

Gas Laws – Dalton, Boyle, Charles, Gay-Lussac & Avogadro

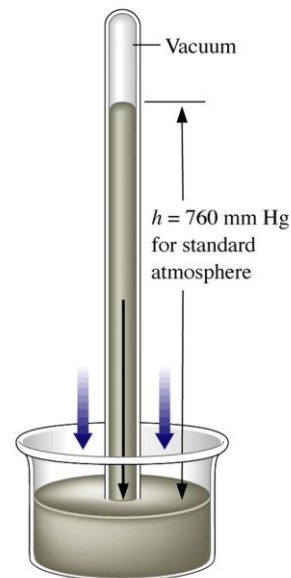
Today we will begin our investigation into the wonderful world of **gas laws**. Basically we will be looking at the different ways a gas reacts when temperature, pressure and volume are changed. The first thing you need to be aware of is that **when solving gas law problems temperature must always be in Kelvin (K)**. To convert Celsius to Kelvin add 273 ($K = ^\circ C + 273$). **Standard temperature is 0 °C or 273 K**.

Volume should be in **liters(L)**, **cubic decimeters (dm³)**, **milliliters(mL)** or **cubic centimeters(cm³)**, whichever is specified. Liters and cubic decimeters are the same and milliliters and cubic centimeters are the same. The most important thing is that both volume measurements use the same unit.

Pressure can be given in a number of different units. All of these values represent Standard pressure, the atmospheric pressure at sea level.

$$1 \text{ atm} = 760 \text{ torr} = 760 \text{ mm Hg} = 101.3 \text{ kPa} = 101325 \text{ Pa} = 14.7 \text{ psi}$$

Atm is the abbreviation for atmospheres; torr is for Evangelista Torrecelli (1608 – 1647). Torrecelli's work with Galileo led him to create the first mercury barometer. When Torrecelli upended a glass tube full of mercury into a dish of mercury, the liquid level fell to about 760 mm. Torrecelli's observations of the daily changes in the level of mercury in the tube led to the concept of changing atmospheric pressure. Notice that both torr and mm Hg are equal, 760 torr = 760 mm Hg (the Hg is mercury). These values are always equal. The next unit is the SI (System International) for pressure. It is the kilopascal, kPa. The last is the unit with which you may be most familiar. It is pounds per square inch, or psi.



Dalton's Law of Partial Pressure

Dalton's Law states that the total pressure of a gas is equal to the sum of its partial pressures. Dry air at sea level is composed mostly of Nitrogen (78.1%), Oxygen (20.9%) and Argon (0.9%).

Dalton's Law of partial pressure uses the following formula: $P_{\text{total}} = P_1 + P_2 + P_3 \dots$ In this equation, P_{total} represents the **total pressure**; P_1 , P_2 , P_3 and so on (when necessary) represent **the partial pressures of each of the different gases**. The important thing to remember when solving these problems is that all of your units are the same. Convert when necessary.

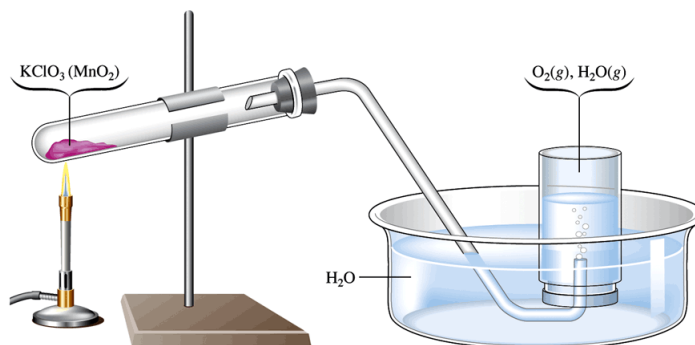
Example: If I have a balloon with the three gases at the following pressures: N: 79.11 kPa, O: 21.22 kPa, and Argon 0.95 kPa, what is the total pressure pushing out on the balloon?

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

$$P_{\text{total}} = 79.11 \text{ kPa} + 21.22 \text{ kPa} + 0.95 \text{ kPa}$$

$$P_{\text{total}} = \mathbf{101.28 \text{ kPa}}$$

Dalton's law is also applicable when it comes to gas collection over water. A mixture of gases results whenever a gas is collected by displacement of water. Observe the diagram to the right. Oxygen gas is produced through the decomposition of potassium chlorate. The gas in the bottle is a mixture of oxygen and water vapor. Water vapor is present because water molecules escape from the surface of the liquid and collect in the space above the liquid. When the rate of evaporation equals the rate of condensation, equilibrium is reached. The pressure exerted by the water vapor depends on temperature and is referred to as the vapor pressure of water.



Example: A sample of solid potassium chlorate (KClO_3) was heated in a test tube and decomposed by the following reaction: $2\text{KClO}_3 \rightarrow 2\text{KCl} + 3\text{O}_2$

The oxygen produced was collected by displacement method at 22°C at a total pressure of 754 torr. The vapor pressure of water at 22°C is 21 torr. Calculate the partial pressure of O_2 in the gas collected.

$$P_{\text{total}} = P_{\text{O}_2} + P_{\text{H}_2\text{O}}$$

$$754 = X + 21$$

$$X = 733 \text{ torr}$$

Mole fraction: the ratio of the number of moles of a given component in a mixture to the total number of moles in the mixture. The formula used in determining mole fractions is: $X_1 = n_1/n_{total} = P_1/P_{total}$ (use either moles or pressure). Mole fraction has no units.

Example: The partial pressure of oxygen was observed to be 156 torr in air with a total atmospheric pressure of 743 torr. Calculate the mole fraction of O₂ present.

$$X_1 = P_1/P_{total}$$

$$X_1 = 156/743$$

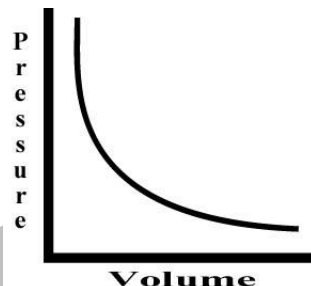
$$X_1 = 0.210$$

Boyle's Law for Pressure – Volume Changes

Boyle's Law is named for Anglo-Irish chemist Robert Boyle (1627 – 1691). **Boyle's Law** states that for a given mass of gas at constant temperature, the volume of the gas varies



inversely with pressure. The formula, ah yes, but before we get to that I want to talk about that I-word from above...inversely. The word **inversely** in this case means as one goes up, the other goes down. As the pressure increases, the volume will decrease and vice-versa. A graph showing an inverse relationship is shown above.



OK, now the formula: $P_1V_1 = P_2V_2$

P₁: 1st pressure P₂: 2nd pressure
V₁: 1st volume V₂: 2nd volume

Example: A balloon contains 30.0 L of helium gas at 100.0 kPa. What is the volume when the balloon rises to an altitude where the pressure is only 25.0 kPa?

$$P_1: 100.0 \text{ kPa} \qquad P_2: 25.0 \text{ kPa}$$

$$V_1: 30.0 \text{ L} \qquad V_2: X$$

$$P_1V_1 = P_2V_2$$

$$(100.0)(30.0) = (25.0)(X)$$

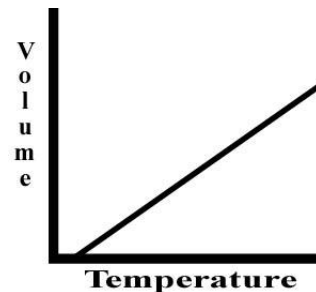
$$3000.0 = 25.0X$$

$$120 \text{ L} = X$$

Charles' Law for Temperature – Volume Changes



Charles's Law is named for the French physicist and balloonist Jacques Charles (1746 – 1823). **Charles' Law** states that the volume of a fixed mass of gas is directly proportional to its Kelvin temperature if the pressure is kept constant. Note, in Charles' Law there is a direct relationship between volume and temperature. The graph of a direct relationship is shown on the right.



The formula is: $V_1/T_1 = V_2/T_2$

Note that with Boyle's Law there was an inverse relationship and we multiplied our original values. With Charles Law there is a direct relationship, so we will divide our values. More appropriately, we will cross multiply.

V₁: 1st volume V₂: 2nd volume
T₁: 1st temperature T₂: 2nd temperature

Example: A balloon, inflated in an air-conditioned room at 27 °C, has a volume of 4.0 L. The balloon is then heated to a temperature of 57 °C. What is the new volume of the balloon if the pressure remains constant?

$$V_1: 4.0 \text{ L} \qquad V_2: X$$

$$T_1: 27 \text{ °C} + 273 = 300 \text{ K} \qquad T_2: 57 \text{ °C} + 273 = 330 \text{ K}$$

$$V_1/T_1 = V_2/T_2$$

$$\frac{4.0}{300} = \frac{X}{330}$$

$$(4.0)(330) = (300)(X)$$

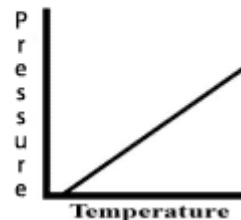
$$1320 = 300X$$

$$4.4 \text{ L} = X$$

Gay-Lussac's Law (Amontons' Law) for Temperature – Pressure Changes



Gay-Lussac's Law is named for the French chemist Joseph L. Gay-Lussac (1778 – 1850). **Gay-Lussac's Law** states that the pressure of a gas is directly proportional to the Kelvin temperature if the volume is kept constant. This law also shows a direct relationship. Thus, as the pressure increases, the temperature will increase and vice versa; and as the pressure decreases, so will the temperature and vice versa. The formula is: $P_1/T_1 = P_2/T_2$



P_1 : 1st pressure P_2 : 2nd pressure
 T_1 : 1st temperature T_2 : 2nd temperature

Example: The gas left in an aerosol can is at a pressure of 100. kPa at 27 °C. If the can is thrown onto a fire, what will be the internal pressure of the gas when its temperature reaches 927 °C?

P_1 : 100.kPa
 T_1 : 27 °C + 273 = 300. K
 P_2 : X
 T_2 : 927 °C + 273 = 1200. K

$$\begin{aligned} P_1/T_1 &= P_2/T_2 \\ \frac{100.}{300.} &= \frac{X}{1200.} \\ (100.)(1200) &= (300.)(X) \\ 120000 &= 300. X \\ \mathbf{400. kPa} &= \mathbf{X} \end{aligned}$$

Avogadro's Law for Mole – Volume Changes



Avogadro postulated that equal volumes of gases at the same temperature and pressure contain the same number of "particles"

The formula: $V_1/n_1 = V_2/n_2$

For a gas at a constant temperature and pressure, the volume is directly proportional to the number of moles of gas.

Example: A 15.5 L sample containing 0.40 moles of oxygen gas (O₂) at a pressure of 1 atm and a temperature of 25°C. If all of the O₂ is converted to ozone (O₃) at the same pressure and temperature, calculate the volume of ozone (O₃).

$$\begin{aligned} 3O_2 &\rightarrow 2O_3 \\ \frac{0.40 \text{ moles } O_2}{1} &\times \frac{2 \text{ moles of } O_3}{3 \text{ moles of } O_2} = 0.27 \text{ moles } O_3 \\ 15.5/0.40 &= X/0.27 \\ \mathbf{X} &= \mathbf{10. L} \end{aligned}$$

Homework:

General Questions

1. What is standard temperature in Celsius? **0 °C** In Kelvin? **273 K**
2. In all gas law calculations, temperature must be measured in **Kelvin**.
3. What is standard pressure in: **1 atm 760 torr 14.7 psi 760 mmHg 101.3 kPa**
4. What does psi stand for? **pounds per square inch**
5. What does atm stand for? **atmospheres**
6. What does kPa stand for? **kilopascals**

Dalton's Law of Partial Pressure:

1. What is Dalton's Law of Partial Pressure?

The total pressure of a gas is equal to the sum of its partial pressures

2. List the three main gases found in the air we breathe and their percentage of the total.
Nitrogen (78.1%), Oxygen (20.9%) and Argon (0.9%)

3. What are the formulas for Dalton's Law of Partial Pressure?

$$P_{\text{total}} = P_1 + P_2 + P_3 \quad X = n_1/n_{\text{total}} = P_1/P_{\text{total}}$$

4. Air contains oxygen, nitrogen, carbon dioxide, and trace amounts of other gases. What is the partial pressure of oxygen if the total pressure = 101.30 kPa, the pressure of nitrogen = 79.10 kPa, the pressure of carbon dioxide = 0.040 kPa, and the pressure of the trace gases = 0.94 kPa?

$$101.3 = 79.1 + 0.040 + 0.94 + x$$

$$x = 21.2 \text{ kPa}$$

5. A gas is collected over water at 25°C. If the vapor pressure of water is 3.2 kPa and the total pressure is 105.2 kPa, what is the partial pressure of the gas?

$$105.2 = 3.2 + x$$

$$x = 102.0 \text{ kPa}$$

6. A balloon contains mostly helium and a little methane. The partial pressure of helium is 101.2 kPa. If the pressure inside the balloon is 101.30 kPa, what is the partial pressure of methane?

$$101.3 = 101.2 + x$$

$$x = 0.1 \text{ kPa}$$

7. Determine the mole fraction of oxygen if the pressure of oxygen is 430 torr and the total pressure is 760 torr.

$$X = 430/760$$

$$X = 0.57$$

8. The total pressure is 1.20 atm. If the mole fraction of nitrogen is 0.856, what is the partial pressure of nitrogen?

$$0.856 = P_1/1.20$$

$$P_1 = 1.03 \text{ atm}$$

Boyle's Law

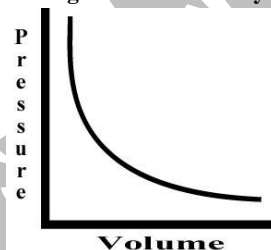
1. What is Boyle's Law?

For a given mass of gas at constant temperature, the volume of the gas varies inversely with pressure

2. What is meant by vary inversely?

As one increases, the other decreases.

3. Draw a graph showing an inverse relationship.



4. What formula is used for Boyle's Law?

$$P_1V_1 = P_2V_2$$

5. A sample of oxygen gas occupies 250 mL at 740 torr pressure. What volume will it occupy at 800 torr pressure?

$$(740)(250) = (800)(V_2)$$

$$231.25 \text{ mL} \rightarrow 200 \text{ mL (using significant digits)}$$

6. A 2.0 liter container of nitrogen had a pressure of 3.2 atm. What volume would be necessary to decrease the pressure to 1.0 atm?

$$(3.2)(2.0) = (1.0)(V_2)$$

$$6.4 \text{ L}$$

7. Ammonia gas occupies a volume of 450. mL at a pressure of 720. mm Hg. What volume would it occupy at standard pressure?

$$(720)(450) = (760)(V_2)$$

$$426 \text{ mL}$$

8. A 175 mL sample of neon had its pressure changed from 75 kPa to 150 kPa. What is the new volume?

$$(75)(175) = (150)(V_2)$$

$$88 \text{ mL}$$

9. A sample of hydrogen at 1.5 atm had its pressure decreased to 0.50 atm producing a new volume of 750. mL. What was its original volume?

$$(1.5)(x) = (0.5)(750)$$

$$250 \text{ mL}$$

10. Chlorine gas occupies a volume of 1.20 liters at 720. torr pressure. What volume will it occupy at 1 atm pressure?

$$1 \text{ atm} = 760 \text{ torr}$$

$$(720.)(1.20) = (760.)(V_2)$$

$$1.14 \text{ L}$$

Charles' Law

1. What is Charles' Law?

The volume of a fixed mass of gas is directly proportional to its Kelvin temperature if the pressure is kept constant

2. What is meant by directly proportional?

As one increases, so does the other & vice versa.

3. Draw a graph that shows the direct relationship between volume and temperature.

4. What formula is used for Charles' Law?

$$V_1/T_1 = V_2/T_2$$

5. A sample of nitrogen occupies a volume of 250. mL at 25 °C. What volume will it occupy at 95 °C?

$$250/298 = V_2/368$$

309 mL

6. Oxygen gas is at a temperature of 40. °C when it occupies a volume of 2.30 liters. To what temperature should it be raised to occupy a volume of 6.5 liters?

$$2.3/313 = 6.5/T_2$$

885 K

7. Hydrogen gas was cooled from 150. °C to 50. °C. Its new volume is 75.0 mL. What was the original volume?

$$V_1/423 = 75/323$$

98.2 mL

8. Chlorine gas occupies a volume of 25.0 mL at 300. K. What volume will it occupy at 600. K?

$$25.0/300. = V_2/600.$$

50.0 mL

9. A sample of neon gas at 50. °C and a volume of 2.50 liters is cooled to 25 °C. What is the new volume?

$$2.5/323 = V_2/298$$

2.31 L

10. Helium occupies a volume of 3.8 liters at -45 °C. What volume will it occupy at 45 °C?

$$3.8/228 = V_2/318$$

5.3 L

Gay-Lussac's Law

1. What is Gay-Lussac's Law?

The pressure of a gas is directly proportional to the Kelvin temperature if the volume is kept constant.

2. What is the relationship between pressure and temperature?

Direct relationship.

3. Draw a graph showing the relationship between pressure and temperature.

4. What is the formula for Gay-Lussac's Law?

$$P_1/T_1 = P_2/T_2$$

5. A gas has a pressure of 6.58 kPa at 540. K. What will the pressure be at 210. K if the volume does not change?

$$6.58/540 = P_2/210$$

2.56 kPa

6. The gas in a container has a pressure of 300. kPa at 27 °C. What is the pressure if the temperature is lowered to -173 °C?

$$300/300 = P_2/100$$

100. kPa

7. The pressure in an automobile tire is 200. kPa at a temperature of 25 °C. At the end of a journey on a hot sunny day the pressure has risen to 223 kPa. What is the temperature of the air in the tire?

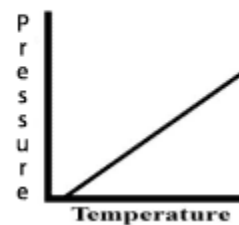
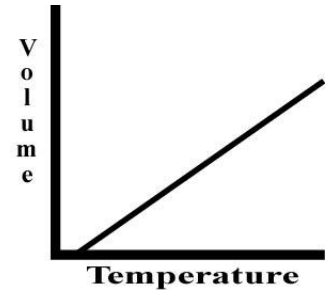
$$200./298 = 223/T_2$$

332 K

8. The gas in a balloon has a pressure of 250. kPa at 18 °C. What will the temperature be if the pressure rises to 294 kPa?

$$250/291 = 294/T_2$$

342 K



9. A gas confined in a rigid container exerts a pressure of 35.5 kPa at a temperature of 19 °C. What will the pressure of the gas be if it is cooled to a temperature of -28 °C?

$$35.5/292 = P_2/245$$

29.8 kPa

Avogadro's Law

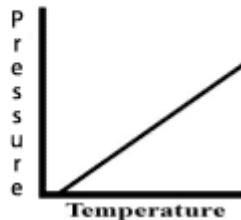
1. What is Avogadro's Law?

For a gas at a constant temperature and pressure, the volume is directly proportional to the number of moles of gas.

2. What is the relationship between moles and volume?

Direct relationship.

3. Draw a graph showing the relationship between moles and volume.



4. What is the formula for Avogadro's Law?

$$V_1/n_1 = V_2/n_2$$

5. If 2.5 moles of a gas have a volume of 6.0 L, what volume would 3.5 moles have at the same temperature and pressure?

$$6.0/2.5 = V_2/3.5$$

8.4 L

6. 5.00 L of a gas is known to contain 0.965 mol. If the amount of gas is increased to 1.80 mol, what new volume will result (at an unchanged temperature and pressure)?

$$5.00/0.965 = V_2/1.80$$

9.33 L

7. A cylinder with a movable piston contains 2.00 g of helium, He, at room temperature. More helium was added to the cylinder and the volume was adjusted so that the gas pressure remained the same. How many grams of helium were added to the cylinder if the volume was changed from 2.00 L to 2.70 L? (The temperature was held constant.)

$$2.00 \text{ grams} \div 4.0 \text{ grams} = 0.50 \text{ moles}$$

$$2.00/0.50 = 2.70/n_2$$

$$n_2 = 0.675 \text{ moles}$$

$$0.675 - 0.50 = 0.175 \text{ moles added}$$

$$0.175 \times 4.0 = 0.70 \text{ grams added}$$

8. 32.0 grams of oxygen has a volume of 24.8 liters. What is the new volume if 36.0 grams of helium is added and the temperature and pressure remain constant?

$$32.0 \div 32.0 = 1.00 \text{ moles O}_2$$

$$36.0 \div 4.0 = 9.0 \text{ mole He}$$

$$24.8/1.0 = V_2/10.0$$

248 L