[TP] When 1 mol of $H_2(g)$ is added to a cylinder of volume V and at temperature T the pressure is 1 bar. Then an additional 0.5 mol of gas $CO_2(g)$ is added to the same cylinder keeping the temperature the same. What is the new pressure in the cylinder?

10% 1. < 1 bar
7% 2. $= 1$ bar
23% 3. Between 1 and 1.5 bar
50% 4. 1.5 bar
9% 5. Between 1.5 and 2 bar
1% 6. $= 2$ bar

291551

163 of 191 1 0

BOSTON UNIVERSITY

1

Lecture 9 CH131 Fall 2020

Thursday, October 8, 2020

- Complete: Gas density
- Dalton's law of partial pressures
- Gas law calculations in chemical reactions

Next lecture: Kinetic molecular theory; Why the gas law does not depend on mass; Distribution of molecular speeds; Real gases; Gas law for real gases: van der Waals equation; Ch10: Solids, liquids and phase transitions

BOSTON UNIVERSITY

2

Gas law calculations

At 100.0°C , the density of water vapor is 0.000588 g/mL and that of liquid water is 0.958 g/mL. How much farther apart of water molecules in the gas phase than those in the liquid phase?

The ratio of the densities,

$$\frac{0.958\ \text{g/mL}}{0.000588\ \text{g/mL}} = 1630.,$$

is how many more liquid water molecules there are in a given volume than there are gaseous water molecules in the same volume.

BOSTON UNIVERSITY 6

6

Gas law calculations

This means the same volume can hold 1630 times as many liquid water molecules as gaseous water molecules.

Since volume is the cube of distance, the cube root of the ratio,

$$1630^{1/3} = 11.8$$

means the gas particles are about 11.8 times farther apart than liquid particles.

So, about a factor of ten farther apart than in liquids or solids.

BOSTON UNIVERSITY 7

7

Partial pressures

We have seen that the ideal gas law is the same for all gases, since it depends only on the number (moles) of particles but not what kind of particles they are.

This means each kind of gas contributes to the total pressure only in proportion to its relative number of moles,

$$P = \frac{n_a RT}{V} + \frac{n_b RT}{V} + \cdots = P_a + P_b + \cdots$$

where P_a, P_b, ..., are the partial pressures of gas a, gas b, etc.,

$$P_a = \frac{n_a RT}{V}, \text{ etc.}$$

8

Partial pressures

A convenient way to calculate partial pressures is to use mole fractions,

$$x_a = \left(\frac{n_a}{n}\right) x_b = \frac{n_b}{n}, \ldots$$

$x_a + x_b = \frac{n_a}{n} + \frac{n_b}{n} = \frac{n_a + n_b}{n}$

$n = n_a + n_b$

$= 1$

$P = 1$ bar

$P_o = \frac{3}{5}$ bar $\quad x_o = \frac{3}{5}$

$P_{\bullet} = \frac{2}{5}$ bar $\quad x_{\bullet} = \frac{2}{5}$

9

Partial pressures

Since

$$P = \left(\frac{n_a}{n}\right)\frac{nRT}{V} + \left(\frac{n_b}{n}\right)\frac{nRT}{V} + \cdots = x_a \frac{nRT}{V} + x_b \frac{nRT}{V} + \cdots = x_a P + x_b P + \cdots$$

we see that the partial pressure of each kind of gas is

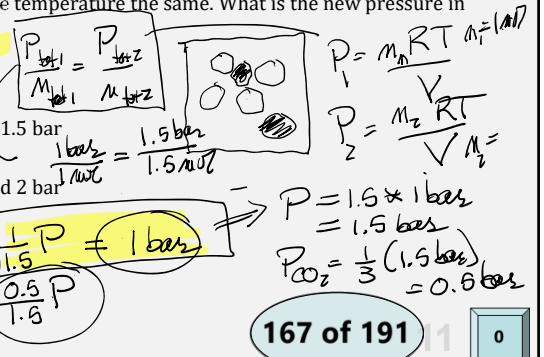
$$P_a = x_a P, P_b = x_b P, \ldots$$

This is known as Dalton's law of partial pressures.

10

[TP] When 1 mol of $H_2(g)$ is added to a cylinder of volume V and at temperature T the pressure is 1 bar. Then an additional 0.5 mol of gas $CO_2(g)$ is added to the same cylinder keeping the temperature the same. What is the new pressure in the cylinder?

3% 1. < 1 bar
5% 2. = 1 bar
12% 3. Between 1 and 1.5 bar
75% 4. 1.5 bar
4% 5. Between 1.5 and 2 bar
1% 6. = 2 bar



$P = n_1 RT / V$

$P_2 = n_2 RT / V$

$P = 1.5 \times 1$ bars $= 1.5$ bars

$P_{CO_2} = \frac{1}{3}(1.5 \text{ bars}) = 0.6$ bars

$P_{H_2} = \frac{n_{H_2}}{n_{H_2} + n_{CO_2}} P = \frac{1}{1.5} P = 1$ bar

$P_{CO_2} = \frac{n_{CO_2}}{n_{H_2} + n_{CO_2}} P = \frac{0.5}{1.5} P$

167 of 191

0

11

Partial pressures

A mixture consisting of 0.513 g of $H_2(g)$ and 16.1 g of $N_2(g)$ occupies 10.0 L at 20.0°C. Calculate the partial pressures of each gas in atm.

First step, calculate the moles of each gas and the total moles.

$n_{H_2} = 0.254 \text{ mol}, n_{N_2} = 0.575 \text{ mol}, n = 0.254 \text{ mol} + 0.575 \text{ mol} = 0.829 \text{ mol}$

12

Partial pressures

A mixture consisting of 0.513 g of $H_2(g)$ and 16.1 g of $N_2(g)$ occupies 10.0 L at 20.0°C. Calculate the partial pressures of each gas in atm.

$n_{H_2} = 0.254 \text{ mol}, n_{N_2} = 0.575 \text{ mol}, n = 0.829 \text{ mol}$

Second step: Use the total moles to calculate the total pressure.

$$P = \frac{nRT}{V} = 0.829 \text{ mol} \times 0.0820575 \frac{\text{L atm}}{\text{K mol}} \times \frac{293.15 \text{ K}}{10.0 \text{ L}} = 1.99 \text{ atm}$$

13

Partial pressures

A mixture consisting of 0.513 g of $H_2(g)$ and 16.1 g of $N_2(g)$ occupies 10.0 L at 20.0°C. Calculate the partial pressures of each gas in atm.

$n_{H_2} = 0.254 \text{ mol}, n_{N_2} = 0.575 \text{ mol}, n = 0.829 \text{ mol}, P = 1.99 \text{ atm}$

Final step: Calculate the partial pressures.

$$P_{H_2} = x_{H_2} P = \frac{0.254}{0.829} \times 1.99 \text{ atm} = 0.612 \text{ atm}$$

$$P_{N_2} = x_{N_2} P = \frac{0.575}{0.829} \times 1.99 \text{ atm} = 1.38 \text{ atm}$$

Check:

$P = P_{H_2} + P_{N_2} = 0.612 \text{ atm} + 1.38 \text{ atm} = 1.99 \text{ atm}$

14

Gas law calculations in chemical reactions

$C_3H_8(g)$ and $O_2(g)$ are placed in a sealed, rigid container. After the container has been heated to 125°C, the partial pressures are $P_{C_3H_8} = 1.00 \text{ atm}$ and $P_{O_2} = 1.00 \text{ atm}$. A spark then initiates the complete combustion of the mixture, forming $CO_2(g)$ and $H_2O(g)$. What is the total pressure in the container at the end of the reaction at 125°C?

Write the balanced chemical equation.

15

Gas law calculations in chemical reactions

$C_3H_8(g)$ and $O_2(g)$ are placed in a sealed, rigid container. After the container has been heated to 125°C, the partial pressures are $P_{C_3H_8} = 1.00$ atm and $P_{O_2} = 1.00$ atm. A spark then initiates the complete combustion of the mixture, forming $CO_2(g)$ and $H_2O(g)$. What is the total pressure in the container at the end of the reaction at 125°C?

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

Determine the limiting reagent

1.00 atm C_3H_8 → 3.00 atm CO_2

1.00 atm O_2 → 0.600 atm CO_2

16

Gas law calculations in chemical reactions

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

1.00 atm O_2 → 0.600 atm CO_2

Determine all partial pressures and the total pressure.

	$C_3H_8(g)$	$O_2(g)$	$CO_2(g)$	$H_2O(g)$	P_{total}
Initial	1.00	1.00	0	0	2
Change	−0.200	−1.00	+0.600	+0.800	
Final	0.80	0.00	0.600	0.800	

18

Gas law calculations in chemical reactions

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

1.00 atm O_2 → 0.600 atm CO_2

Determine all partial pressures and the total pressure.

	$C_3H_8(g)$	$O_2(g)$	$CO_2(g)$	$H_2O(g)$	P_{total}
Initial	1.00	1.00	0	0	2
Change	−0.200	−1.00	+0.600	+0.800	
Final	0.80	0.00	0.600	0.800	

19

Gas law calculations in chemical reactions

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$$

1.00 atm O_2 → 0.600 atm CO_2

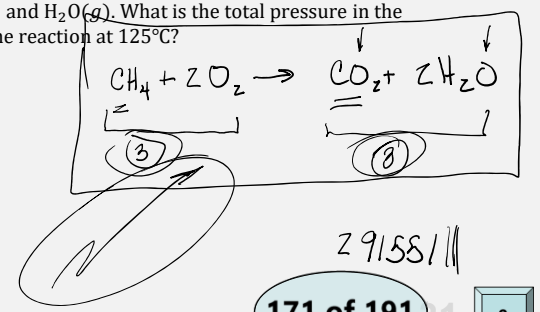
Determine all partial pressures and the total pressure.

	$C_3H_8(g)$	$O_2(g)$	$CO_2(g)$	$H_2O(g)$	P_{total}
Initial	1.00	1.00	0	0	2
Change	−0.200	−1.00	+0.600	+0.800	
Final	0.80	0	0.600	0.800	2.20

20

[TPS] $CH_4(g)$ and $O_2(g)$ are placed in a sealed, rigid container. After the container has been heated to 125°C, the partial pressures are $P_{CH_4} = 1.00$ atm and $P_{O_2} = 1.00$ atm. A spark then initiates the complete combustion of the mixture, forming $CO_2(g)$ and $H_2O(g)$. What is the total pressure in the container at the end of the reaction at 125°C?

1%	1.	0.50 atm
14%	2.	1.00 atm
5%	3.	1.50 atm
71%	4.	2.00 atm
6%	5.	2.50 atm
3%	6.	3.00 atm



171 of 191

21

Gas law calculations in chemical reactions

$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$

$1.00\ \text{atm}\ CH_4 \rightarrow 1.00\ \text{atm}\ CO_2$

$1.00\ \text{atm}\ O_2 \rightarrow 0.500\ \text{atm}\ CO_2$

Determine all partial pressures and the total pressure.

22

Gas law calculations in chemical reactions

$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$

$1.00\ \text{atm}\ O_2 \rightarrow 0.500\ \text{atm}\ CO_2$

Determine all partial pressures and the total pressure.

	$CH_4(g)$	$O_2(g)$	$CO_2(g)$	$H_2O(g)$	P_{total}
Initial	1.00	1.00	0	0	2.00
Change	−0.500	−1.00	+0.500	+1.00	
Final					

23

Gas law calculations in chemical reactions

$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$

$1.00\ \text{atm}\ O_2 \rightarrow 0.500\ \text{atm}\ CO_2$

Determine all partial pressures and the total pressure.

	$CH_4(g)$	$O_2(g)$	$CO_2(g)$	$H_2O(g)$	P_{total}
Initial	1.00	1.00	0	0	2.00
Change	−0.500	−1.00	+0.500	+1.00	
Final					

24

Gas law calculations in chemical reactions

$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$

1.00 atm O_2 → 0.500 atm CO_2

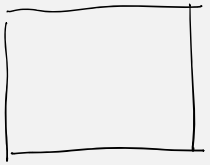
Determine all partial pressures and the total pressure.

	$CH_4(g)$	$O_2(g)$	$CO_2(g)$	$H_2O(g)$	P_{total}
Initial	1.00	1.00	0	0	2.00
Change	−0.500	−1.00	+0.500	+1.00	
Final	0.50	0	0.500	1.00	2.00

25

Kinetic molecular theory

Goal: Microscopic expression for P.



Gas of identical particles
Each particle has the same mass

$m = \frac{M}{N_A}$

moving at speed v_i
How many? $n N_A$ different speed

26

