# The Gas Laws

The gas laws are a set of mathematical laws relating the various properties of gases (pressure, temperature, volume, and amount).

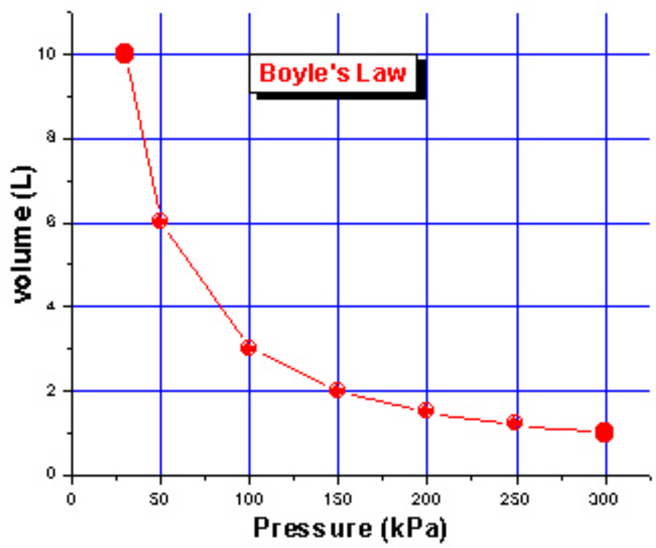
## Boyle's Law

Robert Boyle (1627–1691) studied the relationship between the pressure of a gas in a sealed container and its volume. His data showed that the product of the pressure and volume for the gas is constant. This can be represented by the equation

$$PV = k$$

which is called **Boyle's law**, where $k$ is a constant for a given gas at a specific temperature.

A graph of $V$ vs. $P$ shows an inverse relationship between pressure and volume. In other words, as pressure increases, volume decreases (and vice versa).




Modern experiments have shown that Boyle's law holds precisely only at very low pressures. Measurements at higher pressures show that $PV$ is not constant, but varies with pressure. A gas that strictly obeys Boyle's law is called an **ideal gas**. We will be discussing these in a later lesson.

Because these variations are quite small at pressures close to 1 atm, we will assume that gases obey Boyle's law (unless stated otherwise).

**Example 1**
A sample of helium gas in a balloon has a volume of 4.0 $L$ at a pressure of 210 $kPa$. At what pressure would the volume of the balloon be reduced to 2.5 $L$?

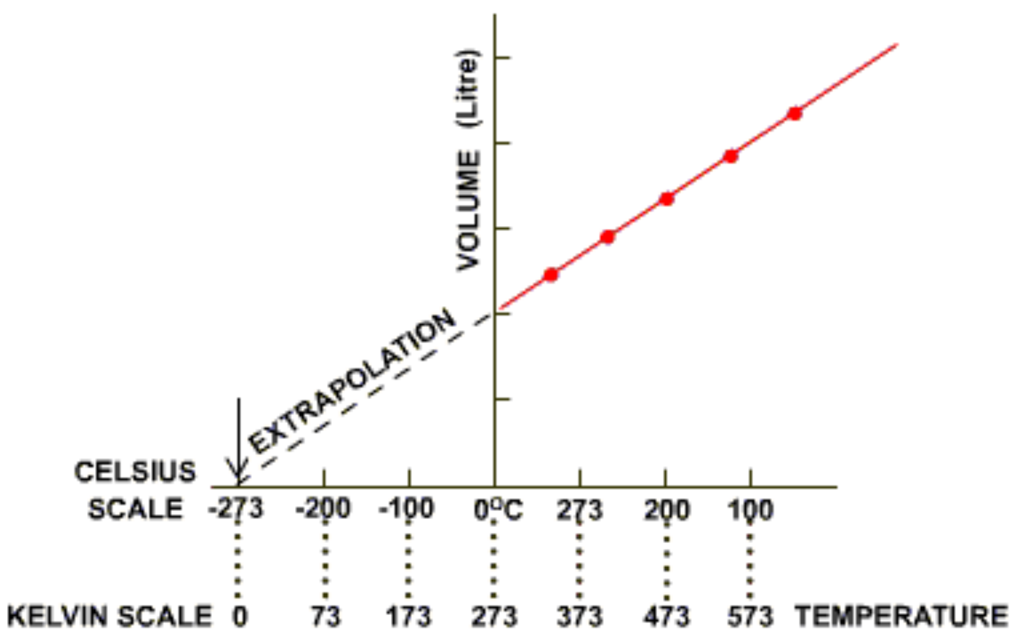
**Charles's Law**

Jacques Charles (1746–1823) studied the relationship between volume and temperature. In his experiments, he observed that as temperature increases, so does the volume of a gas sample when the pressure is held constant. This behavior is represented by the equation known as **Charles's law**

$$V = bT$$

where $T$ is in kelvin and $b$ is a constant.

The graph below shows volume versus temperature for a gas sample kept at constant pressure.



Note that the resulting plot is a straight line. Note also that you can predict the temperature at which the volume will reach a value of zero liters by extrapolating the line at temperatures below those values that were actually measured.

The temperature that corresponds to zero volume is $-273°C$ or $0\ K$. The fact that a gas cannot have a negative volume suggests that $0\ K$ has a special significance. In fact, $0\ K$ is called **absolute zero**, and there is much evidence to suggest that it is impossible to cool anything to $0\ K$ (or lower).

**Example 2**
A gas sample at $40°C$ occupies a volume of $2.32\ L$. If the temperature is raised to $75°C$, what will the volume be, assuming the pressure remains constant?

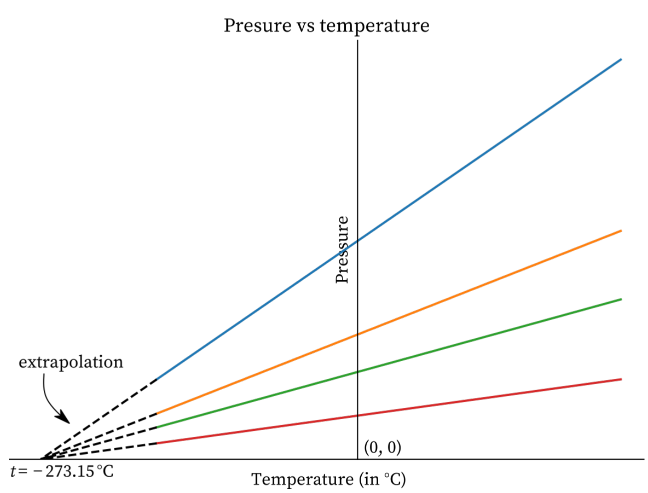
**Gay–Lussac's Law**

Joseph Gay–Lussac (1778–1850) studied the relationship between pressure and temperature. In his experiments, he observed that as temperature increases, so does the pressure of a gas sample when the volume is held constant. This behavior is represented by the equation known as **Gay–Lussac's law**

$$P = cT$$

where $T$ is in kelvin and $c$ is a constant.

The graph below shows pressure versus temperature for several gases kept at constant volume.



Note that for every gas, the relationship is linear. In addition, if we extrapolate the data to determine at what temperature the pressure will be reduced to zero, we get the same result in each case: $-273$°C or 0 *K*.

**Example 3**
The pressure of a gas in a tank is 3.2 *atm* at 22°C. If the temperature rises to 60°C, what will be the gas pressure in the tank?

**Avogadro's Law**

Amadeo Avogadro (1776–1856) studied the relationship between volume and number of moles of gas. In his experiments, he observed that for a gas at constant temperature and pressure, there is a linear relationship between volume and the number of moles of gas. This behavior is represented by the equation known as **Avogardro's law**

$$V = an$$

where *V* is in volume of the gas, *n* is the number of moles of gas, and *a* is a constant.

**Example 4**
Suppose we have a 12.2 *L* sample containing 0.50 mole of oxygen gas $(O_2)$ at a pressure of 1 *atm* and a temperature of 25°C. If all of this $O_2$ were converted to ozone $(O_3)$ at the same temperature and pressure, what would be the volume of the ozone?

## Worksheet

**Boyle's Law**

Assume that the temperature and the amount of gas present are constant in the following problems.

1. The volume of a gas at 99 *kPa* is 300 *mL*. If the pressure is increased to 188 *kPa*, what will be the new volume?

2. The pressure of a sample of helium in a 1 *L* container is 0.988 *atm*. What is the new pressure if the sample is placed in a 2 *L* container?

3. Air trapped in a cylinder fitted with a piston occupies 145.7 *mL* at 1.08 *atm* pressure. What is the new volume of air when the pressure is increased to 1.43 *atm* by applying force to the piston?

4. If it takes 0.05 *L* of oxygen gas kept in a cylinder under pressure to fill an evacuated 4 *L* reaction vessel in which the pressure is 0.98 *atm*, what was the initial pressure of the gas in the cylinder?

5. A sample of neon gas occupies 0.22 *L* at 0.86 *atm*. What will be its volume at 29.2 *kPa* pressure?

6. In a thermonuclear device, the pressure of 0.05 *L* of gas within the bomb casing reaches $4.0 \times 10^6$ *atm*. When the bomb casing is destroyed by the explosion, the gas is released into the atmosphere where it reaches a pressure of 1.0 *atm*. What is the volume of the gas after the explosion?

7. Synthetic diamonds can be manufactured at pressures of $6.0 \times 10^4$ *atm*. If we took 2 *L* of gas at 1.0 *atm* and compressed it to a pressure of $6.0 \times 10^4$ *atm*, what would the volume of that gas be?

8. The highest pressure ever produced in a laboratory setting was about $2.0 \times 10^6$ *atm*. If we have a $1.0 \times 10^{-5}$ *L* sample of a gas at that pressure, then release the pressure until it is equal to 0.275 *atm*, what would the new volume of that gas be?

9. Atmospheric pressure on the peak of Mt. Everest can be as low as 150 *mm Hg*, which is why climbers need to bring oxygen tanks for the last part of the climb. If the climbers carry 10 *L* tanks with an internal gas pressure of $3.04 \times 10^4$ *mm Hg*, what will be the volume of the gas when it is released from the tanks?

10. Divers get "the bends" if they come up too fast because gas in their blood expands, forming bubbles in their blood. If a diver has 0.05 *L* of gas in his blood at a pressure of 250 *atm*, then rises instantaneously to a depth where his blood has a pressure of 50 *atm*, what will the volume of gas in his blood be? Do you think this will harm the diver?

**Charles's Law**
Assume that the pressure and the amount of gas present remain constant in the following problems.

1. A gas at 89°C occupies a volume of 0.67 $L$. At what Celsius temperature will the volume increase to 1.12 $L$?

2. The Celsius temperature of a 3 $L$ sample of gas is lowered from 80°C to 30°C. What will be the resulting volume of this gas?

3. What is the volume of the air in a balloon that occupies 0.62 $L$ at 25°C if the temperature is lowered to 0°C?

4. The temperature inside my refrigerator is about 4°C. If I place a balloon in my fridge that initially has a temperature of 22°C and a volume of 0.5 $L$, what will be the volume of the balloon when it is fully cooled by my refrigerator?

5. A man heats a balloon in the oven. If the balloon initially has a volume of 0.4 $L$ and a temperature of 20°C, what will the volume of the balloon be after he heats it to a temperature of 250°C?

6. On hot days, you may have noticed that potato chip bags seem to "inflate", even though they have not been opened. If I have a 250 $mL$ bag at a temperature of 19°C, and I leave it in my car which has a temperature of 60°C, what will the new volume of the bag be?

7. A soda bottle is flexible enough that the volume of the bottle can change even without opening it. If you have an empty soda bottle (volume of 2 $L$) at room temperature (25°C), what will the new volume be if you put it in your freezer (−4°C)?

8. Some students believe that teachers are full of hot air. If I inhale 2.2 $L$ of gas at a temperature of 18°C and it heats to a temperature of 38°C in my lungs, what is the new volume of the gas?

9. How hot will a 2.3 $L$ balloon have to get to expand to a volume of 400 $L$? Assume that the initial temperature of the balloon is 25°C.

10. I have made a thermometer which measures temperature by the compressing and expanding of gas in a piston. I have measured that at 100°C the volume of the piston is 20 $L$. What is the temperature outside if the piston has a volume of 15 $L$? What would be appropriate clothing for the weather?

**Gay–Lussac's Law**

Assume that the volume and the amount of gas present remain constant in the following problems.

1. A gas in a sealed container has a pressure of 125 *kPa* at a temperature of 30°C. If the pressure in the container is increased to 201 *kPa*, what is the new temperature?

2. The pressure in an automobile tire is 1.88 *atm* at 25°C. What will be the pressure if the temperature warms up to 37°C?

3. Helium gas in a 2 *L* cylinder is under 1.12 *atm* pressure. At 36.5°C that same gas sample has a pressure of 2.56 *atm*. What was the initial temperature of the gas in the cylinder?

4. If a gas sample has a pressure of 30.7 *kPa* at 0°C, by how much does the temperature have to decrease to lower the pressure to 28.4 *kPa*?

5. A rigid plastic container holds 1 *L* methane gas at 0.9 *atm* pressure when the temperature is 22°C. How much more pressure will the gas exert if the temperature is raised to 44.6°C?

6. Determine the pressure change when a constant volume of gas at 1.00 *atm* is heated from 20°C to 30°C.

7. A container of gas is initially at 0.5 *atm* and 25°C. What will the pressure be at 125°C?

8. A gas container is initially at 47 *mm Hg* and 77 *K* (liquid nitrogen temperature). What will the pressure be when the container warms up to room temperature of 25°C?

9. A gas is collected at 22°C and 745 *mm Hg*. When the temperature is changed to 0°C, what is the resulting pressure?

10. A gas has a pressure of 699 *mm Hg* at 40°C. What is the temperature at standard pressure (1 *atm* = 760 *mm Hg*)?

11. If a gas is cooled from 323 *K* to 273.15 *K* and volume is kept constant what final pressure would result if the original pressure was 750.0 *mm Hg*?

12. The temperature of a sample of gas in a steel tank at 30 *kPa* is increased from −100°C to 25°C. What is the final pressure inside the tank?

**Avogadro's Law**
Assume that the pressure and the temperature remain constant in the following problems.

1. If 5.00 $g$ of $O_2$ gas has a volume of 7.20 $L$ at a certain temperature and pressure, what volume does 15.0 $g$ of $O_2$ have under the same conditions?

2. If 4.0 $g$ of helium gas occupies a volume of 22.4 $L$ at 0℃ and a pressure of 1.0 *atm*, what volume does 3.0 $g$ of He occupy under the same conditions?

3. If 3.25 *mol* of argon gas occupies a volume of 100 $L$ at a particular temperature and pressure, what volume does 14.15 *mol* of argon occupy under the same conditions?

4. If 23.2 $g$ of a given gas occupies a volume of 93.2 $L$ at a particular temperature and pressure, what mass of the gas occupies a volume of 10.4 $L$ under the same conditions?