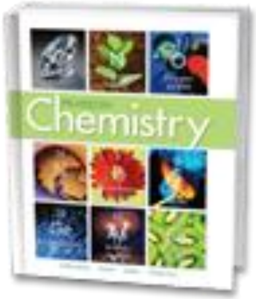


Chapter 14

The Behavior of Gases

14.1 Properties of Gases

14.2 The Gas Laws

14.3 Ideal Gases

14.4 Gases: Mixtures and Movements

How do you fill up a hot air balloon?

A hot air balloon works on the principle that warm air is less dense than cooler air.

Boyle's Law

How are the pressure and volume of a gas related?

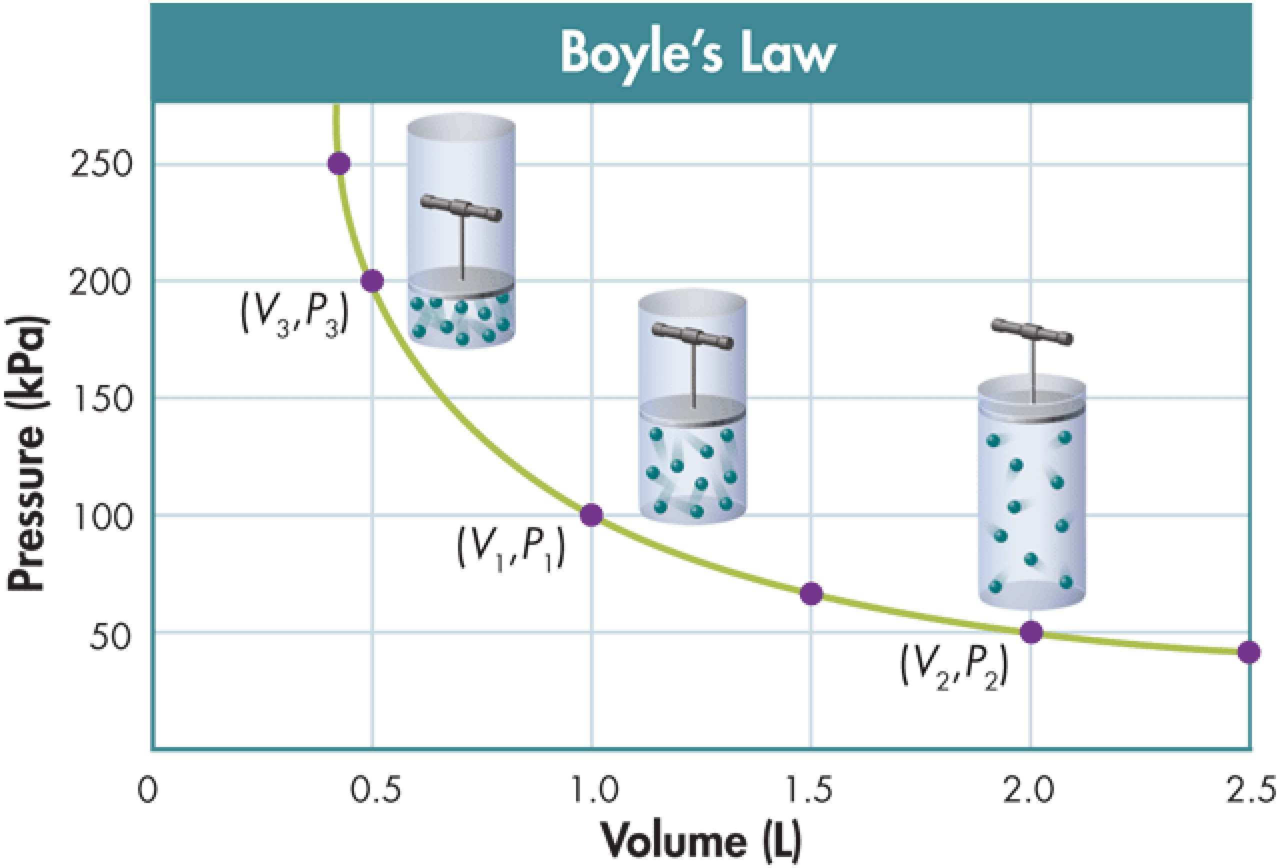
If the temperature is constant, as the pressure of a gas increases, the volume decreases.

- As the pressure decreases, the volume increases.

- Robert Boyle was the first person to study this pressure-volume relationship in a systematic way.
- **Boyle's law** states that for a given mass of gas at constant temperature, the volume of the gas varies inversely with pressure.

$$P_1 \times V_1 = P_2 \times V_2$$

As the volume decreases from 1.0 L to 0.5 L, the pressure increases from 100 kPa to 200 kPa.



Using Boyle's Law

A balloon contains 30.0 L of helium gas at 103 kPa. What is the volume of the helium when the balloon rises to an altitude where the pressure is only 25.0 kPa? (Assume that the temperature remains constant.)

1 Analyze **List the knowns and the unknown.**

Use Boyle's law ($P_1 \times V_1 = P_2 \times V_2$) to calculate the unknown volume (V_2).

KNOWNS	UNKNOWN
P_1 = 103 kPa	V_2 = ? L
V_1 = 30.0 L	
P_2 = 25.0 kPa	

2 Calculate Solve for the unknown.

Start with Boyle's law.

$$P_1 \times V_1 = P_2 \times V_2$$

2 Calculate **Solve for the unknown.**

Rearrange the equation to isolate V_2.

$$P_1 \times V_1 = P_2 \times V_2$$

Isolate V_2 by dividing both sides by P_2:

$$\frac{P_1 \times V_1}{P_2} = \frac{\cancel{P_2} \times V_2}{\cancel{P_2}}$$

$$V_2 = \frac{V_1 \times P_1}{P_2}$$

2 Calculate Solve for the unknown.

Substitute the known values for P_1, V_1, *and* P_2 *into the equation and solve.*

$$V_2 = \frac{30.0\ \text{L} \times 103\ \text{kPa}}{25.0\ \text{kPa}}$$

$$V_2 = 1.24 \times 10^2\ \text{L}$$

3 Evaluate Does the result make sense?

- A decrease in pressure at constant temperature must correspond to a proportional increase in volume.
- The calculated result agrees with both kinetic theory and the pressure-volume relationship.
- The units have canceled correctly.

A sample of neon gas occupies a volume of 677 mL at 134 kPa. What is the pressure of the sample if the volume is decreased to 642 mL?

A sample of neon gas occupies a volume of 677 mL at 134 kPa. What is the pressure of the sample if the volume is decreased to 642 mL?

$$P_1 \times V_1 = P_2 \times V_2$$

$$P_2 = \frac{V_1 \times P_1}{V_2}$$

$$P_2 = \frac{677\ \cancel{mL} \times 134\ kPa}{642\ \cancel{mL}}$$

$$P_2 = 141\ \text{kPa}$$

PEARSON

Charles's Law

How are the temperature and volume of a gas related?

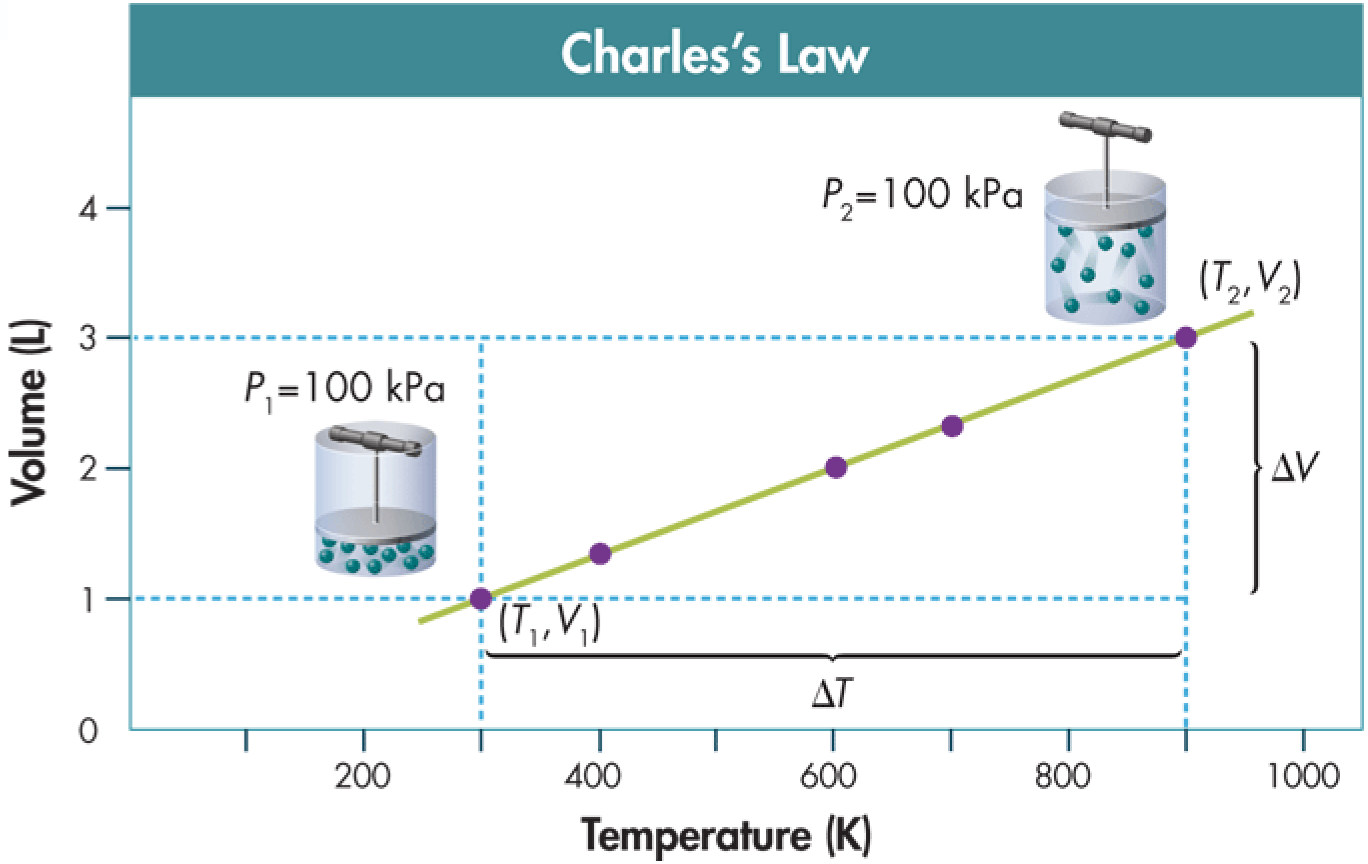
When an inflated balloon is dipped into a beaker of liquid nitrogen, the air inside rapidly cools, and the balloon shrinks.

As the temperature of an enclosed gas increases, the volume increases, if the pressure is constant.

Charles's law states that the volume of a fixed mass of gas is directly proportional to its Kelvin temperature if the pressure is kept constant.

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

The graph shows how the volume changes as the temperature of the gas changes.



A hot air balloon contains a propane burner onboard to heat the air inside the balloon. What happens to the volume of the balloon as the air is heated?

A hot air balloon contains a propane burner onboard to heat the air inside the balloon. What happens to the volume of the balloon as the air is heated?

According to Charles's law, as the temperature of the air increases, the volume of the balloon also increases.

Using Charles's Law

A balloon inflated in a room at $24^{o}C$ has a volume of 4.00 L. The balloon is then heated to a temperature of $58^{o}C$. What is the new volume if the pressure remains constant?

1 Analyze **List the knowns and the unknown.**

Use Charles's law ($V_1/T_1 = V_2/T_2$) to calculate the unknown volume (V_2).

KNOWNS	UNKNOWN
V_1 = 4.00 L	V_2 = ? L
T_1 = 24°C	
T_2 = 58°C	

2 Calculate Solve for the unknown.

Because you will use a gas law, start by expressing the temperatures in kelvins.

$$T_1 = 24^{o}C + 273 = 297\ K$$

$$T_2 = 58^{o}C + 273 = 331\ K$$

2 Calculate Solve for the unknown.

Write the equation for Charles's law.

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

2 Calculate Solve for the unknown.

Rearrange the equation to isolate V_2.

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

Isolate V_2 by multiplying both sides by T_2:

$$T_2 \times \frac{V_1}{T_1} = \frac{V_2}{\cancel{T_2}} \times \cancel{T_2}$$

$$V_2 = \frac{V_1 \times T_2}{T_1}$$

2 Calculate **Solve for the unknown.**

Substitute the known values for T_1, V_1, *and* T_2 *into the equation and solve.*

$$V_2 = \frac{4.00\ \text{L} \times 331\ \cancel{\text{K}}}{297\ \cancel{\text{K}}}$$

$$V_2 = 4.46\ \text{L}$$

3 Evaluate Does the result make sense?

- The volume increases as the temperature increases.
- This result agrees with both the kinetic theory and Charles's law.

What is the temperature of a 2.3 L balloon if it shrinks to a volume of 0.632 L when it is dipped into liquid nitrogen at a temperature of 77 K?

What is the temperature of a 2.3 L balloon if it shrinks to a volume of 0.632 L when it is dipped into liquid nitrogen at a temperature of 77 K?

$$T_1 = \frac{V_1 \times T_2}{V_2}$$

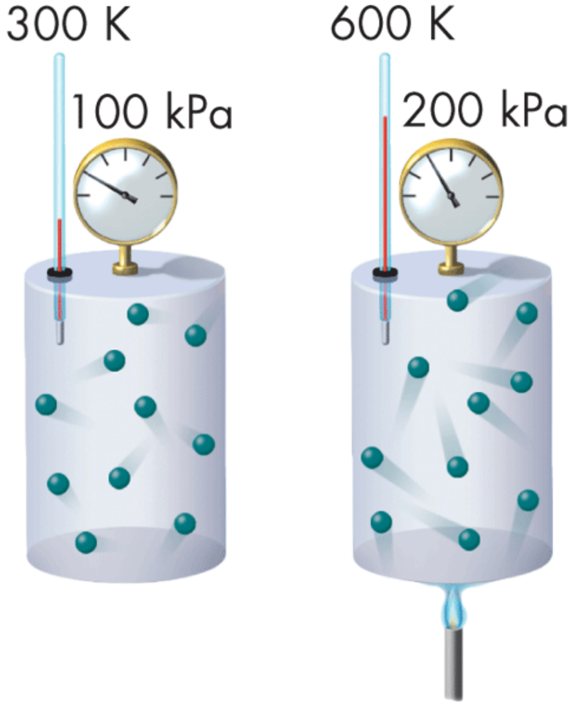
$$T_1 = \frac{2.3\ \text{L} \times 77\ \text{K}}{0.642\ \text{L}}$$

$$T_1 = 276\ \text{K}$$

Gay-Lussac's Law

How are the pressure and temperature of a gas related?

As the temperature of an enclosed gas increases, the pressure increases, if the volume is constant.



<u>Gay-Lussac's law</u> states that the pressure of a gas is directly proportional to the Kelvin temperature if the volume remains constant.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Gay-Lussac's law can be applied to reduce the time it takes to cook food.

- In a pressure cooker, food cooks faster than in an ordinary pot because trapped steam becomes hotter than it would under normal atmospheric pressure.
- But the pressure rises, which increases the risk of an explosion.
- A pressure cooker has a valve that allows some vapor to escape when the pressure exceeds the set value.

Using Gay-Lussac's Law

Aerosol cans carry labels warning not to incinerate (burn) the cans or store them above a certain temperature. This problem will show why it is dangerous to dispose of aerosol cans in a fire. The gas in a used aerosol can is at a pressure of 103 kPa at 25^{o}C. If the can is thrown onto a fire, what will the pressure be when the temperature reaches 928^{o}C?

1 Analyze **List the knowns and the unknown.**

Use Gay Lussac's law ($P_1/T_1 = P_2/T_2$) to calculate the unknown pressure (P_2).

KNOWNS	UNKNOWN
P_1 = 103 kPa	P_2 = ? kPa
T_1 = 25°C	
T_2 = 928°C	

2 Calculate **Solve for the unknown.**

Remember, because this problem involves temperatures and a gas law, the temperatures must be expressed in kelvins.

$$T_1 = 25^{o}C + 273 = 298\ K$$

$$T_2 = 928^{o}C + 273 = 1201\ K$$

2 Calculate Solve for the unknown.

Write the equation for Gay Lussac's law.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

2 Calculate **Solve for the unknown.**

Rearrange the equation to isolate P_2.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Isolate P_2 by multiplying both sides by T_2:

$$T_2 \times \frac{P_1}{T_1} = \frac{P_2}{\cancel{T_2}} \times \cancel{T_2}$$

$$P_2 = \frac{P_1 \times T_2}{T_1}$$

2 Calculate **Solve for the unknown.**

Substitute the known values for P_1, T_2, and T_1 into the equation and solve.

$$P_2 = \frac{103 \text{ kPa} \times 1201 \cancel{\text{K}}}{298 \cancel{\text{K}}}$$

$$P_2 = 415 \text{ kPa}$$

$$P_2 = 4.15 \times 10^2 \text{ kPa}$$

3 Evaluate Does the result make sense?

- From the kinetic theory, one would expect the increase in temperature of a gas to produce an increase in pressure if the volume remains constant.
- The calculated value does show such an increase.

A pressure cooker containing kale and some water starts at 298 K and 101 kPa. The cooker is heated, and the pressure increases to 136 kPa. What is the final temperature inside the cooker?

A pressure cooker containing kale and some water starts at 298 K and 101 kPa. The cooker is heated, and the pressure increases to 136 kPa. What is the final temperature inside the cooker?

$$T_2 = \frac{P_2 \times T_1}{P_1}$$

$$T_2 = \frac{136\ \text{kPa} \times 298\ \text{K}}{101\ \text{kPa}}$$

$$T_2 = 400\ \text{K}$$

The Combined Gas Law

How are the pressure, volume, and temperature of a gas related?

There is a single expression, called the **combined gas law,** that combines Boyle's law, Charles's law, and Gay-Lussac's law.

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

When only the amount of gas is constant, the combined gas law describes the relationship among pressure, volume, and temperature.

You can derive the other laws from the combined gas law by holding one variable constant.

- Suppose you hold the temperature constant ($T_1 = T_2$).
- Rearrange the combined gas law so that the two temperature terms on the same side of the equation.

$$P_1 \times V_1 = \frac{P_2 \times V_2 \times T_1}{T_2}$$

You can derive the other laws from the combined gas law by holding one variable constant.

- Because ($T_1 = T_2$), the ratio of T_1 to T_2 is equal to one.
- Multiplying by 1 does not change a value in an equation.

$$P_1 \times V_1 = \frac{P_2 \times V_2 \times \cancel{T_1}}{\cancel{T_2}}$$

You can derive the other laws from the combined gas law by holding one variable constant.

- So when temperature is constant, you can delete the temperature ratio from the rearranged combined gas law.
- What you are left with is the equation for Boyle’s law.

$$P_1 \times V_1 = P_2 \times V_2$$

You can derive the other laws from the combined gas law by holding one variable constant.

- A similar process yields Charles's law when pressure remains constant.
- Another similar process yields Gay-Lussac's law when volume remains constant.

Using the Combined Gas Law

The volume of a gas-filled balloon is 30.0 L at 313 K and 153 kPa pressure. What would the volume be at standard temperature and pressure (STP)?

1 Analyze **List the knowns and the unknown.**

Use the combined gas law ($P_1V_1/T_1 = P_2V_2/T_2$) to calculate the unknown volume (V_2).

KNOWNS	UNKNOWN
V_1 = 30.0 L	V_2 = ? L
T_1 = 313 K	
P_1 = 153 kPa	
T_2 = 273 K (standard temperature)	
P_2 = 101.3 kPa (standard pressure)	

2 Calculate Solve for the unknown.

State the combined gas law.

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

2 Calculate Solve for the unknown.

Rearrange the equation to isolate V_2.

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

Isolate P_2 by multiplying both sides by T_2:

$$\frac{T_2}{P_2} \times \frac{P_1 \times V_1}{T_1} = \frac{\cancel{P_2} \times V_2}{\cancel{T_2}} \times \frac{\cancel{T_2}}{\cancel{P_2}}$$

$$V_2 = \frac{V_1 \times P_1 \times T_2}{P_2 \times T_1}$$

2 Calculate Solve for the unknown.

Substitute the known quantities into the equation and solve.

$$V_2 = \frac{30.0\ \text{L} \times 153\ \text{kPa} \times 273\ \text{K}}{101.3\ \text{kPa} \times 313\ \text{K}}$$

$$V_2 = 39.5\ \text{L}$$

3 Evaluate Does the result make sense?

- A decrease in temperature and a decrease in pressure have opposite effects on the volume.
- To evaluate the increase in volume, multiply V_1 (30.0 L) by the ratio of P_1 to P_2 (1.51) and the ratio of T_1 to T_2 (0.872).
- The result is 39.5 L.

Which of the following equations could be used to correctly calculate the final temperature of a gas?

A. $T_2 = \dfrac{V_1 \times P_1 \times V_2}{P_2 \times T_1}$

B. $T_2 = \dfrac{V_2 \times P_2 \times T_1}{V_1 \times P_1}$

C. $T_2 = \dfrac{V_2 \times P_1 \times T_1}{V_1 \times P_2}$

D. $T_2 = \dfrac{V_1 \times P_1 \times T_1}{V_2 \times P_2}$

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A. $T_2 = \dfrac{V_1 \times P_1 \times V_2}{P_2 \times T_1}$

B. $T_2 = \dfrac{V_2 \times P_2 \times T_1}{V_1 \times P_1}$

C. $T_2 = \dfrac{V_2 \times P_1 \times T_1}{V_1 \times P_2}$

D. $T_2 = \dfrac{V_1 \times P_1 \times T_1}{V_2 \times P_2}$

- If the temperature is constant, as the pressure of a gas increases, the volume decreases.
- As the temperature of an enclosed gas increases, the volume increases, if the pressure is constant.
- As the temperature of an enclosed gas increases, the pressure increases, if the volume is constant.
- When only the amount of gas is constant, the combined gas law describes the relationship among pressure, volume, and temperature.

- Boyle's law: $P_1 \times V_1 = P_2 \times V_2$

- Charles's law: $\dfrac{V_1}{T_1} = \dfrac{V_2}{T_2}$

- Gay-Lussac's law: $\dfrac{P_1}{T_1} = \dfrac{P_2}{T_2}$

- combined gas law: $\dfrac{P_1 \times V_1}{T_1} = \dfrac{P_2 \times V_2}{T_2}$

- **<u>Boyle's law</u>:** for a given mass of gas at constant temperature, the volume of the gas varies inversely with pressure
- **<u>Charles's law</u>:** the volume of a fixed mass of gas is directly proportional to its Kelvin temperature if the pressure is kept constant
- **<u>Gay-Lussac's law</u>:** the pressure of a gas is directly proportional to the Kelvin temperature if the volume is constant
- **<u>combined gas law</u>:** the law that describes the relationship among the pressure, temperature, and volume of an enclosed gas

END OF 14.2