Simple Step-by-Step Guides to Solving Chemistry Problems

Gas Laws

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GAS LAWS

Despite considerable differences in chemical properties, amazingly all gases more or less obey the gas laws. The gas laws deal with how gases behave with respect to pressure, volume, temperature, and amount (number of moles).

Pressure (P): Units of pressure used are standard atmosphere (atm), pascal (pa) and torr (mm Hg). As it name implies, one (1) atmosphere is the average pressure at sea level. The SI unit for pressure is the pascal (pa). 101,325 pascal equals 1 atmosphere. A torr (Torr) is a unit of pressure applied by a depth of one millimetre of mercury (mmHg). One atmosphere equals 760 torr.

1 atmosphere = 101,325 pa = 760 torr = 760 mm Hg

Volume (V): any volume units can be used (litres, cm^3, dm^3 etc); what ever unit you adopt, ensure it is used for all volume values.

Temperature (T): temperature must be on the Kelvin scale for all gas calculations. The Kelvin scale is related to the Celsius scale. The temperature in Kelvin (K) is equal to the temperature T in degrees Celsius (°C) plus 273.15. Thus, water freezes at 273.15K (0°C) and boils at 373.15K (100°C). Room temperature, often quoted as 25°C = 298.15K.

At constant temperature the pressure of a gas increases its volume decreases. When the volume of gases increases, its pressure decreases (**Boyles Law**). At constant pressure, as the volume of gases increases, its temperature also increases, and vice-versa (**Charles Law**). Similarly, as the pressure of gases at constant volume increases, so does the temperature of the gas and vice-versa (**Gay-Lussac Law**). These three gas laws can be combined:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

The subscripts 1 and 2, denote initial and final conditions. So long as you ensure that you use the Kelvin temperature scale and that you use the same units for both initial and final pressure and volume, calculations based on the gas laws are straightforward.

STP = Standard Temperature Pressure = 273K, 1 atmosphere

RTP = Room Temperature Pressure = 298K, 1 atmosphere

Partial Pressure

The total pressure exerted by a mixture of gases is the sum of the partial pressures of component gases. In other words

$$P_{Total} = P_A + P_B + P_C \ldots etc$$

Example 1: If 22.5 L of nitrogen at 748 mm Hg are compressed to 725 mm Hg at constant temperature. What is the new volume?

Answer:

Use: $P_1 V_1 = P_2V_2$

V_1 = 22.5L P_1 = 748 mmHg
V_2 = ? P_2 = 725 mmHg

Rearranging to make V_2 the subject of the equation and solve,

$$V_2 = \frac{V_1P_1}{P_2} = \frac{22.5 \text{ x } 748}{725} = \mathbf{23.2L}$$

Example 2: What pressure is required to compress 196.0 litres of air at 1.00 atmosphere into a cylinder whose volume is 26.0 litres?

Answer:

Use: : $P_1 V_1 = P_2V_2$

V_1 = 196 litres P_1 = 1 atm
V_2 = 26 litres P_2 = ?

Rearranging to make V_2 the subject of the equation and solving:

$$P_2 = \frac{V_1P_1}{V_2} = \frac{(196 \text{ x} 1)}{26} = \mathbf{7.5 \text{ atm}}$$

Example 3: A 40.0 L tank of ammonia has a pressure of 12.7 kPa. Calculate the volume of the ammonia if its pressure is changed to 8.4 kPa while its temperature remains constant.

Answer:

Use: $P_1 V_1 = P_2V_2$

V_1 = 40L P_1 = 12.7 kPa
V_2 = ? P_2 = 8.4 kPa

Rearranging to make V_2 the subject of the equation and solving

$$V_2 = \frac{V_1 P_1}{P_1} = \frac{40 \text{ x} 12.7 \text{ x} 10^3}{8.4 \text{ x } 10^3} = \mathbf{60.47 \text{ L}}$$

Example 4: Calculate the decrease in temperature when 6.00 L at 20.0 °C is compressed to 4.00 L.

Answer:

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

V_1 = 6L T_1 = 20 + 273 = 293K
V_2 = 4L T_2 = ?

Rearranging to make T_2 the subject of the equation and solving:

$$T_2 = \frac{V_2 T_1}{V_1} = \frac{4 \text{ x } 296}{6} = \mathbf{197.3K}$$

Example 5: A gas occupies 900.0 mL at a temperature of 27.0 °C. What is the volume at 132.0 °C?

Answer

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

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V_1 = 900 mL T_1 = 27 + 273 = 300K

V_2 = ? T_2 = 132 + 273 = 405K

Rearranging to make V_2 the subject of the equation and solving:

$$V_2 = \frac{V_1T_2}{T_1} = \frac{900\ x\ 405}{300} = \mathbf{1215\ mL}$$

Example 6: A gas balloon has a volume of 106.0 liters when the temperature is 45.0 °C and the pressure is 740.0 mm of mercury. What will its volume be at 20.0 °C and 780 .0 mm of mercury pressure?

Answer:

Use: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

P_1 = 740 mm Hg P_2 = 780 mm Hg

V_1= 106 litres V_2 = ?

T_1 = 45 + 273 = 318K T_2 = 20 + 273 = 293K

Rearranging to make V_2 the subject of the equation and solving

$$V_2 = \frac{P_1V_1T_2}{T_1P_2} = \frac{740 \text{ x } 106 \text{ x } 293}{318 \text{ x } 780} = \mathbf{92.66\ litres}$$

Example 8: A gas is heated from 263.0 K to 298.0 K and the volume is increased from 24.0 liters to 35.0 litres by moving a large piston within a cylinder. If the original pressure was 1.00 atm, what would the final pressure be?

Answer:

Use: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

P_1 = 1 atm P_2 = ?

V_1= 24 litres V_2 =35 litres

T_1 = 263K T_2 = 298K

Rearranging to make P_2 the subject of the equation and solving

$$P_2 = \frac{P_1V_1T_2}{T_1V_2} = \frac{1 \text{ x } 24 \text{ x } 298}{263 \text{ x } 35} = \mathbf{0.78\ atm}$$

Ideal Gas Equation

Since the same volumes of gas contain the same number of moles, the gas laws can be rewritten as:

$$PV = nRT$$

where n = number of moles and R is the Universal Gas constant (8.314 kJ mol^{-1} K^{-1}). Remember that the number of moles (n) of a substance is linked to its mass (m) and relative formula mass (M_r), ie.

$$n = \frac{m}{M_r}$$

So, the Ideal Gas Equation can be rewritten as:

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

This allows the determination of the formula and relative formula mass of gases.

Note:

The four variables represent four different properties of a gas:

- Pressure (P), often measured in atmospheres (atm), kilopascals (kPa), or millimeters mercury/torr (mm Hg, torr)
- Volume (V), given in cm^3, litres (L), or m^3 (SI unit)
- Number of moles of gas (n)
- Temperature of the gas (T) measured in degrees Kelvin (K)

R is the ideal gas constant, which takes on different forms depending on which units are in use. The two most common formulations of *R* are given by:

R = 8.314 J mol^{-1}K^{-1}
P in Pascals (Pa)
V in cubic meters (m^3)
T in Kelvin

R = 0.0821 litre atm mol^{-1}K^{-1}
P in atmospheres (atm)
V in litres (L)
T in Kelvin

Example 9: A toy balloon filled with air has an internal pressure of 1.25 atm and a volume of 2.50 L, and a temperature of 285 K. How many moles of gas does the balloon hold?

Answer:

Use: $PV = nRT$

P = 1.25 atm, V = 2.5L, R = 8.314 Jmol^{-1}K-1, T = 285K, n = ?

Rearranging to make *n* the subject of the equation:

$$n = \frac{PV}{nRT} = \frac{1.25 \text{ x } 2.5}{0.821 \text{ x } 285} = \mathbf{0.134\ moles}$$

Example 10: What is the volume of 23 g of neon gas at 1°C and a pressure of 1500 kPa?

Answer:

Use: $PV = nRT$

P = 1500000Pa, V =?, n = $\frac{23}{20}$ = 1.15, R = 8.314 k J mol^{-1}K^{-1}, T = 274K

Rearranging and making V the subject of the equation:

$$V = \frac{nRT}{P} = \frac{1.15 \times 274}{1500000} = 1.746 \times 10^{-3}\ m^3 = \mathbf{1746\ cm^3}$$

Practice Problems

1. The pressure of a gas is reduced from 1200.0 mm Hg to 850.0 mm Hg as the volume of its container is increased by moving a piston from 85.0 mL to 350.0 mL. What would the final temperature be if the original temperature was 90.0 °C?

2. If 10.0 litres of oxygen at STP are heated to 512°C, what will be the new volume of gas if the pressure is also increased to 1520.0 mm of mercury?

3. How many moles of gas occupy 98 L at a pressure of 2.8 atmospheres and a temperature of 292 K?

4. If 5.0 moles of O_2 and 3.0 moles of N_2 are placed in a 30.0 L tank at a temperature of 250°C, what will the pressure of the resulting mixture of gases be?

5. A balloon is filled with 35.0 L of helium in the morning when the temperature is 20.00C. By noon the temperature has risen to 45.00C. What is the new volume of the balloon?

6. A 0.035 m^3 tank of oxygen is at 315 K with an internal pressure of 1.92×10^7 Pa. How many moles of gas does the tank contain?

7. A balloon that can hold 85 L of air is inflated with 3.5 moles of gas at a pressure of 1.0 atmosphere. What is the temperature in 0 C of the balloon?

8. $CaCO_3$ decomposes at 1200°C to form CO_2 gas and CaO. If 25 L of CO_2 are collected at 1200°C, what will the volume of this gas be after it cools to 250°C?

9. A helium balloon with an internal pressure of 1.00 atm and a volume of 4.50 L at 20.00Cis released. What volume will the balloon occupy at an altitude where the pressure is 0.600 atm and the temperature is –20°C?

10. There are 135 L of gas in a container at a temperature of 260°C. If the gas was cooled until the volume decreased to 75 L, what would the temperature of the gas be?

11. A 7.5 m^3 container holds 62 moles of gas at a temperature of 215°C. What is the pressure in atmospheres inside the container?

12. 6.0 L of gas in a piston at a pressure of 1.0 atm are compressed until the volume is 3.5 L. What is the new pressure inside the piston?

13. A gas canister can tolerate internal pressures up to 210 atmospheres. If a 2.0 L canister holding 3.5 moles of gas is heated to 1350°C, will the canister explode?

14. The initial volume of a gas at a pressure of 3.2 atm is 2.9 L. What will the volume be if the pressure is increased to 4.0 atm?

15. Two flasks are connected with a stopcock. Flask #1 has a volume of 2.5 L and contains oxygen gas at a pressure of 0.70 atm. Flask #2 has a volume of 3.8 L and contains hydrogen gas at a pressure of 1.25 atm. When the stopcock between the two flasks is opened and the gases are allowed to mix, what will the resulting pressure of the gas mixture be?

16. A weather balloon has a volume of 35 L at sea level (1.0 atm). After the balloon is released it rises to where the air pressure is 0.75 atm. What will the new volume of the weather balloon be?

Answers are given on the following page.

Practice Problems Answers:

17. The pressure of a gas is reduced from 1200.0 mm Hg to 850.0 mm Hg as the volume of its container is increased by moving a piston from 85.0 mL to 350.0 mL. What would the final temperature be if the original temperature was 90.0 °C?

Answer:

Use: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

P_1 = 1200 mmHg, V_1 = 85 mL, T_1 = 90 + 273 = 363K

P_2 = 850 mmHg, V_2 = 350 mL, T_2 = ?

Rearranging, to make T_2 the subject of the equation,

$$T_2 = \frac{P_2V_2T_1}{P_1V_1} = \frac{850 \text{ x } 350 \text{ x } 363}{1200 \text{ x } 85} = \mathbf{1058.8K}$$

18. If 10.0 litres of oxygen at STP are heated to 512°C, what will be the new volume of gas if the pressure is also increased to 1520.0 mm of mercury?

Answer:

Use: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

P_1 = 1 atm = 760 mmHg, V_1 = 10 litres, T_1 = 273K
P_2 = 1520 mmHg, V_2 = ?, T_2 = 512 + 273 = 785K

Rearranging, to make V_2 the subject of the equation,

$$V_2 = \frac{P_1V_1T_2}{P_2T_1} = \frac{760 \text{ x } 10 \text{ x } 785}{1520 \text{ x } 273} = \mathbf{14.4\ litres}$$

19. How many moles of gas occupy 98 L at a pressure of 2.8 atmospheres and a temperature of 292 K?

Answer:

Use: $PV = nRT$

P = 2.8 atm, V = 98L, R = 0.0821 L atm mol^{-1}K^{-1}, n = ?

Rearranging the equation to make *n* the subject, and solving,

$$n = \frac{PV}{RT} = \frac{28 \text{ x } 98}{0.0821 \text{ x } 292} = \mathbf{114.5\ moles}$$

20. If 5.0 moles of O_2 and 3.0 moles of N_2 are placed in a 30.0 L tank at a temperature of 250°C, what will the pressure of the resulting mixture of gases be?

Answer:

Use: $PV = nRT$

P_{O2} = ?, V = 30L, R =0.0821 L atm mol^{-1}K^{-1}, T = 250 + 298 = 548K

P_{N2} = ?, n_{O2} = 5 moles, n_{N2} = 3 moles

Rearranging Ideal Gas equation to make n the subject and then solving for O_2 and N_2

O_2: $PV = \frac{nRT}{V} = \frac{5 \text{ x } 0.0821 \text{ x } 548}{30} = 7.5 \text{ atm}$

N_2: $PV = \frac{nRT}{V} = \frac{3 \text{ x } 0.0821 \text{ x } 548}{30} = 4.5 \text{ atm}$

$P_{Tot} = P_{O2} + P_{N2}$ = 7.5 + 4.5 = **12 atm**

21. A balloon is filled with 35.0 L of helium in the morning when the temperature is 20.00C. By noon the temperature has risen to 45.00C. What is the new volume of the balloon?

Answer:

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

V_1 = 35 L, T_1 = 20 + 273 = 293K
V_2 =?, T_2 = 45 + 273 318K

Rearranging to make V_2 the subject of the equation and solving,

$$V_2 = \frac{V_1\, T_2}{T_1} = \frac{35 \text{ x } 318}{293} = \mathbf{37.99\ L}$$

22. A 0.035 m^3 tank of oxygen is at 315 K with an internal pressure of 1.92 x 10^7 Pa. How many moles of gas does the tank contain?

Answer:

Use: $PV = nRT$

P = 1.92 x 10^7 Pa, V = 0.035 m^3, R = 8.314 J mol^{-1}K^{-1}, T= 315K

$$n = \frac{PV}{nRT} = \frac{1.92 \text{ x } 10^7 \text{x } 0.035}{8.314 \text{ x } 315} = \mathbf{257.3\ moles}$$

23. A balloon that can hold 85 L of air is inflated with 3.5 moles of gas at a pressure of 1.0 atmosphere. What is the temperature in 0 C of the balloon?

Answer:

Use: $PV = nRT$

P = 1 atm, V = 85L, n = 3.5, R = 0.0821 L atm mol^{-1}K^{-1}, T = 0 + 273 = 273K

Rearranging Ideal Gas equation to making *T* the subject, and solving

$$T = \frac{PV}{nR} = \frac{1 \text{ x } 85}{3.5 \text{ x } 0.0821} = \mathbf{295.8K}$$

24. $CaCO_3$ decomposes at 1200°C to form CO_2 gas and CaO. If 25 L of CO_2 are collected at 1200°C, what will the volume of this gas be after it cools to 250°C?

Answer:

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

V_1= 25L, T_1 = 1200 + 273 = 1473K
V_2 = ?, T_2 = 250 + 274 = 524K

Rearranging to make V_2 the subject of the equation

$$V_2 = \frac{V_1\,T_2}{T_1} = \frac{25 \text{ x } 1473}{524} = \mathbf{70.2\ L}$$

25. A helium balloon with an internal pressure of 1.00 atm and a volume of 4.50 L at 20.00Cis released. What volume will the balloon occupy at an altitude where the pressure is 0.600 atm and the temperature is –20°C?

Answer:

Use: $\frac{P_1\,V_1}{T_1} = \frac{P_2V_2}{T_2}$

P_1 = 1.00 atm, V_1 = 4.50 L, T_1 = 20 +273 = 293 K,

P_2 = 0.600 atm, V_2 = ?, T_2 = -20.0 + 273= 253 K

$$V_2 = \frac{P_1\,V_1 T_2}{T_2 P_2} = \frac{1 \text{ x } 4.5 \text{ x } 253}{25 \text{ x } 0.6} = \mathbf{6.37L}$$

26. There are 135 L of gas in a container at a temperature of 260°C. If the gas was cooled until the volume decreased to 75 L, what would the temperature of the gas be?

Answer:

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

V_1 = 135L, T_1 = 260 +273 = 533K, T_2 = ?, V_2 = 75 L

Rearranging and making T_2 the subject of the equation, and solving,

$$T_2 = \frac{V_2\,T_1}{V_1} = \frac{75 \text{ x } 533}{135} = \mathbf{296K}$$

27. A 7.5 m^3 container holds 62 moles of gas at a temperature of 215°C. What is the pressure in atmospheres inside the container?

Answer:

Use: $PV = nRT$

P = ?, V = 7.5 m^3 (7500L), n = 62, R = 0.0821 L atm $mol^{-1}K^{-1}$, T = 215 + 73 = 488 K

Rearranging to make P the subject of the equation and solving,

$$P = \frac{nRT}{V} = \frac{62 \text{ x } 0.0821 \text{ x } 488}{7500} = \mathbf{0.331\ atm}$$

28. 6.0 L of gas in a piston at a pressure of 1.0 atm are compressed until the volume is 3.5 L. What is the new pressure inside the piston?

Answer:

Use: $P_1 V_1 = P_2 V_2$

P_1 = 1.0 atm, V_1 = 6.0 L, P_2 = ?, V_2 = 3.5 L

Rearrange to make P_2 the subject of the equation and solving,

$$P_2 = \frac{P_1 V_1}{V_2} = \frac{1 \text{ x } 6}{3.5} = \mathbf{1.71\ atm}$$

29. A gas canister can tolerate internal pressures up to 210 atmospheres. If a 2.0 L canister holding 3.5 moles of gas is heated to 1350°C, will the canister explode?

Answer:

Use: $PV = nRT$

P = ?, V = 2.5L, n = 3.5 mole, R = 0.0821 L atm $mol^{-1}K^{-1}$, T = 1350 + 273 = 1623K

Rearranging the equation to make P the subject and solving,

$$PV = nRT = \frac{3.5 \text{ x } 0.0821 \text{ x } 1623}{2.0} = \mathbf{233\ atm}$$

Yes, the canister will explode.

30. The initial volume of a gas at a pressure of 3.2 atm is 2.9 L. What will the volume be if the pressure is increased to 4.0 atm?

Answer

Use: $P_1 V_1 = P_2 V_2$

P_1 = 3.2 atm, V_1 = 2.9 L, P_2 = 4.0 atm, V_2 = ?

Rearrange and male V2 the subject of the equation and solve,

$$V_2 = \frac{P_1 V_1}{P_2} = \frac{3.2 \text{ x } 2.9}{4} = \mathbf{2.32L}$$

31. Two flasks are connected with a stopcock. Flask #1 has a volume of 2.5 L and contains oxygen gas at a pressure of 0.70 atm. Flask #2 has a volume of 3.8 L and contains hydrogen gas at a pressure of 1.25 atm. When the stopcock between the two flasks is opened and the gases are allowed to mix, what will the resulting pressure of the gas mixture be?

Answer:

Use: $P_1 V_1 = P_2 V_2$

Treat the gases separately:

Oxygen: P_1 = 0.7 atm, V_1 = 2.5L, P_2 = ?, V_2 = 6.3L

Rearrange the equation and make P_2 the subject and solve,

$$P_2 = \frac{P_1 V_1}{V_2} = \frac{0.7 \text{ x } 2.5}{6.3} = \mathbf{0.28 \text{ atm}}$$

Hydrogen: P_1 = 1.25 atm, V_1 = 3.8L, P_2 = ?, V_2 = 6.3L

Rearrange the equation and make P_2 the subject and solve,

$$P_2 = \frac{P_1 V_1}{V_2} = \frac{1.25 \text{ x } 3.8}{6.3} = \mathbf{0.75 \text{ atm}}$$

$P_{Tot} = P_{O2} + P_{H2}$ = 0.28 + 0.75 = **1.3 atm**

32. A weather balloon has a volume of 35 L at sea level (1.0 atm). After the balloon is released it rises to where the air pressure is 0.75 atm. What will the new volume of the weather balloon be?

Answer:

Use: $P_1 V_1 = P_2 V_2$

P_1 = 1.0 atm, V_1 = 35 L, P_2 = 0.75 atm, V_2 = ?

Rearranging, making V_2 the subject of the equation and solving,

$$V_2 = \frac{P_2 V_2}{P_2} = \frac{1 \text{ x } 35}{0.75} = \mathbf{46.7 \text{ L}}$$