosphere) is 24.0 L.

Molar Volume will vary with both temperature and pressure

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

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

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

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 x V_m
Thus 0.25 moles will occupy 0.025 x 24 = 0.6 L = 600cm^3

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

Answer:

V_m = 23,000 cm^3
Number of moles = 0.5
Volume of gas = Number of moles x V_m
Thus 0.5 moles will occupy 0.5 x 23 = 11.5 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

a. 2 moles of CH_4

b. 0.3 moles of NH_3

c. 1.6 moles of C_2H_4

d. 3 moles of SO_2

e. 0.26 moles of NO

f. 5.7 moles of HBr

g. 0.22 moles of Cl_2

h. 0.020 moles of CO_2

i. 15 moles of O_2

j. 3.5×10^{-3} moles of H_2

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, CO_2, is 23 L/mol. How many moles of carbon dioxide are present in 250 cm^3 of the gas?*

Answer

V_m = 23 L = 23,000 cm^3

Number of moles = Volume /V_m

Thus, number of moles present in 250cm^3 = 250/23000 = 0.01087 moles

Example 4: *A sample of oxygen gas, O_2, occupies a volume of 5 litres at STP. What is the mass of the gas?*

Answer

V_m (at STP) = 22.4 L = 22,400 cm^3

$M_r[O_2]$ = 32

Number of Moles = Volume /V_m

Number of moles present in 5 L = 5/22.4 = 0.223 moles

Mass of O_2 = number of moles x M_r

Mass of O_2 = 0.223 x 32 = 37.14 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 dm^3 (24 000 cm^3) under these conditions.*

a. 200 cm^3 of CH_4

b. 10 cm^3 of NH_3

c. 3400 cm^3 of C_2H_4

d. 657 cm^3 of SO_2

e. 400 cm^3 of NO

f. 2500 cm^3 of HBr

g. 700 L of Cl_2

h. 0.5 L of CO_2

i. 9.5×10^{-3} L of O_2

j. 7.89L of H_2

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 cm^3 of CH_4

b. 10 cm^3 of NH_3

c. 3400 cm^3 of C_2H_4

d. 657 cm^3 of SO_2

e. 1400 cm^3 of NO

f. 2500 cm^3 of HBr

g. 760 cm^3 of Cl_2

h. 5 L of CO_2

i. 9.5 L of O_2

j. 7.89 L of H_2

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 cm^3 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 cm^3 (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 x 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 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 x 10^{-3}
Thus 2.946 x 10^{-3} moles has a mass of 0.442 g
M_r = mass / number of moles = 0.442/ 2.946 x 10^{-3} = **150 g mol^{-1}**

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 = mass / number of moles = 0.714/ 0.1116 = **64 g mol^{-1}**

c. 0.402 g of gas occupies 100 cm^3

Answer

Number of moles in 100 cm3 of a gas = V/V_m = 100/22400 = 4.464 x 10^{-3}
Thus 4.464 x 10^{-3} moles of gas has a mass of 0.402 g
M_r = mass / number of moles = 0.402/.464 x 10^{-3} = **90 g mol^{-1}**

d. 2.25 g of gas occupies 600 cm^3

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 = mass / number of moles = 2.25 4.464 x 10^{-3} = **84 g mol^{-1}**

e. 0.0893 g of gas occupies 1000 cm^3

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 = mass / number of moles 0.0893/ 0.0446 = **2 g mol^{-1}**

f. 0.1875 g of gas occupies 150 cm^3

Answer

Number of moles of gas = V/V_m = 150/22400 = 6.7 x 10^{-3}
Thus 6.7 x 10^{-3} moles of gas has a mass of 0.1875 g
M_r = mass / number of moles = 0.1875 / 6.7 x 10^{-3} = **28 g mol^{-1}**

g. 1.90 g of gas occupies 600 cm^3

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 = mass / number of moles = 1.90 / 0.0268 x 1.90 = **71**

h. 0.235 g of gas occupies 94 cm^3

Answer

Number of moles of gas = V/V_m = 94/22400 = 4.18 x 10^{-3}
Thus 4.18 x 10^{-3} moles of gas has a mass of 0.235 g
M_r = mass / number of moles =0.235 / 4.18 x 10^{-3} = **56 g mol^{-1}**

i. 4.286 g of gas occupies 1200 cm^3

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 = mass / number of moles = 4.286 /0.0536 = **80 g mol^{-1}**

j. 2.143 g of gas occupies 1600 cm^3

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 = mass / number of moles = 2.143 /0.0714 x 2.143 = **30 g mol^{-1}**

Molar Volume from Mass

Example 6: *976 cm^3 of oxygen was found to have a mass of 1.3 g. Calculate the molar volume of oxygen, under these conditions.*

Answer

V_m = Volume of Gas/ Number of Moles
Volume of gas = 976 cm^3
$M_r[O_2]$ = 32
Number of moles in 1.3 g of O_2 = mass/M_r = 1.3/32 = 0.0406
V_m = 976/0.0406 = 24,0246 cm^3 = **24.02 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, C_3H_8, must be burned in oxygen, to give 100 cm^3 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_3H_8	+	$5O_2$	$\rightarrow$	$3CO_2$	+	$4H_2O$
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 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 123cm^3 of hydrogen.*

(3)

Answer

	$2H_{2(g)}$	+	$O_{2(g)}$	→	$2H_2O_{(l)}$
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 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?*

$$C_6H_{10(l)} + H_{2(g)} \rightarrow C_6H_{12(g)}$$

Answer

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

M_r [C_6H_{10}] = (6 x 12) + (10 x 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 x V_m = 0.1 x 24 = 2.4 L = 2,400 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

	$2Mg_{(s)}$	+	$H_2SO_{4(l)}$	→	$MgSO_{4(g)}$	+	$H_{2(g)}$
A_r/M_r	24		98		120		2
Mass (g)	12						0.5
Volume (L)							0.25 x 24 = 6
No. of moles	0.5		0.25		0.25		0.5/2 = 0.25
Reaction coefficients	2	:	1		1		1

V_m (at RTP) = 24 L
A_r [Mg] = 24 g mol^{-1}
M_r [H_2]= 2 g mol^{-1}
Number of moles of Mg in 12 g = mass/M_r = 12/24 = 0.5
According to the reaction coefficients 2 moles of Mg can produce 1 mole H_2
Thus 0.5 moles of Mg can produce 0/5/2 = 0.25 moles H_2
Volume occupied by 0.25 moles H_2 = number of moles x Vm = 0.25 x 24 = **6 L**

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.*

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

c. *Calculate the molar volume given that 0.25 moles of a gas occupies a volume of 4,680 cm^3.*

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

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

Calculate the volume of oxygen needed for the complete combustion of 125cm^3 of methane and the volume of carbon dioxide which would be produced.

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)?*

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:*

$2N_{2(g)} + 3H_{2\,(g)} \rightarrow 2NH_{3(g)}$

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:

$4NH_{3(g)} + 5O_{2(g)} \rightarrow 4NO_{(g)} + 6H_2O_{(l)}$

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.

$2SO_{2(g)} + O_{2(g)} \rightarrow SO_{3(g)}$

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?*

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2\,(aq)} + H_{2\,(g)}$$

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?*

$$3F_{2(g)} + 3H_2O_{(l)} \rightarrow 6HF_{(aq)} + O_{3(g)}$$

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

$$2PbS_{(s)} + 3O_{2(g)} \rightarrow 2PbO_{(s)} + 2SO_{2(g)}$$

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:*

$$CO_{(g)} + Cl_{2\,(g)} \rightarrow COCl_{2(g)}$$

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?

$$2\ KClO_{3\,(s)} \rightarrow 2\ KCl_{(s)}\ +\ 3O_{2(g)}$$

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?

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

$$2Na_{(s)}\ + H_2O_{(l)}\ \rightarrow\ Na_2O_{(aq)}\ + H_{2(g)}$$

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:-

$$2\ H_2O_{2(l)}\ \rightarrow\ 2\ H_2O_{(l)}\ +\ O_{2(g)}$$

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:

$$SO_{2(g)} + Ca(OH)_{2(aq)} \rightarrow CaSO_{3(aq)} + H_2O_{(l)}$$

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

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

$$2\ C_2H_{6(g)}\ +\ 7\ O_{2(g)}\ \rightarrow\ 4\ CO_{2(g)}\ +\ 6\ H_2O_{(l)}$$

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 2.4 L*

a. 2 moles of CH_4

Answer:

Volume = Number of Moles x V_m
= 2 x 22.4
= 44.8 L

b. 0.3 moles of NH_3

Answer:

Volume = Number of Moles x V_m
= 0.3 x 22.4
= 6.72 L

c. 1.6 moles of C_2H_4

Answer:

Volume = Number of Moles x V_m
= 1.6 x 22.4
= 38.84 L

d. 3 moles of SO_2

Answer:

Volume = Number of Moles x V_m
= 3 x 22.4
= 67.2 L

e. 0.26 moles of NO

Answer:

Volume = Number of Moles x V_m
= 0.26 x 22.4
= 5.82 L

f. 5.7 moles of HBr

Answer:

Volume = Number of Moles x V_m
= 5.7 x 22.4

=127.68 L

g. 0.22 moles of Cl_2

Answer:

Volume = Number of Moles x V_m
= 0.22 x 22.4
= 4.93 L

h. 0.020 moles of CO_2

Answer:

Volume = Number of Moles x V_m
= 0.020 x 22.4
= 0.448 L

i. 15 moles of O_2

Answer:

Volume = Number of Moles x V_m
= 15 x 22.4
= 336 L

j. 3.5 x 10^{-3} moles of H_2

Answer:

Volume = Number of Moles x V_m
= 3.5 x 10^{-3} x 22.4
= 0.0784 L

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

Number of moles = Volume /V_m
= 200/24000
= **8.33 x 10^{-3}** OR

200cm^3 = 200/1000 = 0.2 L

Number of moles = 0.2/24

= **8.33×10^{-3}**

b. 10 cm^3 of NH_3

Answer

Number of moles = Volume /V_m

= 10/24000

=4.17×10^{-3}

c. 3400 cm^3 of C_2H_4

Answer

Number of moles = Volume /V_m

= 3400/24000

= **0.142**

d. 657 cm^3 of SO_2

Answer

Number of moles = Volume /V_m

= 657/24000

= **0.027**

e. 400 cm^3 of NO

Answer

Number of moles = Volume /V_m

= 1400/24000

= **0.017**

f. 2500 cm^3 of HBr

Answer

Number of moles = Volume /V_m

= 2400/24000

= **0.1**

g. 700 L of Cl_2

Answer

Number of moles = Volume /V_m

= 700/24

= **29.2**

h. 0.5 L of CO_2

Answer

Number of moles = Volume /V_m
= 0.5/24
=**0.021**

i. 9.5 L of O_2

Answer

Number of moles = Volume /V_m
= 9.5/24
=.**0.396**

j. 7.89L of H_2

Answer

Number of moles = Volume /V_m
= 7.89/24
= **0.329**

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 cm^3 of CH_4

Answer

M_r [CH_4] = 16
Number of moles = V/V_m
Number of moles = 200/24000 = 8.33×10^{-3}
Mass = Number of moles x M_r
Mass = $8.33 \times 10^{-3} \times 16$ = **0.13 g**

b. 10 cm^3 of NH_3

Answer

M_r [NH_3] = 17
Number of Moles = V/V_m
Number of moles = 10/24000 = 4.17×10^{-4}
Mass = Number of moles x M_r
Mass =$4.17 \times 10^{-4} \times 17$ = **7.08×10^{-3} g**

c. 3400 cm^3 of C_2H_4

Answer

M_r [C_2H_4] = 28
Number of Moles = V/V_m
Number of moles = 3400/24000 = 0.142
Mass = Number of moles x M_r
Mass = 0.142 x 28 = **3.97 g**

d. 657 cm^3 of SO_2

Answer
M_r [SO_2] = 64
Number of Moles = V/V_m
Number of moles = 657/24000 = 0.0273
Mass = Number of moles x M_r
Mass =0.0273 x 64 = **1.752 g**

e. 1400 cm^3 of NO

Answer
M_r [NO] = 30
Number of Moles = V/V_m
Number of moles = 1400/2400 = 0.058
Mass = Number of moles x M_r
Mass = **1.75 g**

f. 2500 cm^3 of HBr

Answer
M_r [HBr] = 81
Number of Moles = V/V_m
Number of moles = 2500/24000 = 0.104
Mass = Number of moles x M_r
Mass = 0.104 x 81 = **8.44 g**

g. 760 cm^3 of Cl_2

Answer
M_r [Cl_2] = 71
Number of Moles = V/V_m
Number of moles = 760/24000 = 0.0317
Mass = Number of moles x M_r
Mass =0.03127 x 71 = **2.25 g**

h. 5 L of CO_2

Answer
M_r [CO_2] = 44
Number of Moles = V/V_m
Number of moles = 5/24 = 0.208 g

Mass = Number of moles x M_r
Mass =0.208 x 44 = **9.17 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 x M_r
Mass =0.396 x 32 = **12.7 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 x M_r
Mass = 0.329 x 2 = **0.658 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 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 = 2.946×10^{-3}
Thus 2.946×10^{-3} moles has a mass of 0.442 g
M_r = mass / number of moles = 0.442/ 2.946×10^{-3} = **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 = mass / number of moles = 0.714/ 0.1116 = **64**

c. 0.402 g of gas occupies 100 cm^3

Answer
Number of moles in 100 cm3 of a gas = V/V_m = 100/22400 = 4.464×10^{-3}
Thus 4.464×10^{-3} moles of gas has a mass of 0.402 g
M_r = mass / number of moles = 0.402/.464 $\times 10^{-3}$ = **90**

d. 2.25 g of gas occupies 600 cm^3

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 = mass / number of moles = 2.25 4.464 x 10^{-3} = **84**

e. 0.0893 g of gas occupies 1000 cm^3

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 = mass / number of moles 0.0893/ 0.0446 = **2**

f. 0.1875 g of gas occupies 150 cm^3

Answer

Number of moles of gas = V/V_m = 150/22400 = 6.7 x 10^{-3}
Thus 6.7 x 10^{-3} moles of gas has a mass of 0.1875 g
M_r = mass / number of moles = 0.1875 / 6.7 x 10^{-3} = **28**

g. 1.90 g of gas occupies 600 cm^3

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 = mass / number of moles = 1.90 / 0.0268 x 1.90 = **71**

h. 0.235 g of gas occupies 94 cm^3

Answer

Number of moles of gas = V/V_m = 94/22400 = 4.18 x 10^{-3}
Thus 4.18 x 10^{-3} moles of gas has a mass of 0.235 g
M_r = mass / number of moles =0.235 / 4.18 x 10^{-3} = **56**

i. 4.286 g of gas occupies 1200 cm^3

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 = mass / number of moles = 4.286 /0.0536 = **80**

j. 2.143 g of gas occupies 1600 cm^3

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 = mass / number of moles = 2.143 /0.0714 x 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 CO_2 occupies 24 L
Therefore 0.25 moles CO_2 will occupies = number of moles x V_m = 0.25 x 24 = **6 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 O_2 in 20L of air = 20/100 x 20 = 4L
Number of moles of O_2 in 4L = 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 cm^3.*

Answer

0.25 moles occupies a volume of 4680 cm^3
V_m = Volume / Number of moles = 4680 / 0.25 = 18,720 cm^3 = 18.72 L

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

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2\,H_2O_{(g)}$$

Calculate the volume of oxygen needed for the complete combustion of 125cm^3 of methane and the volume of carbon dioxide which would be produced.

Answer

	$CH_{4(g)}$	+	$2O_{2(g)}$	$\rightarrow$	$CO_{2(g)}$	+	$2H_2O_{(g)}$
Volume (cm^3)	125		2 x 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 CH_4 reacts with 2 volumes of O_2 to produce 1 volume of CO_2 and 2 volumes of H_2O
Therefore 125 cm^3 CH_4 will require 2 x 125 = **250 cm^3** O_2 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 x 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 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:*

$$2N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$$

Answer

	$2N_{2(g)}$	+	$3H_2$	→	$2NH_{3(g)}$
Volume (L)	20/3 x 2= 13.33		20		20/3 x 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 3volumes of H_2 to produce 2 volumes of NH_3
Therefore, 20 L N_2 will produce 20 x 3/2 = **13.33 L NH_3**

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)?*

Answer

	$2C_6H_{6(l)}$	+	$15O_{2(g)}$	→	$12CO_{2(g)}$	+	$6H_2O_{(g)}$
Volume (cm^3)	25		25/2 x 15 = **187.5**		25/2 x 12 = 150		25/2 x 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 3 volumes of CO_2 and 4 volumes of H_2O
Therefore 60 cm^3 CO_2 will require produced from the combustion of 60/3 = **20 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

	$N_{2(g)}$	+	$2O_{2(g)}$	→	$2NO_{2(g)}$
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 produces 3 x 2 = **6 L** of NO_2

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

$$4NH_{3\,(g)} + 5O_{2(g)} \rightarrow 4NO_{(g)} + 6H_2O_{(l)}$$

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

	$4NH_{3(g)}$	$5O_{2(g)}$	→	$4NO_{(g)}$	+	$6H_2O_{(l)}$
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 NO = **10 L**

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

$$2SO_{2(g)} + O_{2(g)} \rightarrow SO_{3(g)}$$

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

	$2SO_{2(aq)}$	+	$O_{2(aq)}$	→	$2SO_{3(aq)}$
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 SO_2 react with 1 volume of O_2 to produce 2 volumes of $2SO_3$
Therefore, the volume of O_2 required to produce 200 cm^3 SO_3 = $100cm^3$
Volume of air required = 100/20 x 100 = 500 cm^3

Practice Problems 6

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

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2\,(aq)} + H_{2\,(g)}$$

Answer

	$Mg_{(s)}$	+	$2HCl_{(aq)}$	$\rightarrow$	$MgCl_{2\,(aq)}$	+	$H_{2(g}$
A_r/ M_r	24		36.5		95		2
Reaction Coefficients	1	:	2	:	1	:	1
Volume (cm^3)							200
Mass (g)	$8.9 \times 10^{-3} \times 24$ = **0.214**						
Number of Moles	8.9×10^{-3}		$2 \times 8.9 \times 10^{-3}$		8.9×10^{-3}		8.9×10^{-3}

Number of moles of H_2 in $200cm^3$ = volume / V_m = 200/22400 = 8.9×10^{-3}
According to the reaction coefficients1 mole of H_2 is generated from 1 mole Mg
Therefore, $200cm^3$ H_2 will be generated from 8.9×10^{-3} moles Mg
Mass of 8.9×10^{-3} moles Mg = mass x M_r = 8.9×10^{-3} x 24 = **0.214 g**

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?*

$$3F_{2(g)} + 3H_2O_{(l)} \rightarrow 6HF_{(aq)} + O_{3(g)}$$

Answer

	$3F_{2(g)}$	+	$3H_2O_{(l)}$	$\rightarrow$	$6HF_{(aq)}$	+	$O_{3(g}$
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 F_2 = mass/M_r = 0.95/19 = 0.05
According to the reaction coefficients 3 moles of F_2 generate 1 mole of O_3
Therefore 0.05 moles F_2 will generate 0.05/3 = 0.0167 moles O_3
Volume of 0.0167 moles O_3 = number of moles x V_m = 0.0167 x 22400 = **373.3 cm^3**

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

$2PbS_{(s)} + 3O_{2(g)} \rightarrow 2PbO_{(s)} + 2SO_{2(g)}$

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

Answer

	$2PbS_{(s)}$	+	$3O_{2(g)}$	→	$PbO_{(s)}$	+	$SO_{2(g}$
A_r/ M_r	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 O_2
Therefore, 0.4 moles of PbS requires 1.5 x 0.4 = 0.6 moles of O_2
Volume occupied by 0.6 moles O_2 = number of moles x V_m = 0.6 x 24 = 14.4 dm^3 = **14,400 cm^3**

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

$$CO_{(g)} + Cl_{2\ (g)} \rightarrow COCl_{2(g)}$$

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

Answer

	$CO_{(g)}$	+	$Cl_{2(g)}$	→	$COCl_{2\ (g)}$
A_r/ M_r	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 $COCl_2$ = mass/ M_r = 10/99 = 0.101
According to the reaction coefficients, 1 mole of $COCl_2$ is produced from 1 mole CO
Therefore, the number of moles of CO required to generate 0.101 moles of $COCl_2$ = 0.101
Volume occupied by 0.101 moles of CO = number of moles x V_m = 0.101 x 22,400 = **2,262 cm^3**

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

$$2\ KClO_3 \rightarrow 2\ KCl + 3O_2$$

Answer

	$2KClO_3$	→	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 O_2 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 $KClO_3$ = 4.46 x 2/3 = 2.98
Mass of 2.98 moles $KClO_3$ = number of moles x M_r = 2.98 x 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

	$2C_8H_{18(aq)}$	-	$25O_{2(aq)}$	→	$16CO_{2(g)}$	+	$18H_2O_{(l)}$
A_r/M_r	114		32		44		18
Reaction coefficients	2		25		4		6
Volume (L)			109.65 x 24 = **2631.6**				
Mass	1,000						
Number of Moles	1000/114 = 8.77		25/2 x 8.77 = 109.65				

Number of moles C_8H_{18} in 1 kg (1000 g) = 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 x 8.77 = 109.65 moles O_2
Volume of 109.65 moles O2 at STP = number of moles x Vm = L

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

$$2Na_{(s)} + H_2O_{(l)} \rightarrow Na_2O_{(aq)} + H_{2(g)}$$

Answer

	$2Na_{(s)}$	+	$H_2O_{(l)}$	→	$Na_2O_{(aq)}$	+	$H_{2(g)}$
A_r/M_r	23		18		64		18
Reaction coefficients	2		1		1		1
Volume (L)							30
Mass	2.68 x 23 = **61.6**						
Number of Moles	2 x 1.34 = 2.68						30/22.4 = 1.34

Number of moles in 30 L 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 H_2 = 2 x 1.34 = 2.68
Mass of 2.68 moles Na = number of moles x Ar = 2.68 x 23 = **61.6 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: -

$$2\ H_2O_{2(aq)} \rightarrow 2\ H_2O_{(l)} + O_{2(g)}$$

Answer

	$2H_2O_{2(l)}$	→	$2H_2O_{(l)}$	+	$O_{2(g)}$
Ar/Mr	34		18		32
Reaction Coefficients	2		2		1
Mass (g)	1.7				0.8
Volume (L)					0.025 x 22.4 = **0.56**
No. of moles	1.7/34 = 0.05				0.05/2 = 0.025

$M_r[H_2O_2] = 34$
Number of moles in 1.7 g H_2O_2 = mass/Mr = 1.7/34 = 0.05
According to the reaction coefficients 2moles H_2O_2 will decompose to produce 1 mole O2
Therefore, 0.05 moles of H_2O_2 will produce 0.5 x 0.05 = 0.025 moles O_2
Volume occupied by 0.025 moles O_2 = number of moles x V_m = 0.05 x 22.4 = **0.56 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:

$$SO_{2(g)} + Ca(OH)_{2(aq)} \rightarrow CaSO_{3(aq)} + H_2O_{(l)}$$

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

Answer

	$SO_{2(g)}$	+	$Ca(OH)_{2(aq)}$	→	$CaSO_{3(aq)}$	+	$H_2O_{(l)}$
A_r/M_r	64		74		120		18
Reaction coefficients	1		1		1		1
Volume (dm^3)	1000						
Mass			4.64 x 74 = 3303.6				
Number of Moles	1000/22.4 4 = 4.64		4.64				

Number of moles in 1000 dm^3 SO_2 = Volume/ V_m = 1000/22.4 = 4.64
According to the reaction coefficients, 1 mole SO_2 is removed by 1 mole of $Ca(OH)_2$
Thus 4.64 moles of $Ca(OH)_2$ can remove 4.64 moles of SO_2
Mass of 4.64 moles $Ca(OH)_2$ = number of moles x M_r = 4.64 x 74 = **3303.6 g**

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

$$2\ C_2H_6(g)\ +\ 7\ O_2(g)\ \rightarrow\ 4\ CO_2(g)\ +\ 6\ H_2O(l)$$

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

	$2C_2H_6$	+	$7O_2$	→	$4CO_2$	+	$6H_2O$
Mr	30		32		44		18
Reaction coefficients	2		7		4		6
Volume (L)			22.4 x 10.5 = **235.2**				
Mass (g)	90		336				
Number of Moles	90/30 = 3		7/2 x 3 = 10.5				

$M_r[C_2H_6] = 30$
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 x 7/2 = 10.5 moles of O_2 for total combustion
Volume of 10.5 moles O_2 = number of moles x V_m = 10.5 x 22.4 = **235.2 L**