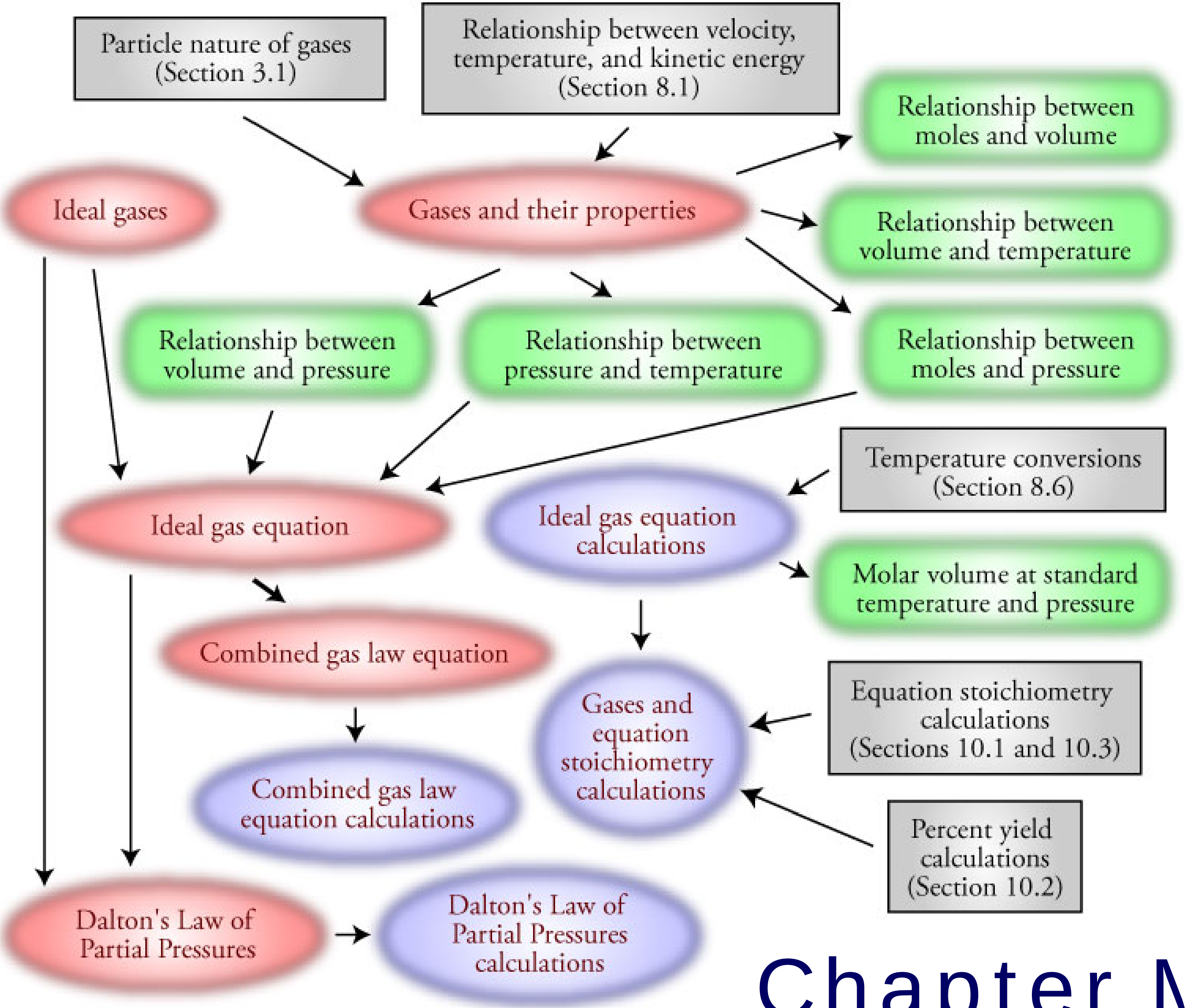
Chapter 13

Gases

Chapter Map



Particle nature of gases (Section 3.1)

Relationship between velocity, temperature, and kinetic energy (Section 8.1)

Ideal gases

Gases and their properties

Relationship between moles and volume

Relationship between volume and temperature

Relationship between volume and pressure

Relationship between pressure and temperature

Relationship between moles and pressure

Ideal gas equation

Ideal gas equation calculations

Temperature conversions (Section 8.6)

Molar volume at standard temperature and pressure

Combined gas law equation

Gases and equation stoichiometry calculations

Equation stoichiometry calculations (Sections 10.1 and 10.3)

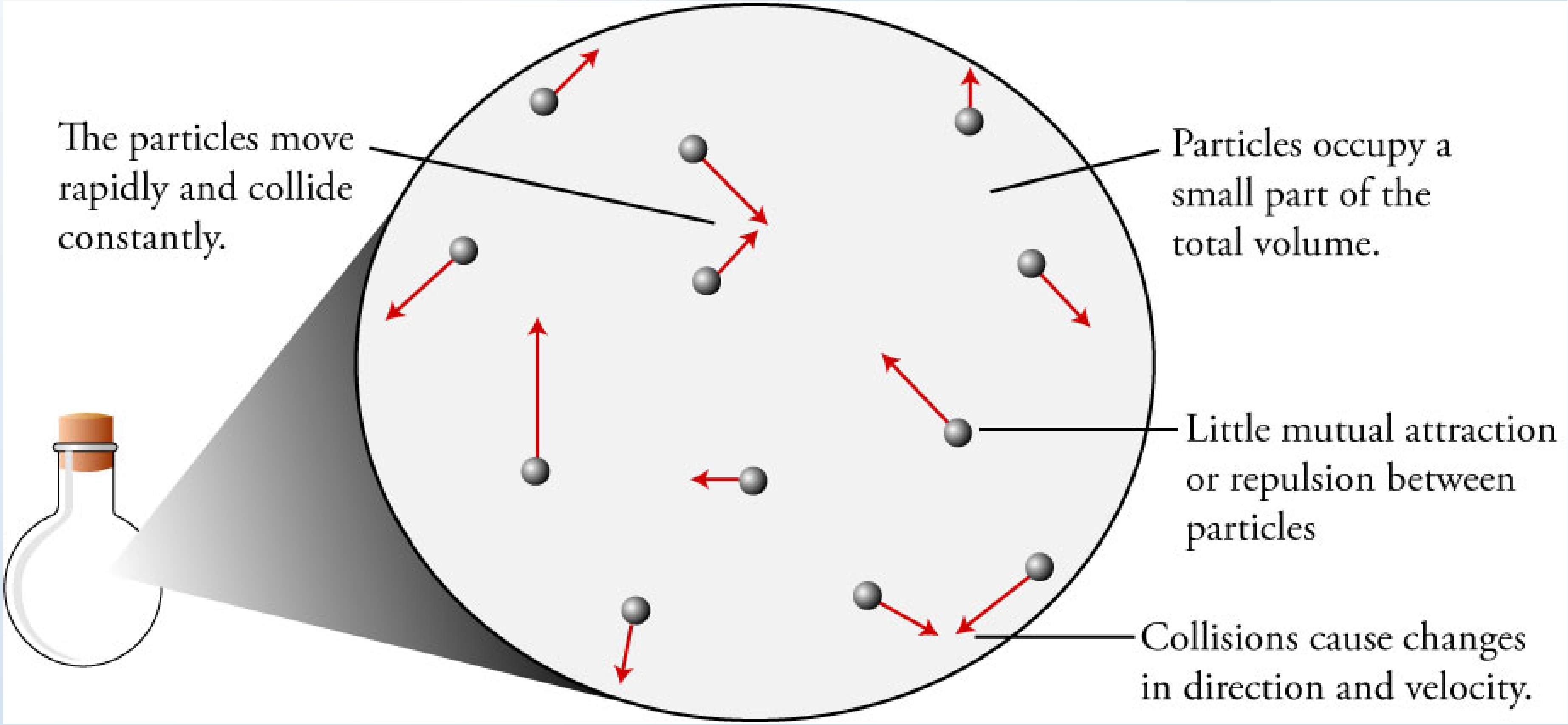
Combined gas law equation calculations

Percent yield calculations (Section 10.2)

Dalton's Law of Partial Pressures

Dalton's Law of Partial Pressures calculations

Gas

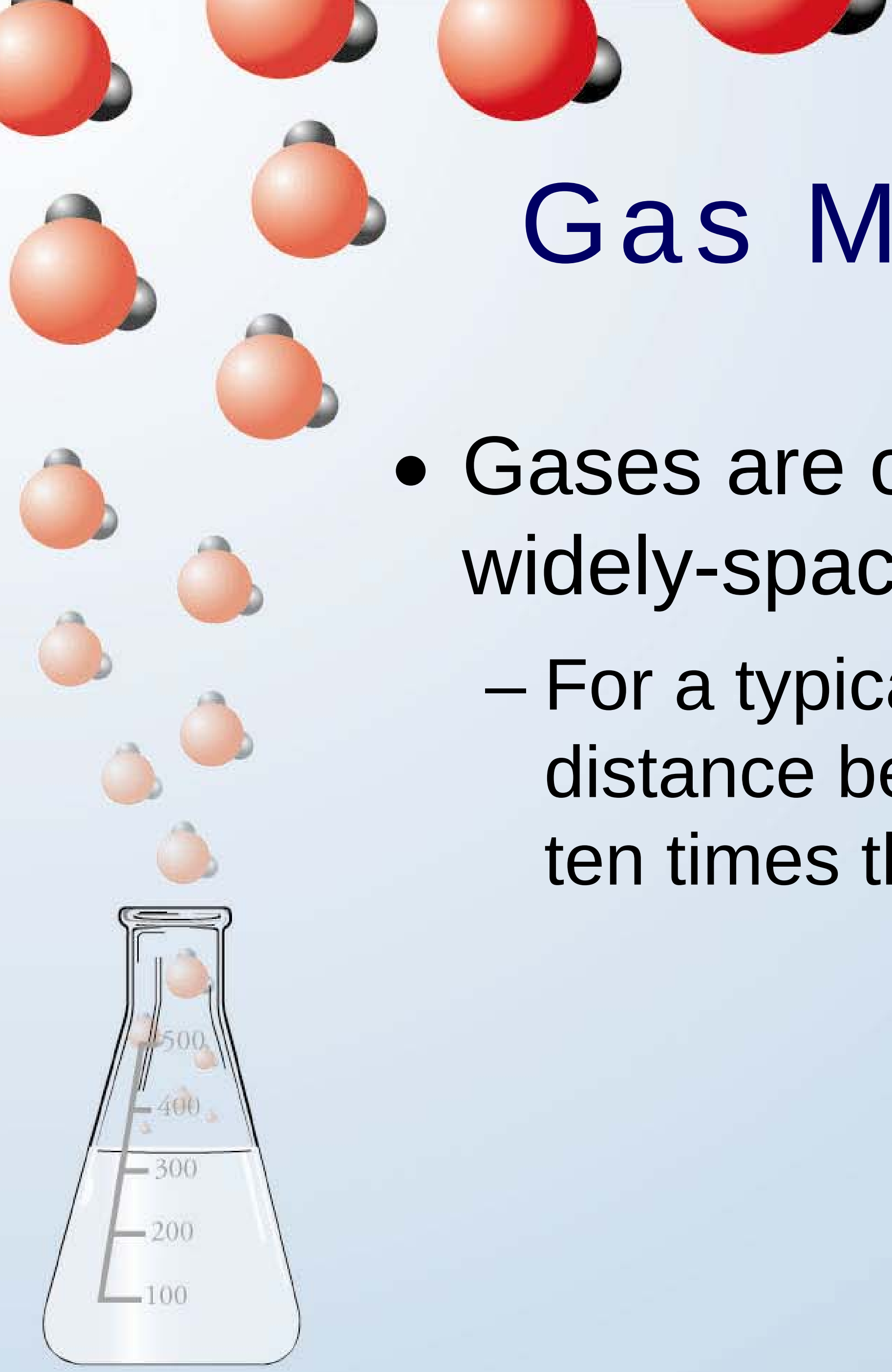


The particles move rapidly and collide constantly.

Particles occupy a small part of the total volume.

Little mutual attraction or repulsion between particles

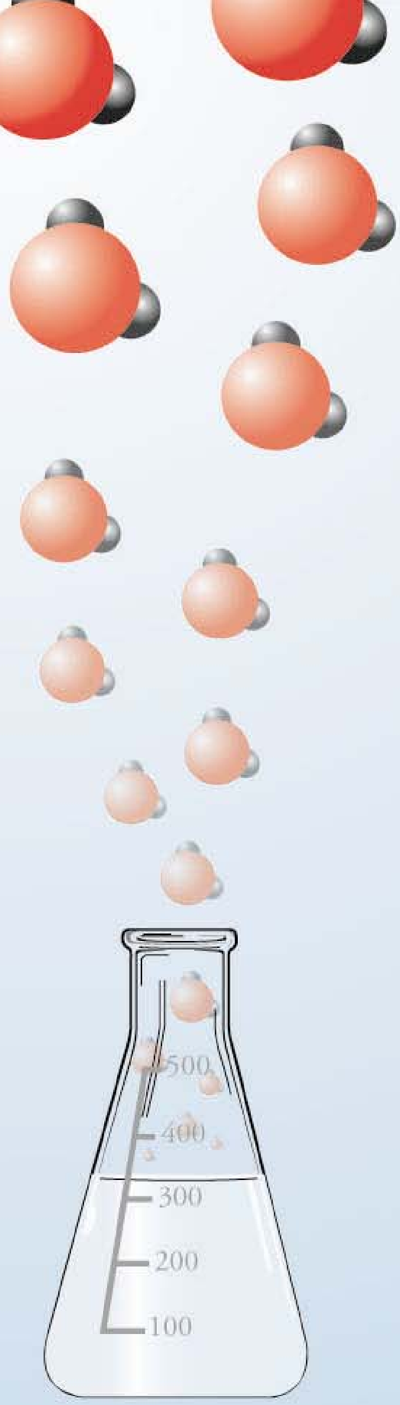
Collisions cause changes in direction and velocity.



Gas Model

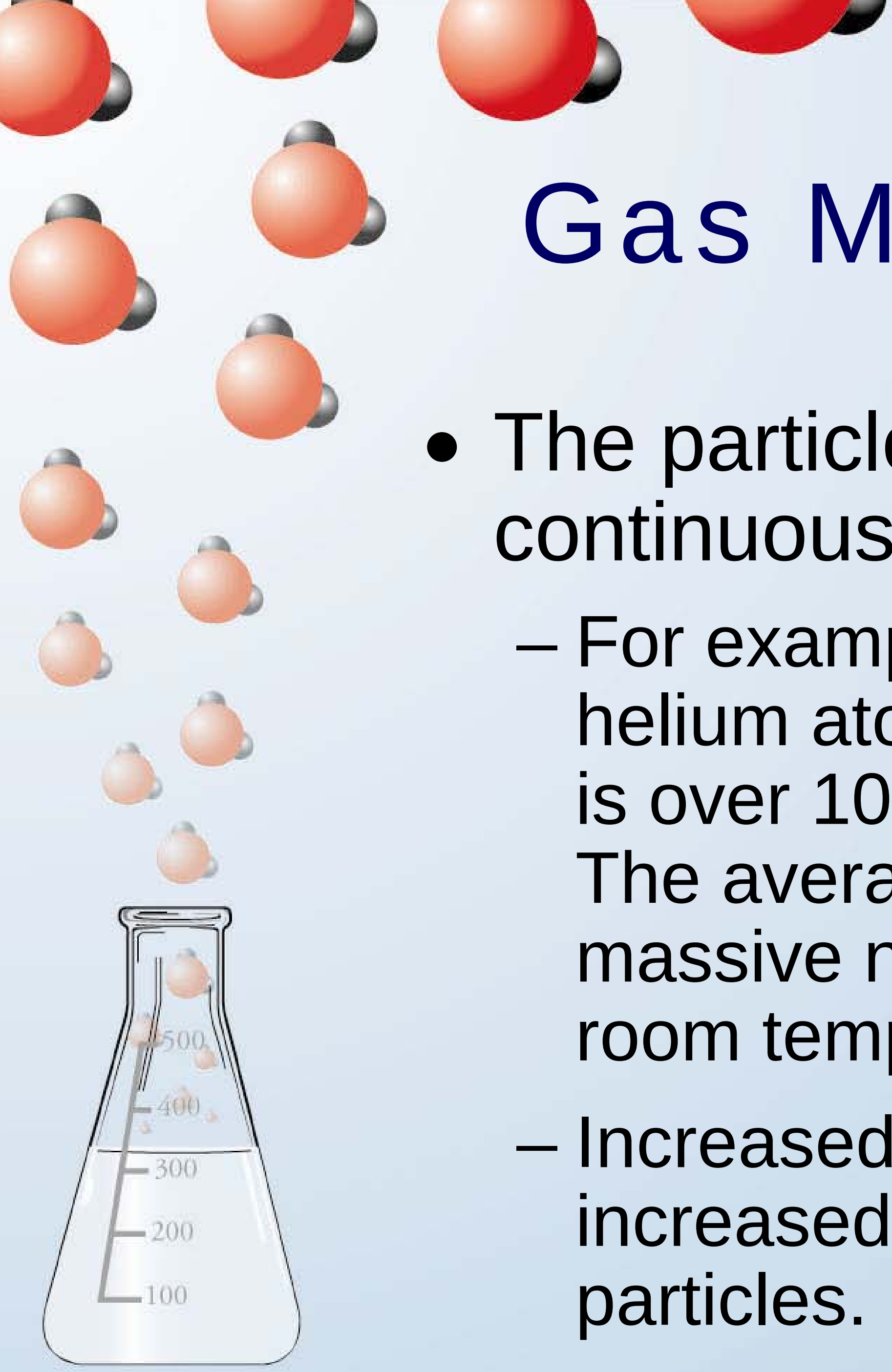
- Gases are composed of tiny, widely-spaced particles.
  - For a typical gas, the average distance between particles is about ten times their diameter.

Gas Model (cont.)



- Because of the large distance between the particles, the volume occupied by the particles themselves is negligible (approximately zero).
  - For a typical gas at room temperature and pressure, the gas particles themselves occupy about 0.1% of the total volume. The other 99.9% of the total volume is empty space. This is very different than for a liquid for which about 70% of the volume is occupied by particles.

Gas Model (cont.)

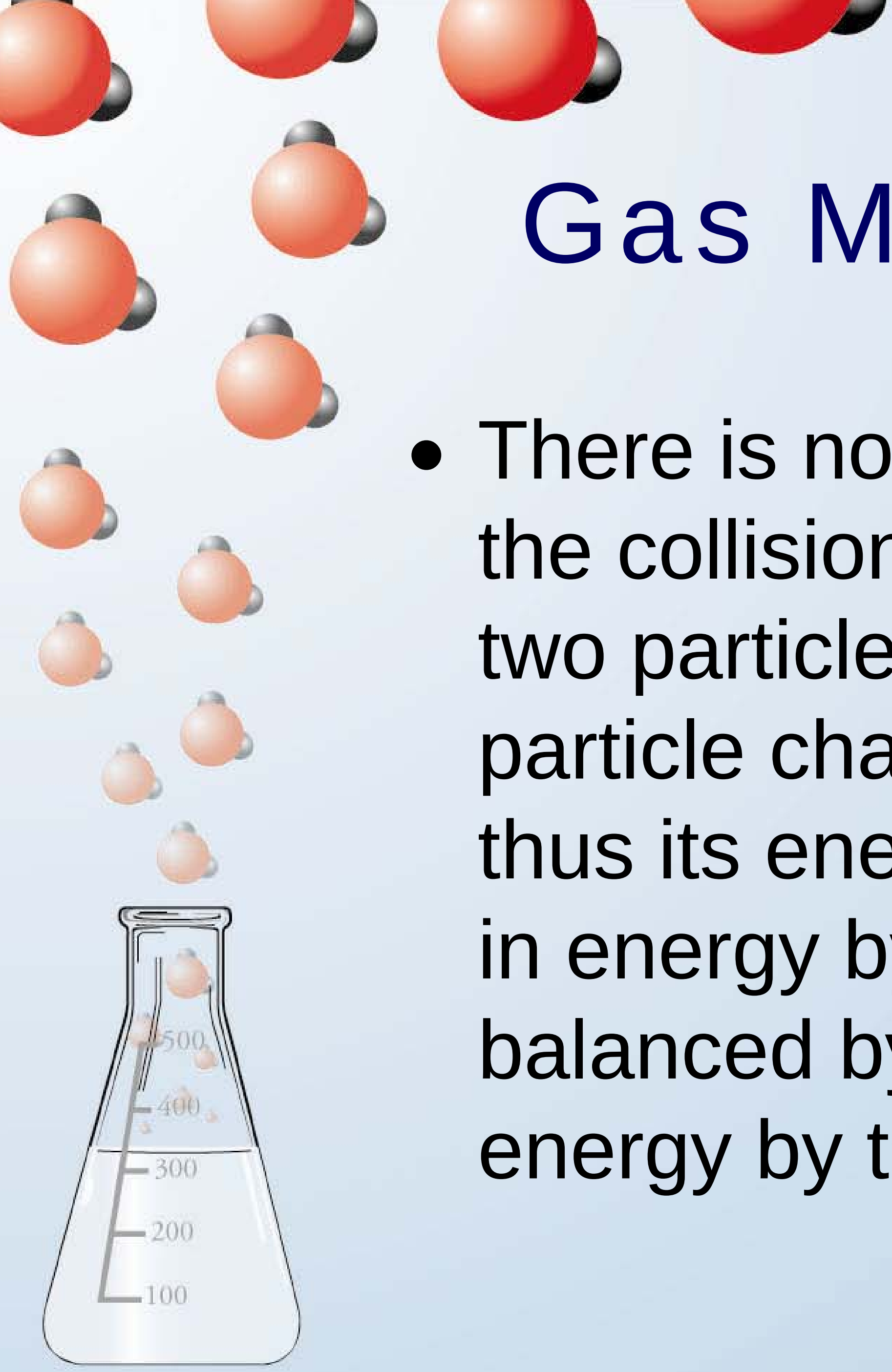


- The particles have rapid and continuous motion.
  - For example, the average velocity of a helium atom, He, at room temperature is over 1000 m/s (or over 2000 mi/hr). The average velocity of the more massive nitrogen molecules, N_2, at room temperature is about 500 m/s.
  - Increased temperature means increased average velocity of the particles.

Gas Model (cont.)

- The particles are constantly colliding with the walls of the container and with each other.
  - Because of these collisions, the gas particles are constantly changing their direction of motion and their velocity. In a typical situation, a gas particle moves a very short distance between collisions. Oxygen, O_2, molecules at normal temperatures and pressures move an average of 10^{-7} m between collisions.

Gas Model (cont.)

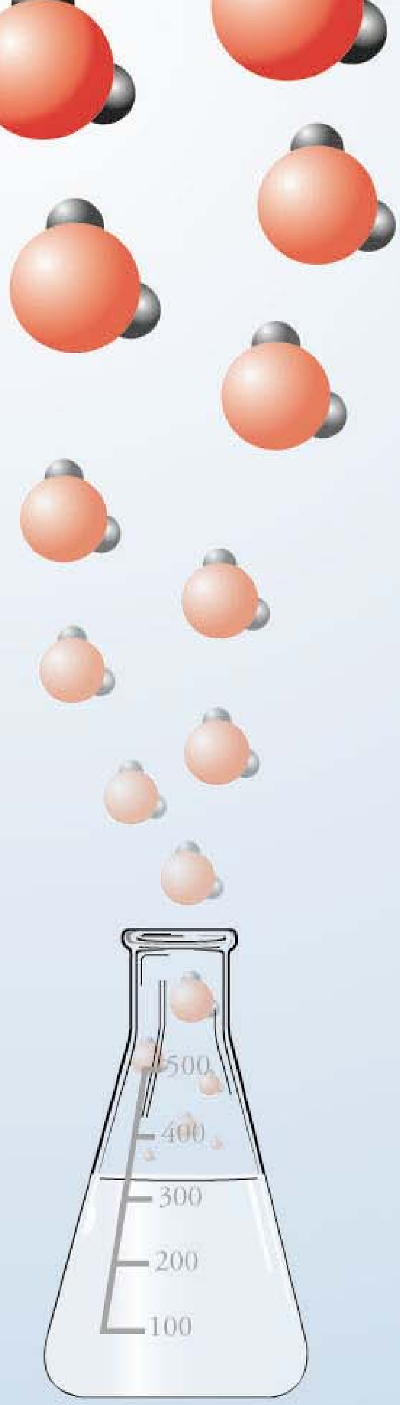


- There is no net loss of energy in the collisions. A collision between two particles may lead to each particle changing its velocity and thus its energy, but the increase in energy by one particle is balanced by an equal decrease in energy by the other particle.

Ideal Gas

- The particles are assumed to be point-masses, that is, particles that have a mass but occupy no volume.
- There are no attractive or repulsive forces at all between the particles.

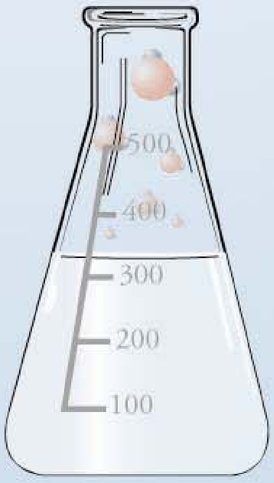
Gas Properties and their Units



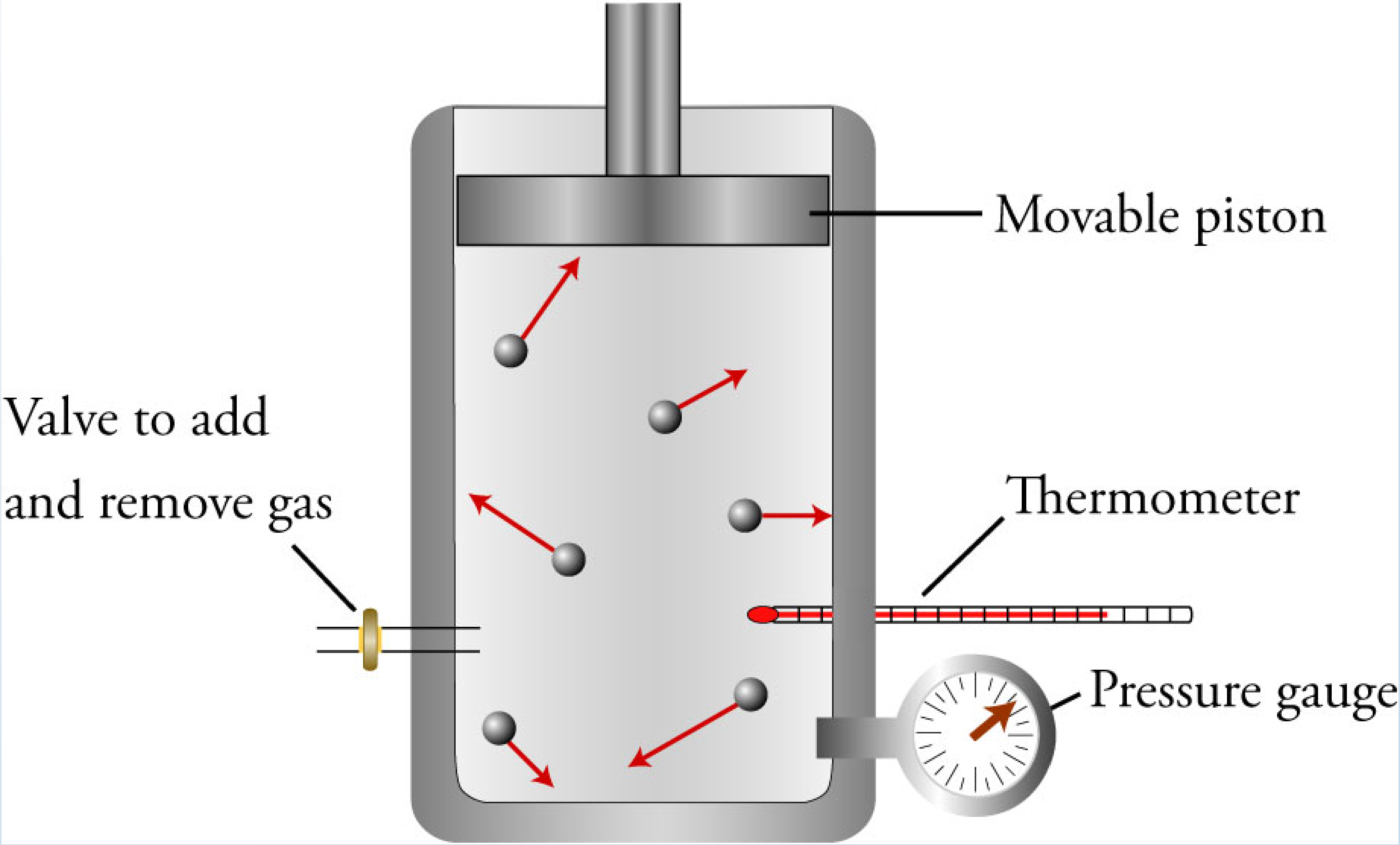
- Pressure (P) = Force/Area
  - units
    - 1 atm = 101.325 kPa = 760 mmHg = 760 torr
    - 1 bar = 100 kPa = 0.9869 atm = 750.1 mmHg
- Volume (V)
  - unit usually liters (L)
- Temperature (T)
  - ? K = --- °C + 273.15
- Number of gas particles expressed in moles (n)

Gas Law Objectives

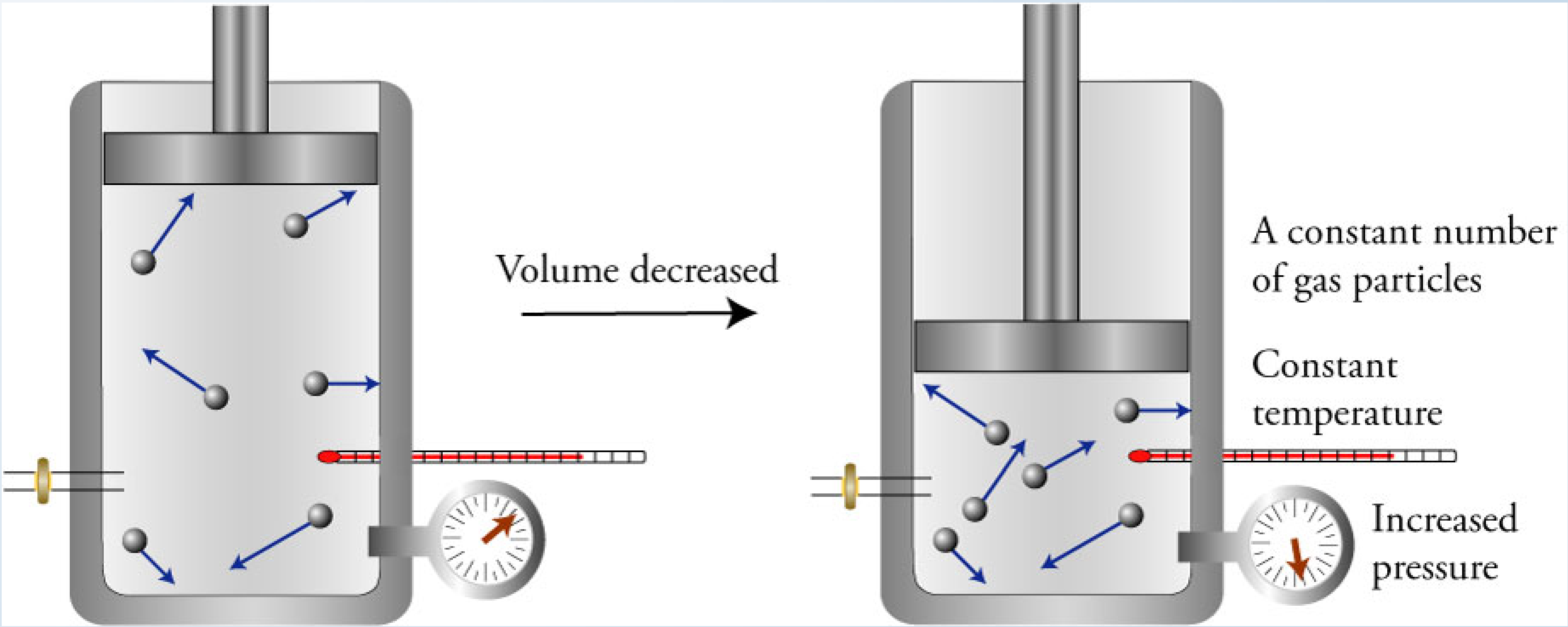
- For each of the following pairs of gas properties, (1) describe the relationship between them, (2) describe a simple system that could be used to demonstrate the relationship, and (3) explain the reason for the relationship.
    - V and P when n and T are constant
    - P and T when n and V are constant
    - V and T when n and P are constant
    - n and P when V and T are constant
    - n and V when P and T are constant



Apparatus for Demonstrating Relationships Between Properties of Gases



Decreased Volume Leads to Increased Pressure



P α 1/V   if n and T are constant

Relationship between P and V

Decreased volume

↓

Increased $\dfrac{\text{number of gas particles}}{\text{volume of container}}$

↓

Increased number of particles close to any area of wall

↓

Increased $\dfrac{\text{number of collisions per second}}{\text{area of wall}}$

↓

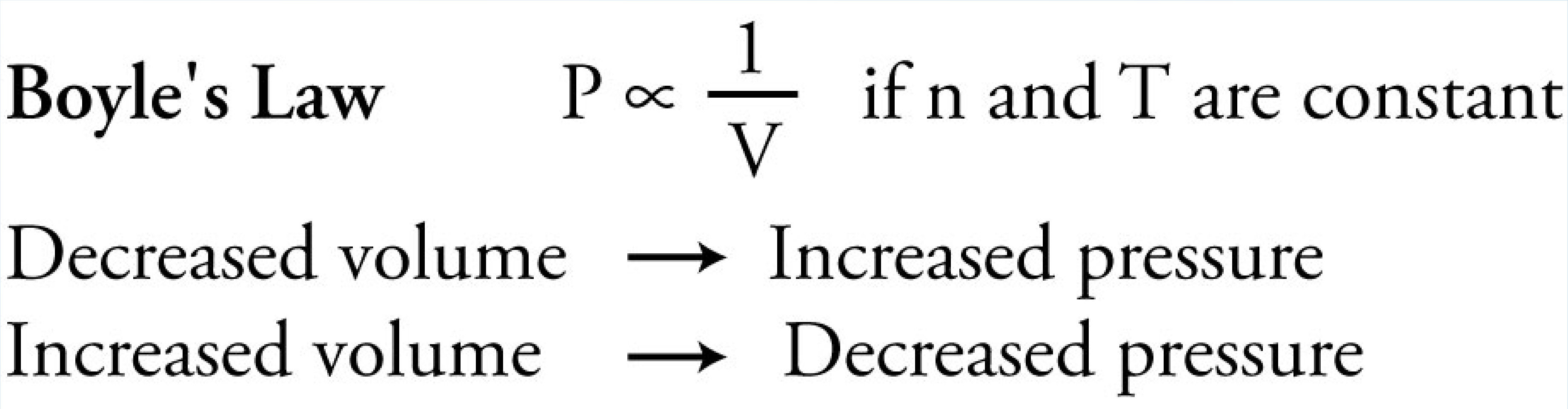
Increased $\dfrac{\text{force due to collisions}}{\text{area of wall}}$

↓

Increased gas pressure

Boyle's Law

- The pressure of an ideal gas is inversely proportional to the volume it occupies if the moles of gas and the temperature are constant.

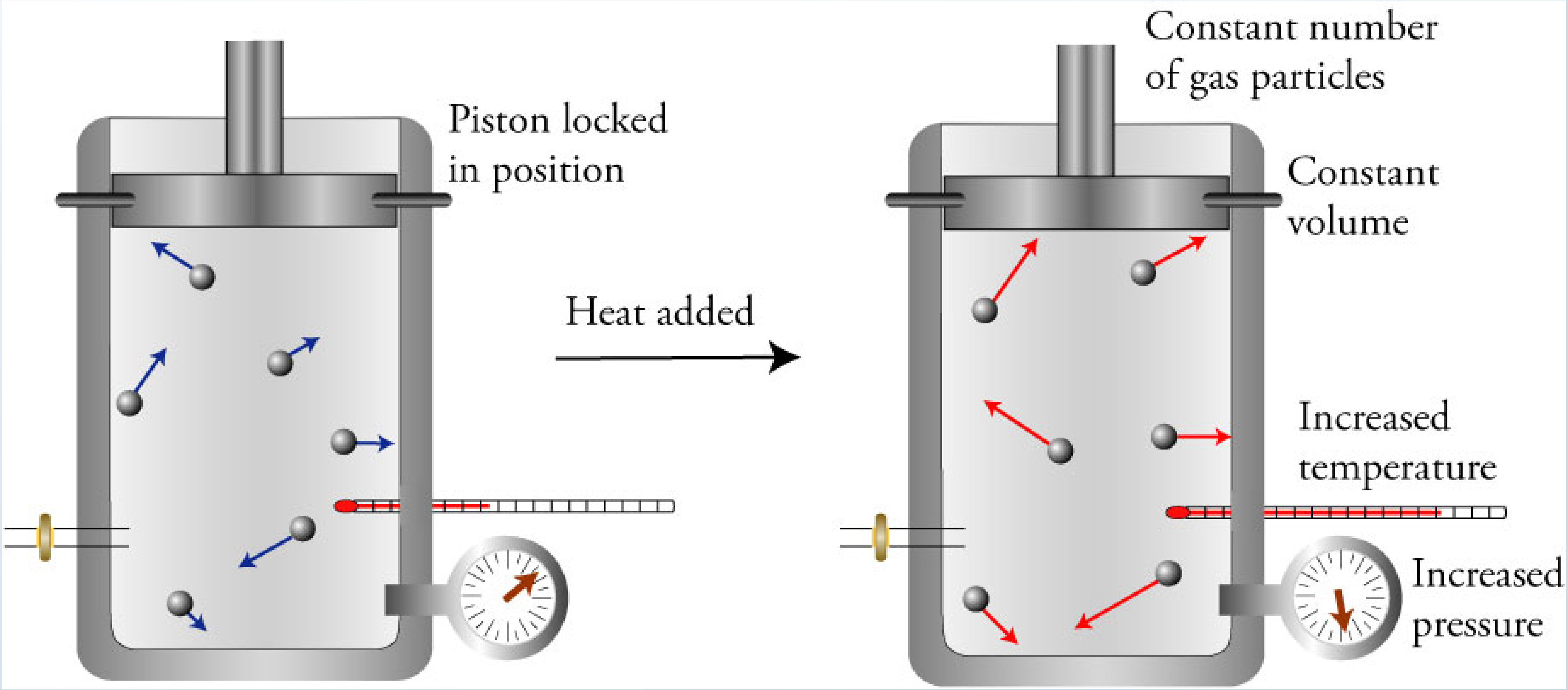


Boyle's Law $P \propto \frac{1}{V}$ if n and T are constant

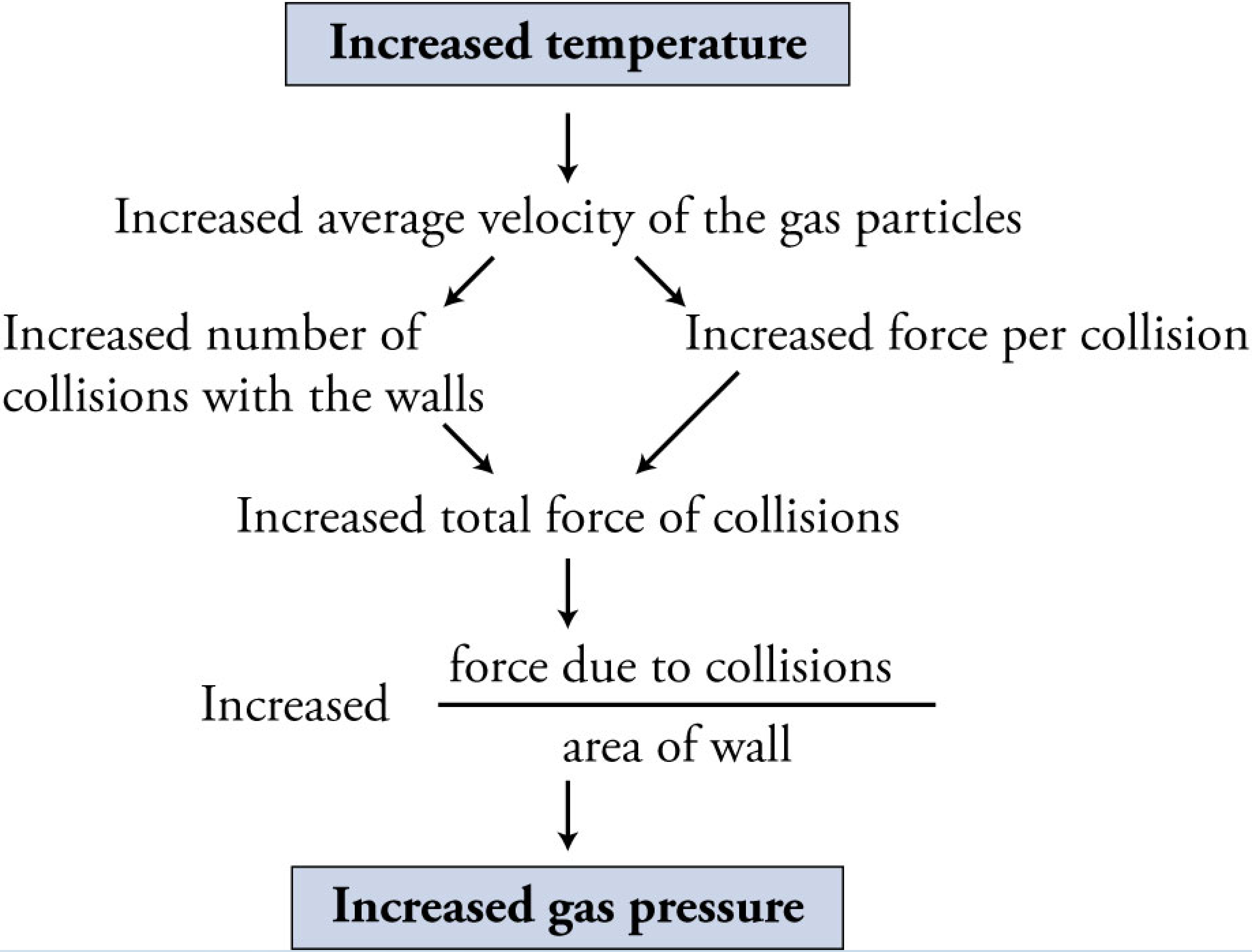
Decreased volume → Increased pressure

Increased volume → Decreased pressure

Increased Temperature Leads to Increased Pressure



P α T if n and V are constant



Increased temperature

Increased average velocity of the gas particles

Increased number of collisions with the walls

Increased force per collision

Increased total force of collisions

Increased $\dfrac{\text{force due to collisions}}{\text{area of wall}}$

Increased gas pressure

Gay-Lussac's Law

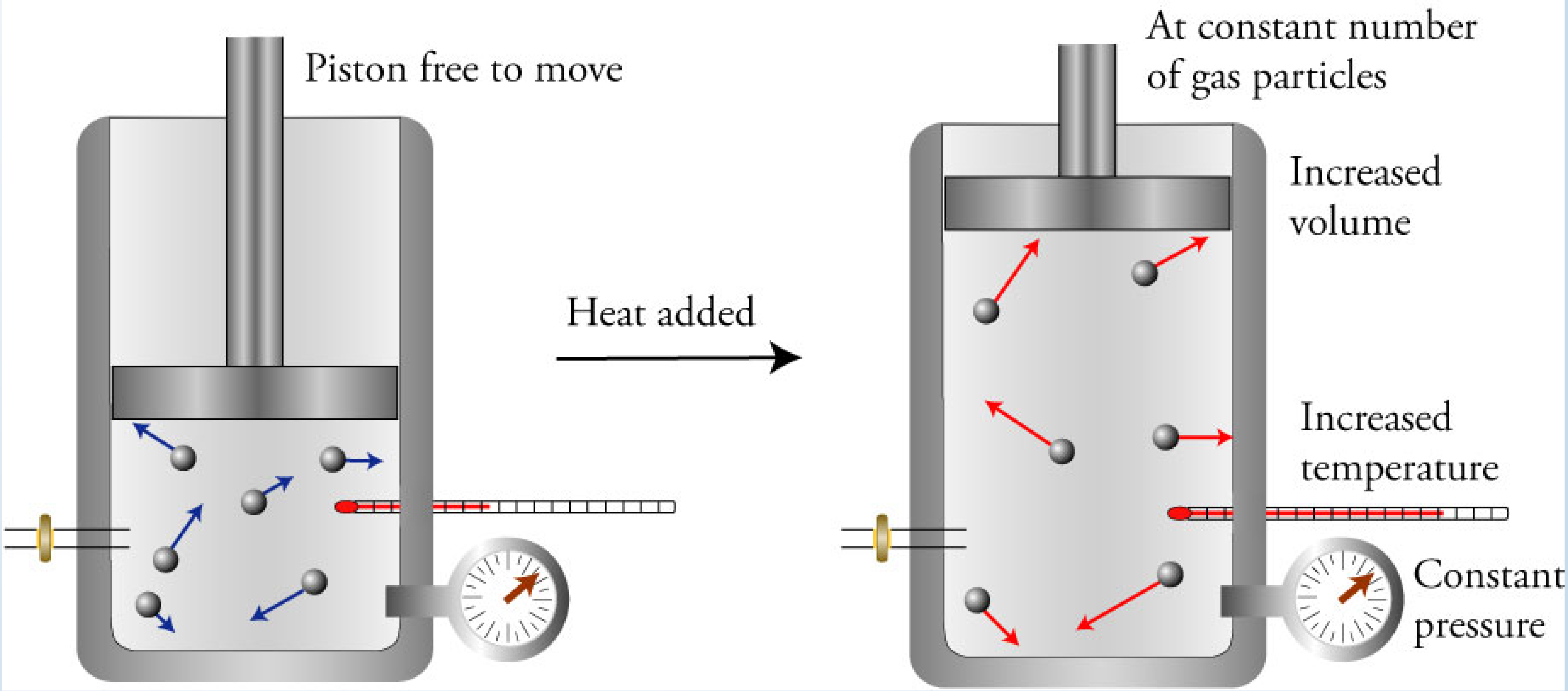
- The pressure of an ideal gas is directly proportional to the Kelvin temperature of the gas if the volume and moles of gas are constant.

$P \propto T$ if n and V are constant

Increased temperature → Increased pressure

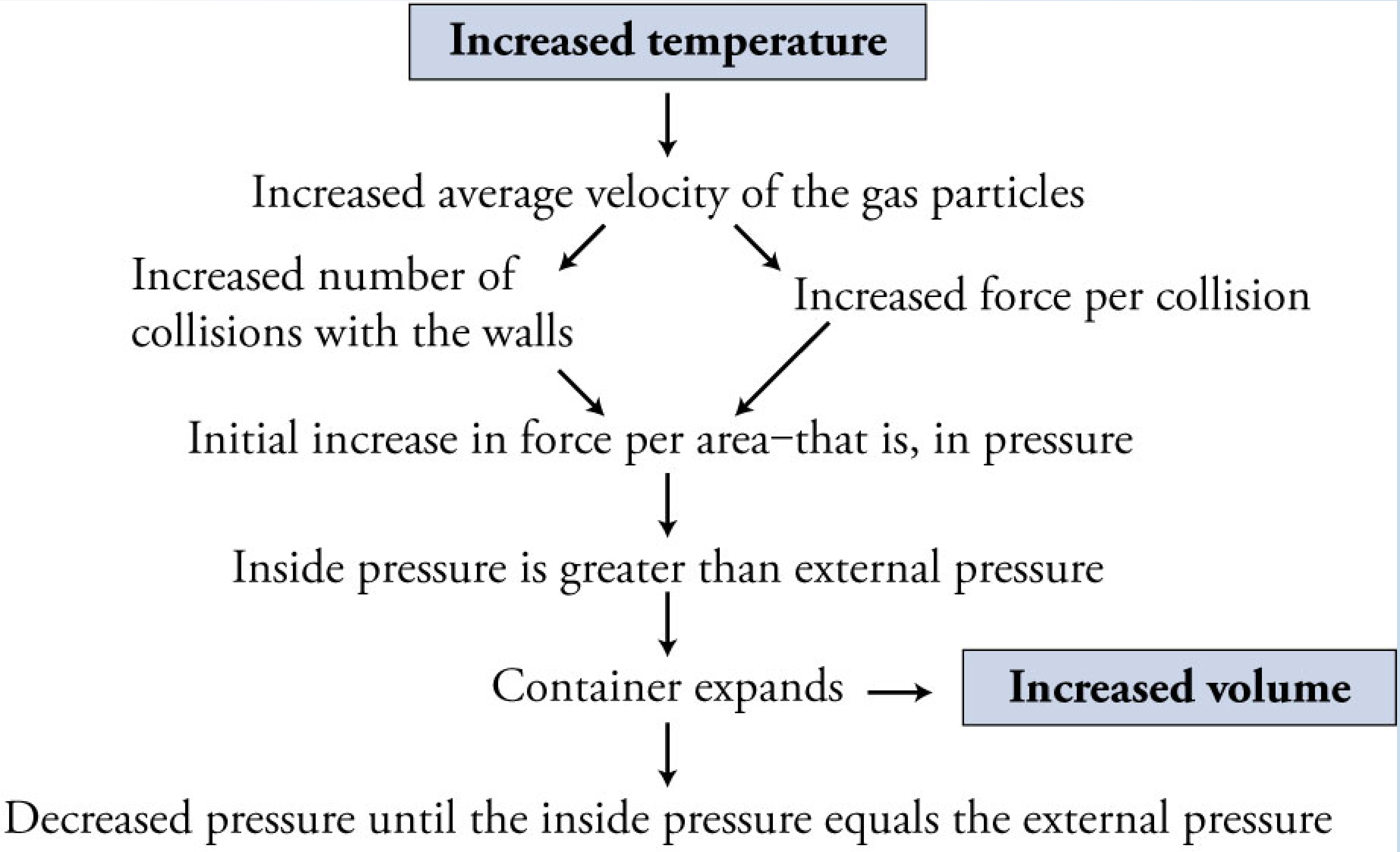
Decreased temperature → Decreased pressure

Increased Temperature Leads to Increased Volume



V α T   if n and P are constant

Relationship between T and V



Increased temperature

Increased average velocity of the gas particles

Increased number of collisions with the walls

Increased force per collision

Initial increase in force per area−that is, in pressure

Inside pressure is greater than external pressure

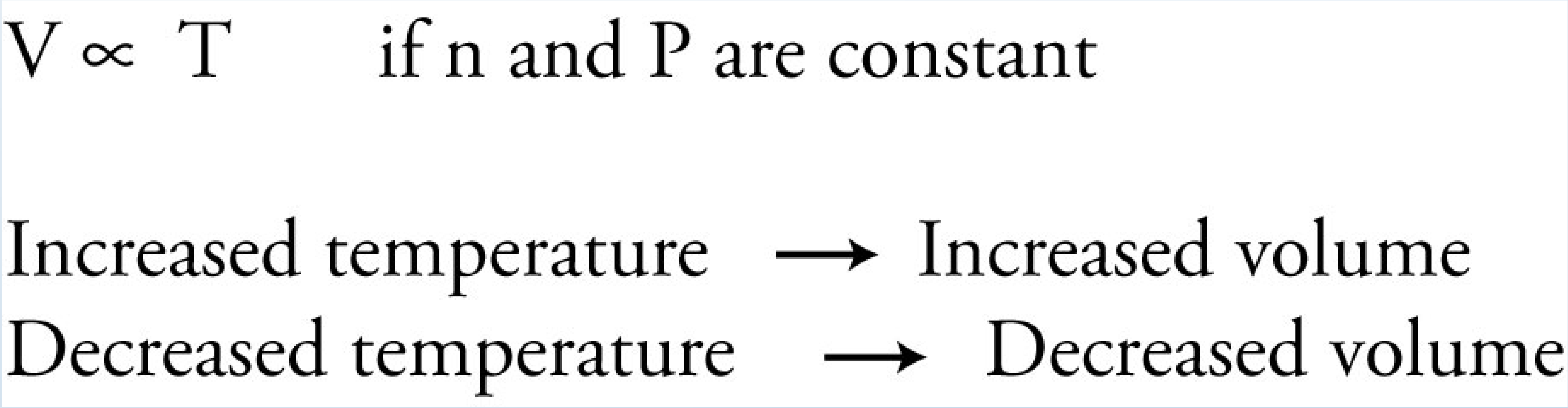
Container expands

Increased volume

Decreased pressure until the inside pressure equals the external pressure

Charles' Law

- For an ideal gas, volume and temperature described in kelvins are directly proportional if moles of gas and pressure are constant.

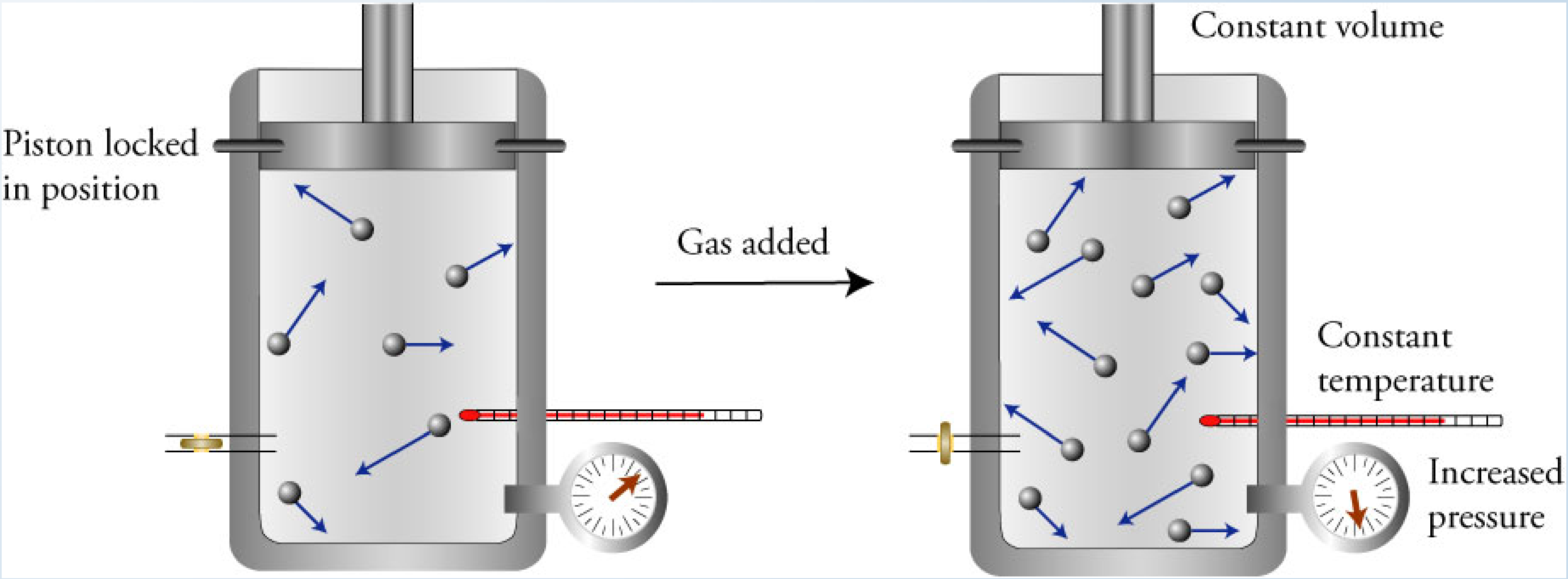


$V \propto T$ if n and P are constant

Increased temperature → Increased volume

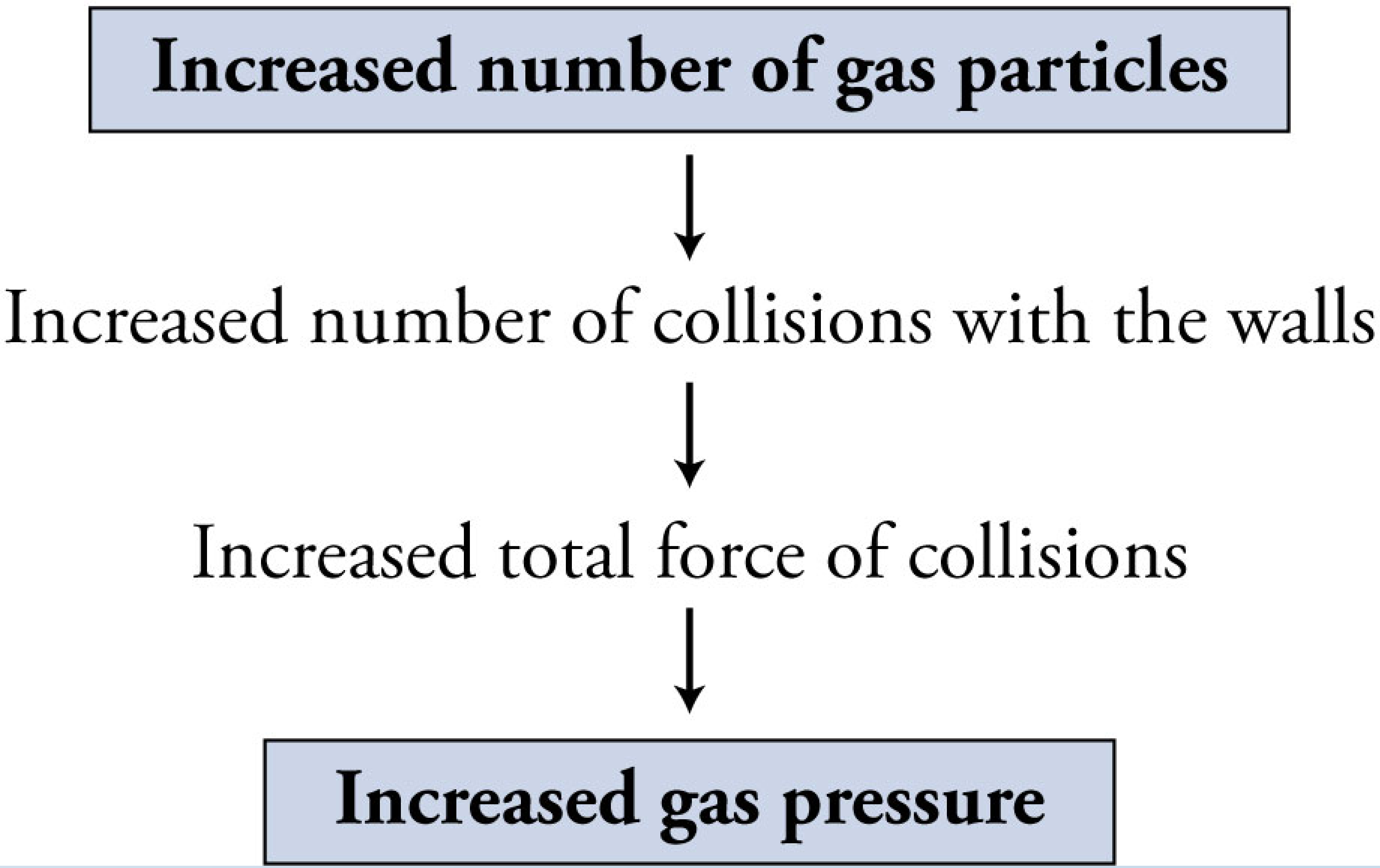
Decreased temperature → Decreased volume

Increased Moles of Gas Leads to Increased Pressure



$P \alpha n$ if T and V are constant

Relationship between n and P



Increased number of gas particles

↓

Increased number of collisions with the walls

↓

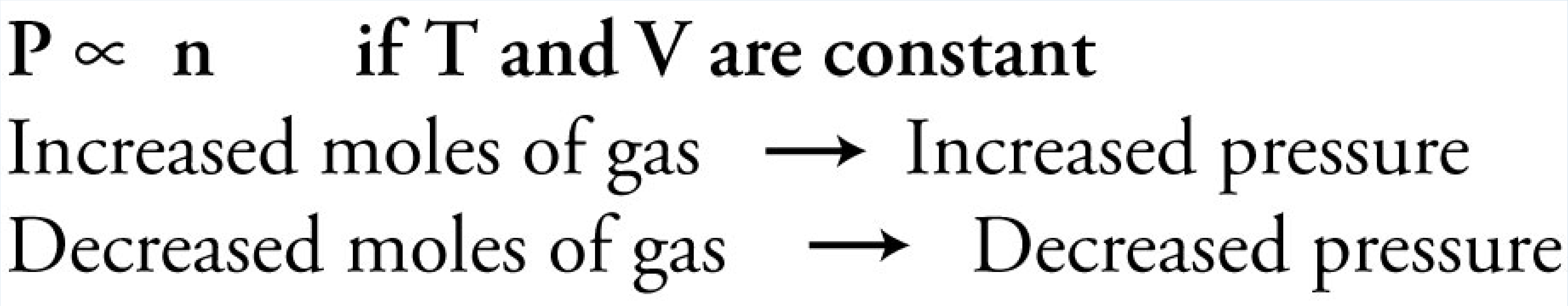
Increased total force of collisions

↓

Increased gas pressure

Relationship Between Moles of Gas and Pressure

- If the temperature and the volume of an ideal gas are held constant, the moles of gas in a container and the gas pressure are directly proportional.

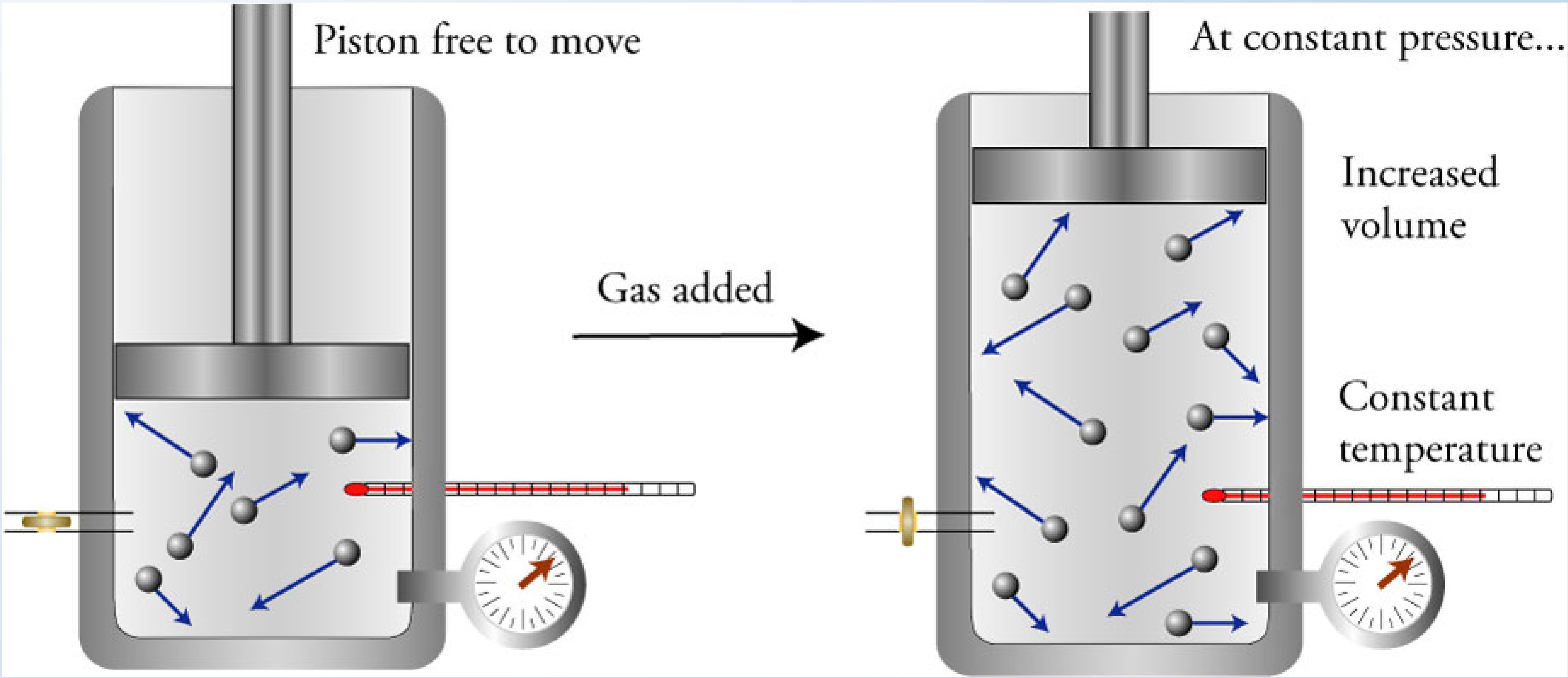


$P \propto n$ if T and V are constant

Increased moles of gas → Increased pressure

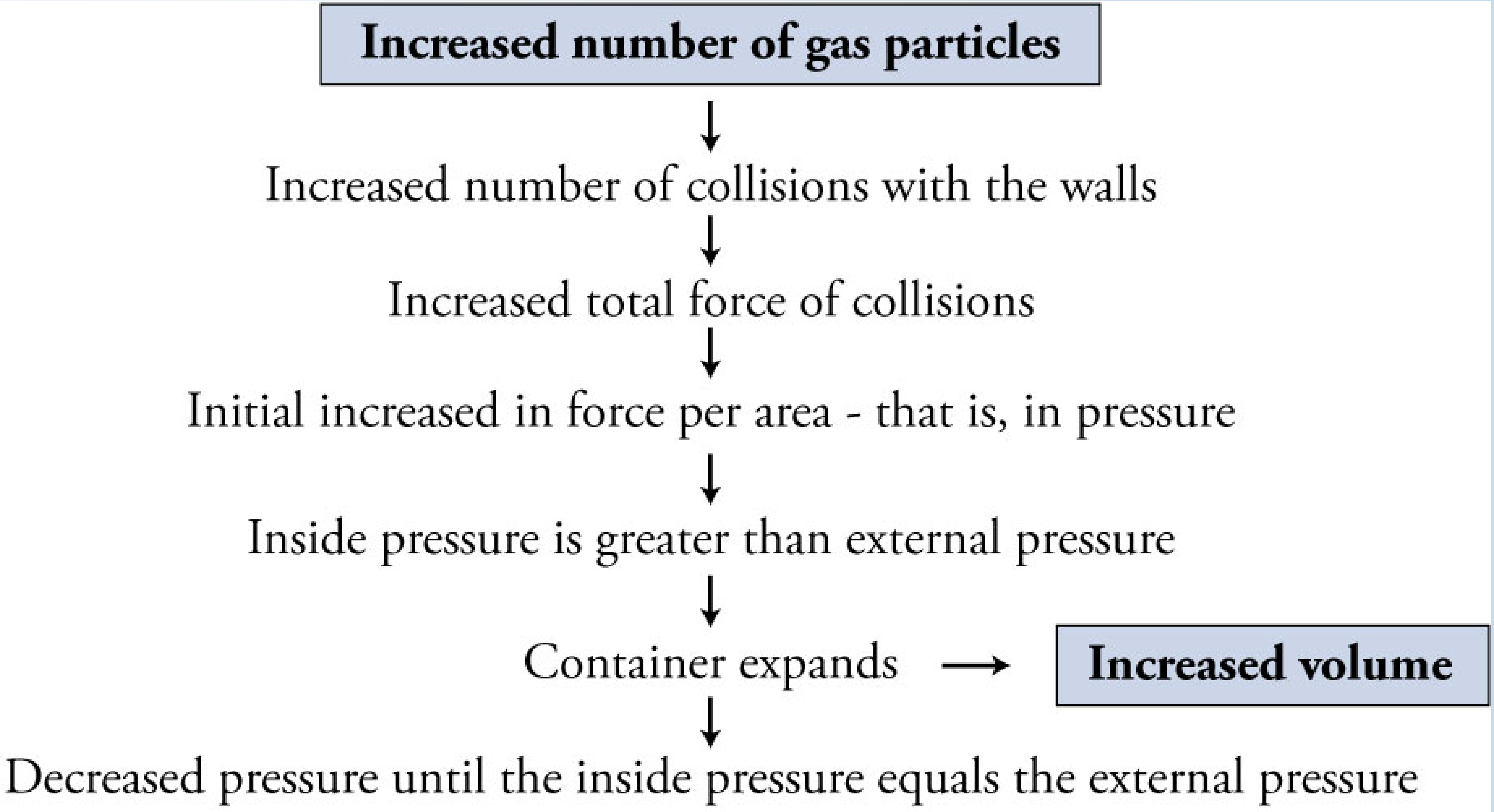
Decreased moles of gas → Decreased pressure

Increased Moles of Gas Leads to Increased Volume



$V \propto n$ if T and P are constant

Relationship between n and V



Increased number of gas particles

↓

Increased number of collisions with the walls

↓

Increased total force of collisions

↓

Initial increased in force per area - that is, in pressure

↓

Inside pressure is greater than external pressure

↓

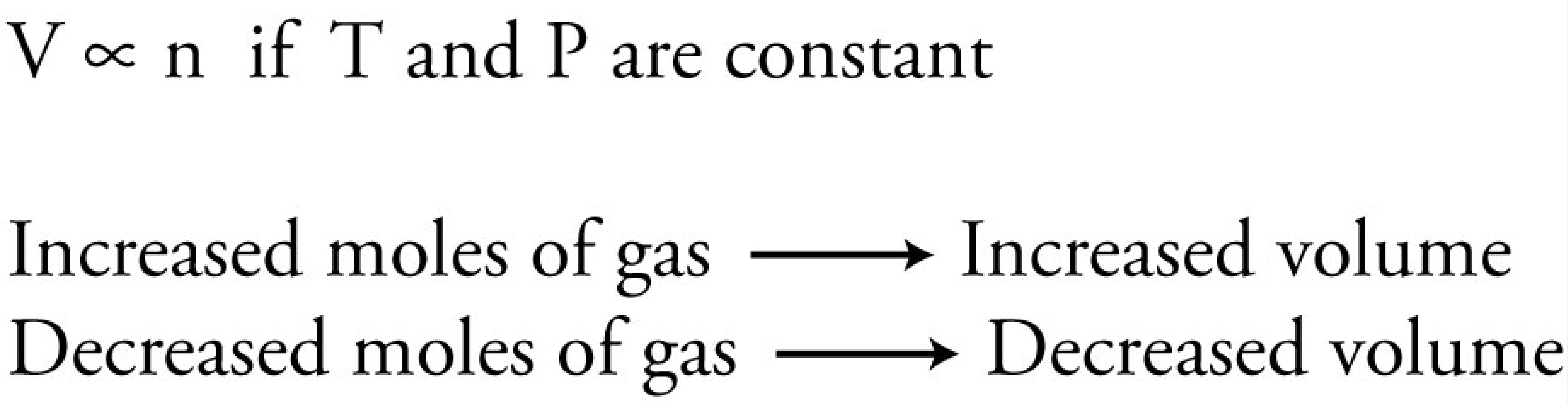
Container expands → **Increased volume**

↓

Decreased pressure until the inside pressure equals the external pressure

Avogadro's Law

- For an ideal gas, the volume and moles of gas are directly proportional if the temperature and pressure are constant.

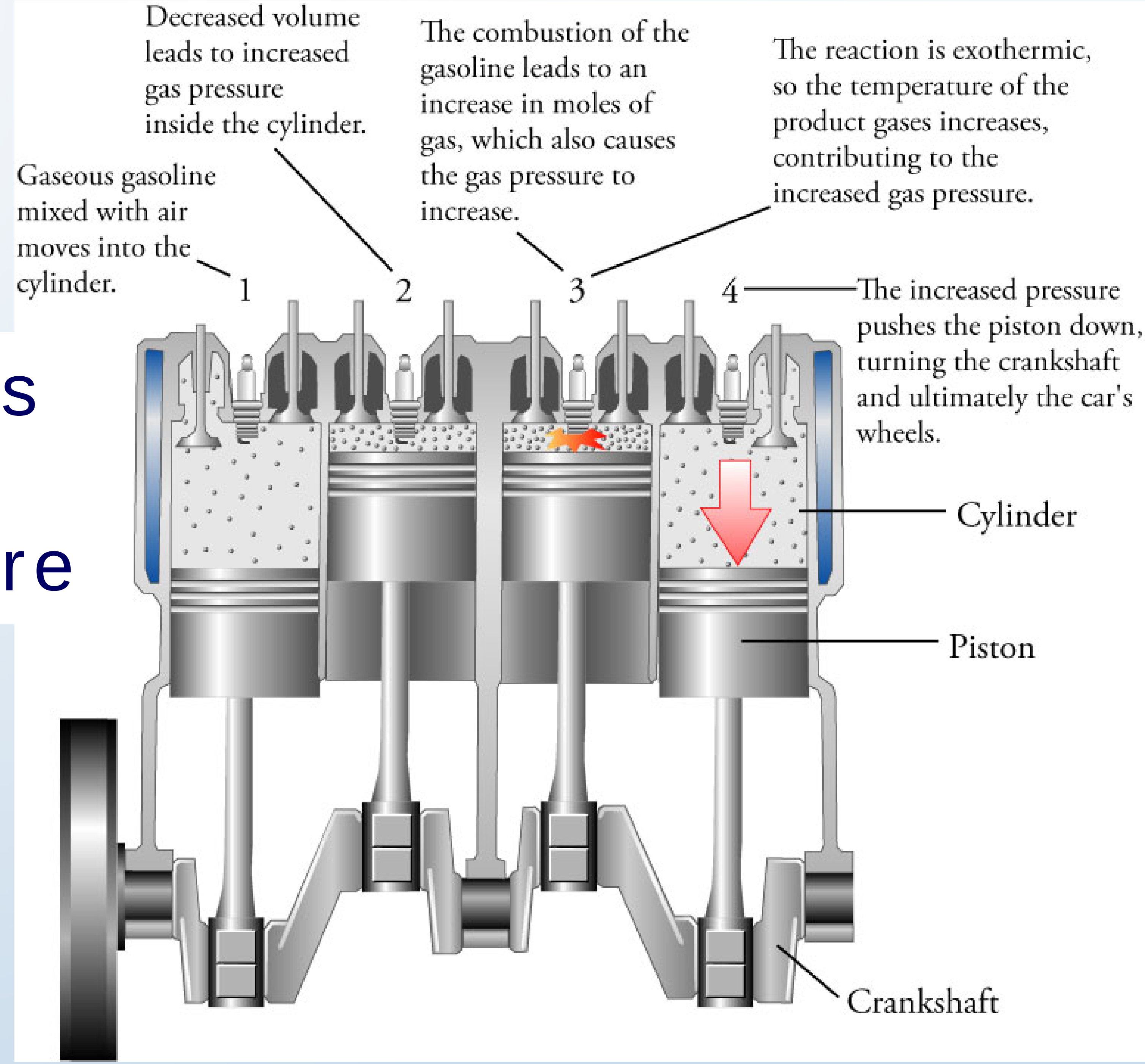


$V \propto n$ if T and P are constant

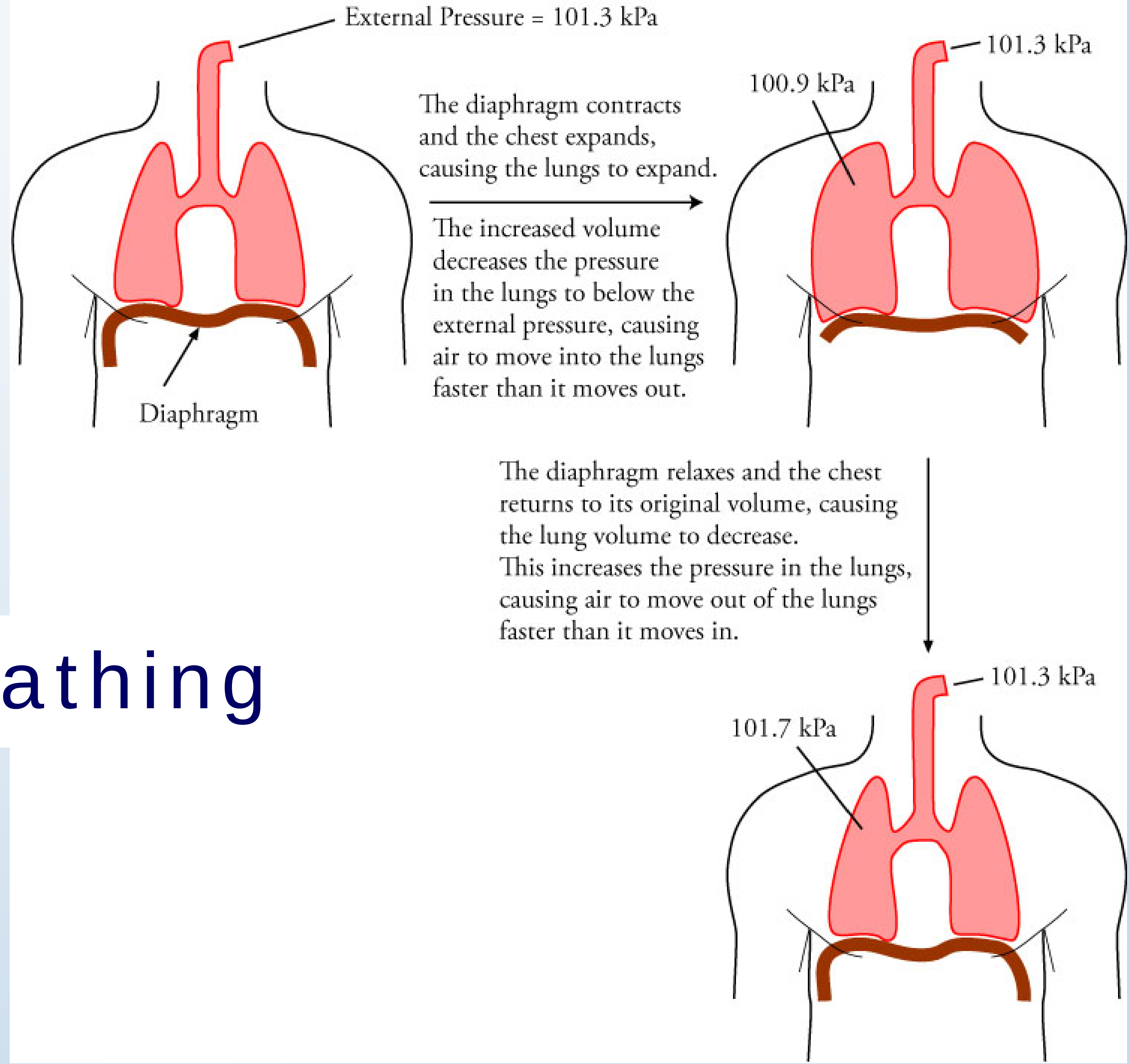
Increased moles of gas ⟶ Increased volume

Decreased moles of gas ⟶ Decreased volume

Engines and Pressure



Breathing



The diaphragm contracts and the chest expands, causing the lungs to expand.

The increased volume decreases the pressure in the lungs to below the external pressure, causing air to move into the lungs faster than it moves out.

The diaphragm relaxes and the chest returns to its original volume, causing the lung volume to decrease.
This increases the pressure in the lungs, causing air to move out of the lungs faster than it moves in.

Ideal Gas Equation

$P \propto n$ if T and V are constant

$P \propto T$ if n and V are constant

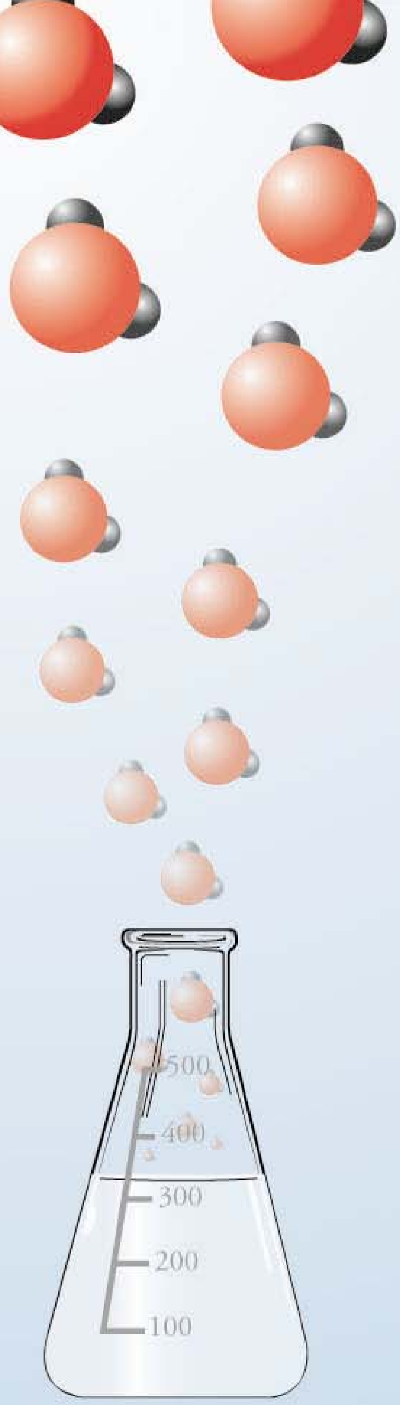
$P \propto \dfrac{1}{V}$ if n and T are constant

or $P \propto \dfrac{nT}{V}$

so $P = \text{(a constant)}\,\dfrac{nT}{V}$

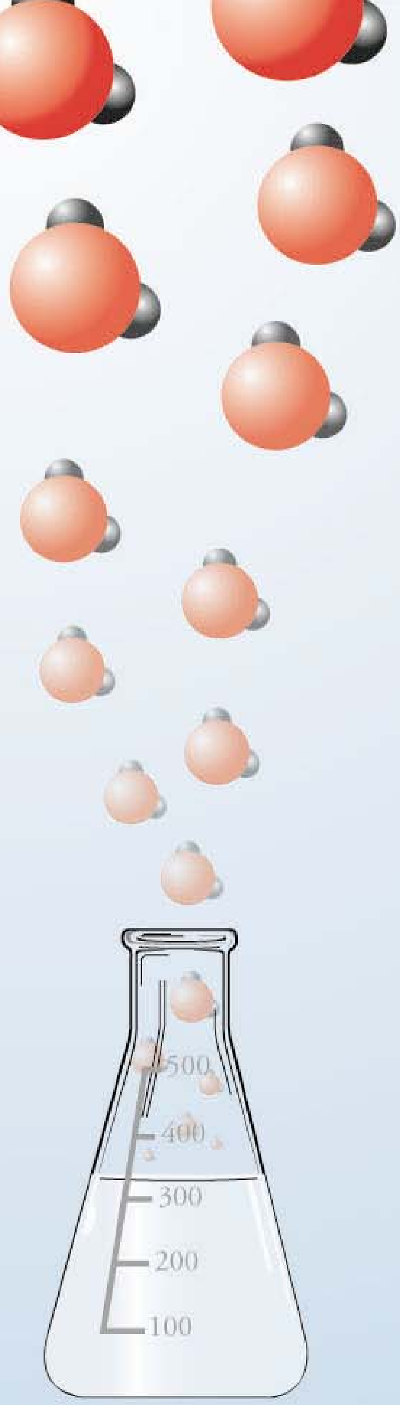
$$\boldsymbol{PV = nRT} \quad \frac{0.082058\ \text{L} \bullet \text{atm}}{\text{K} \bullet \text{mol}} \quad \text{or} \quad \frac{8.3145\ \text{L} \bullet \text{kPa}}{\text{K} \bullet \text{mol}}$$

Ideal Gas Equation Problems

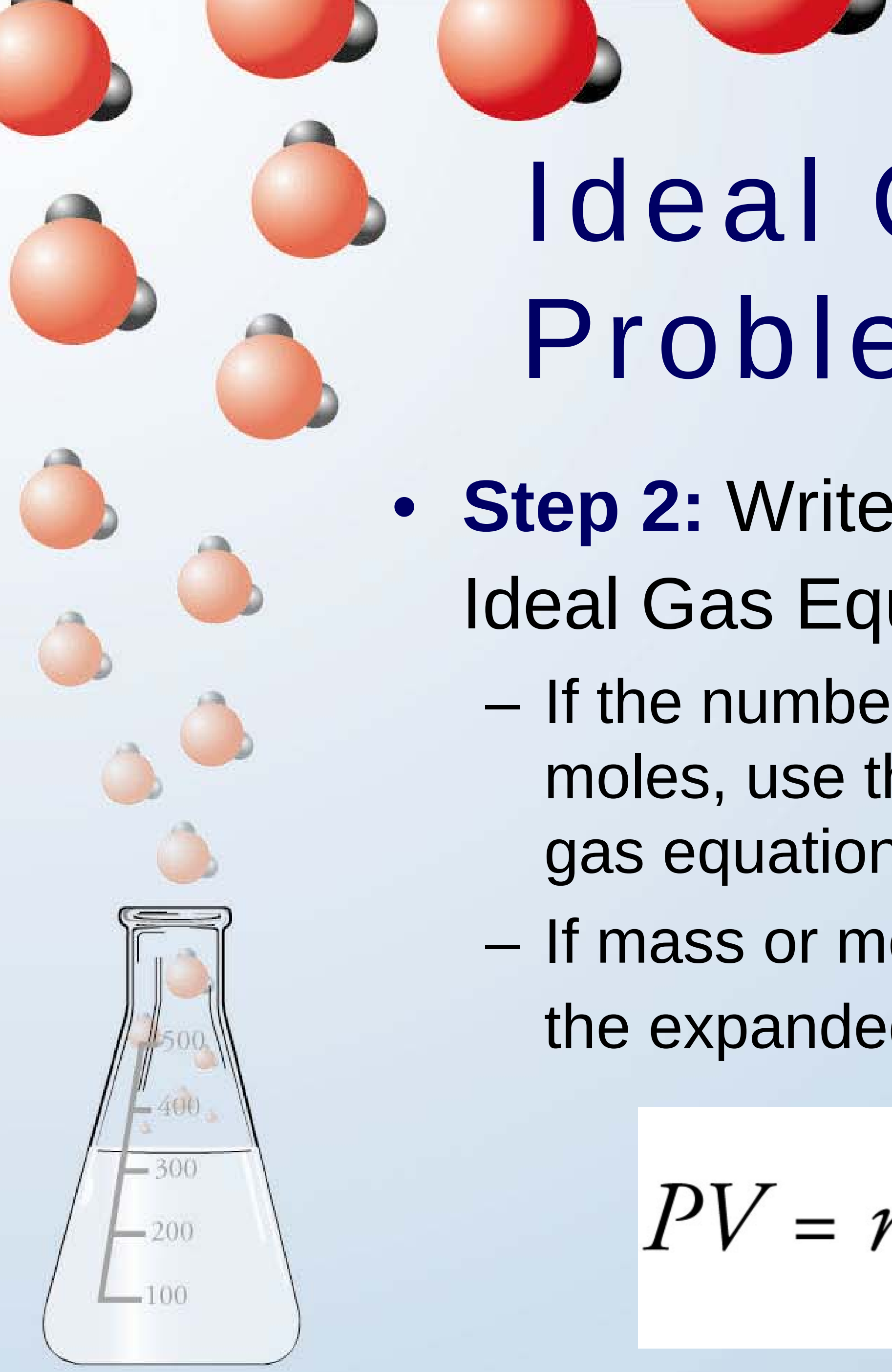


- **Tip-off** – The usual tip-off that you can use the ideal gas equation to answer a question is that you are given three properties of a sample of gas and asked to calculate the fourth. A more general tip-off is that only one gas is mentioned and there are no changing properties.

Ideal Gas Equation Problem Step 1



- **Step 1:** Assign variables to the values given and the value that is unknown. Use P for pressure, V for volume, n for moles, T for temperature, g for mass, and M for molar mass.

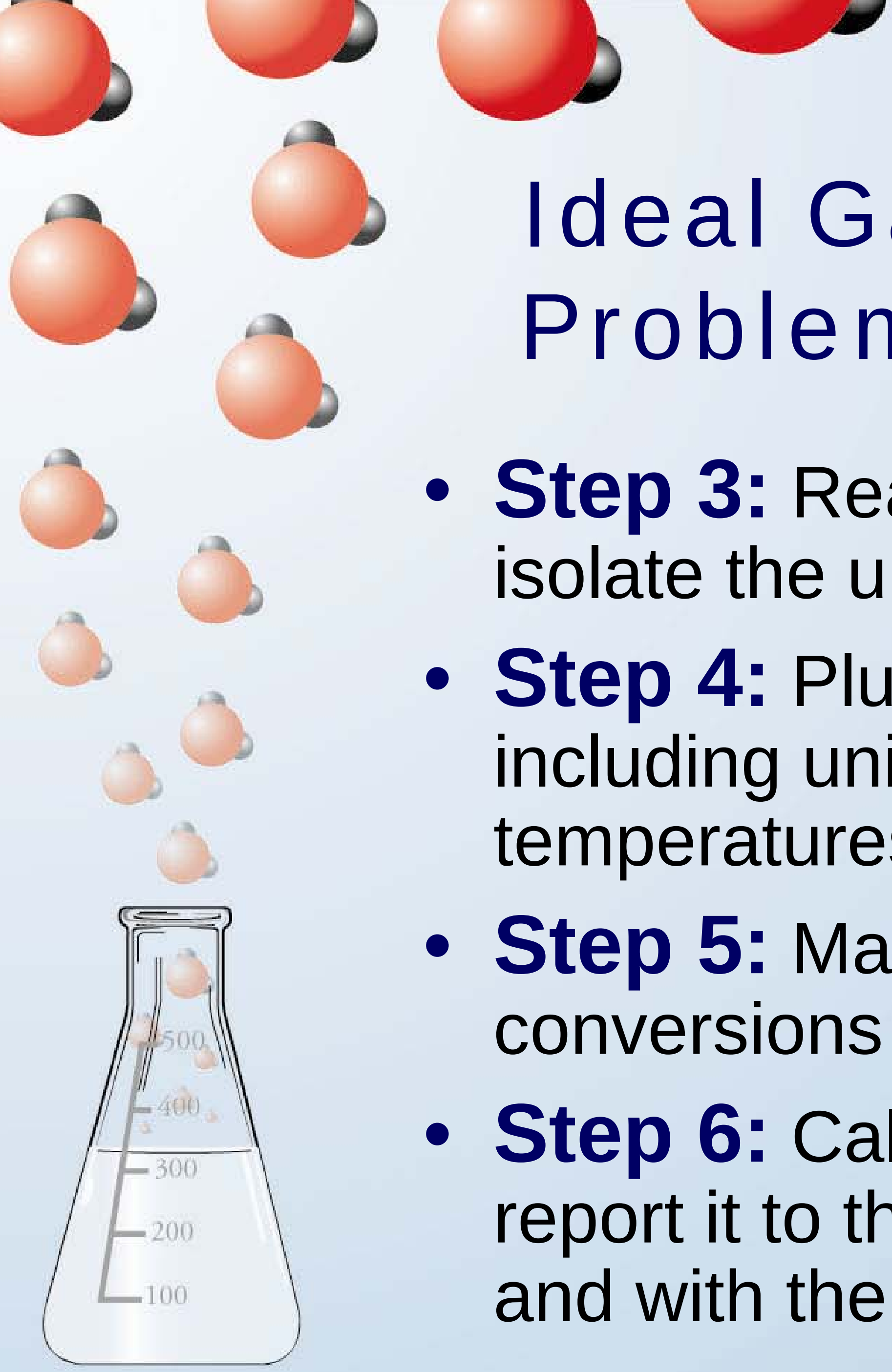


Ideal Gas Equation Problem Step 2

- **Step 2:** Write the appropriate form of the Ideal Gas Equation.
  - If the number of particles is given or desired in moles, use the most common form of the ideal gas equation.
  - If mass or molar mass is given or desired, use the expanded form of the ideal gas equation.

$$PV = nRT \qquad PV = \frac{g}{M}RT$$

Ideal Gas Equation Problem Steps 3-6



- **Step 3:** Rearrange the equation to isolate the unknown.
- **Step 4:** Plug in the known values, including units. Be sure to use kelvin temperatures.
- **Step 5:** Make any necessary unit conversions and cancel your units.
- **Step 6:** Calculate your answer and report it to the correct significant figures and with the correct unit.

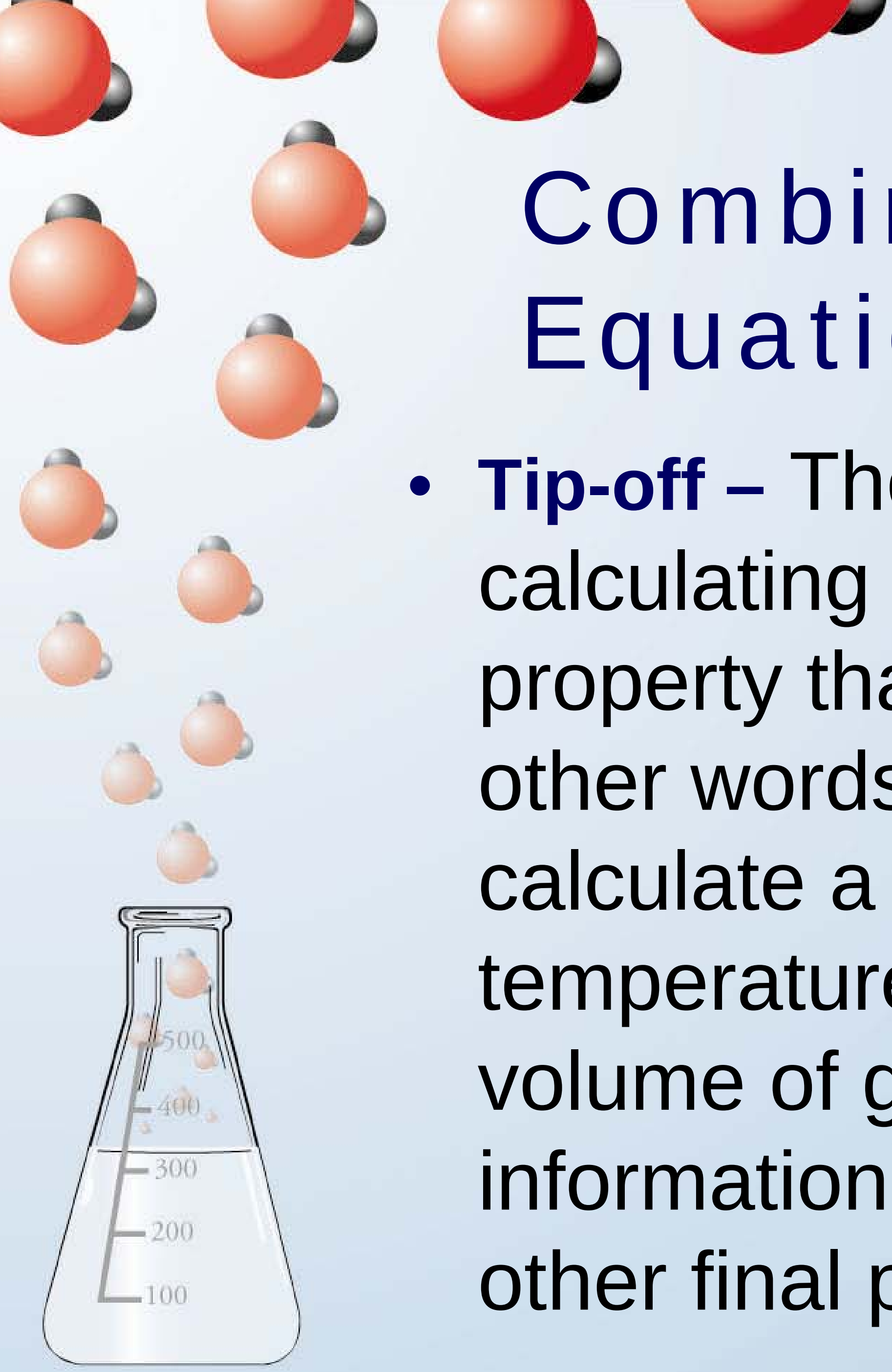
$$\frac{PV}{nT} = R$$

$$P_1V_1 = n_1RT_1 \quad \text{so} \quad \frac{P_1V_1}{n_1T_1} = R$$

$$P_2V_2 = n_2RT_2 \quad \text{so} \quad \frac{P_2V_2}{n_2T_2} = R$$

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

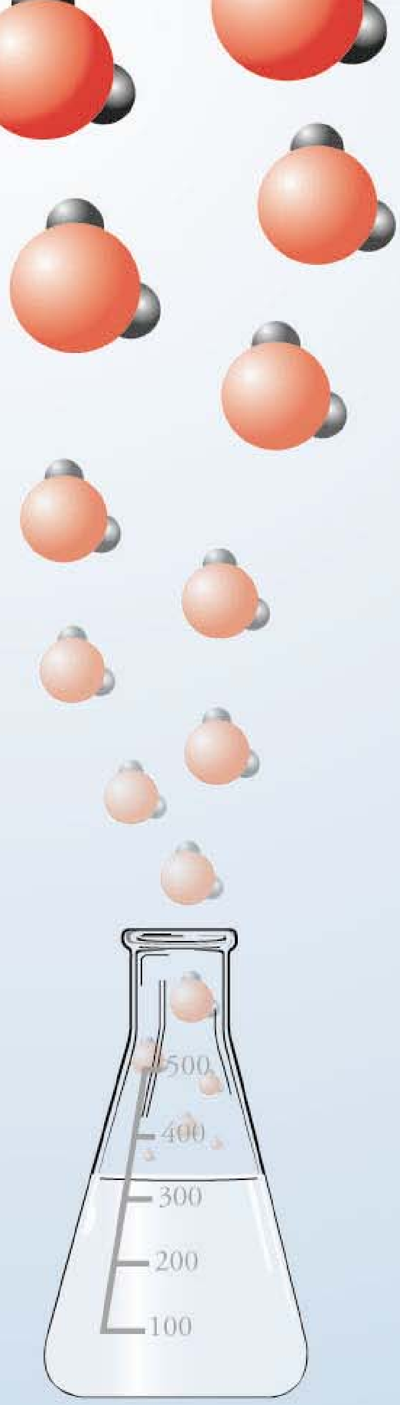
Combined
Gas Law
Equation



Combined Gas Law Equation Problems

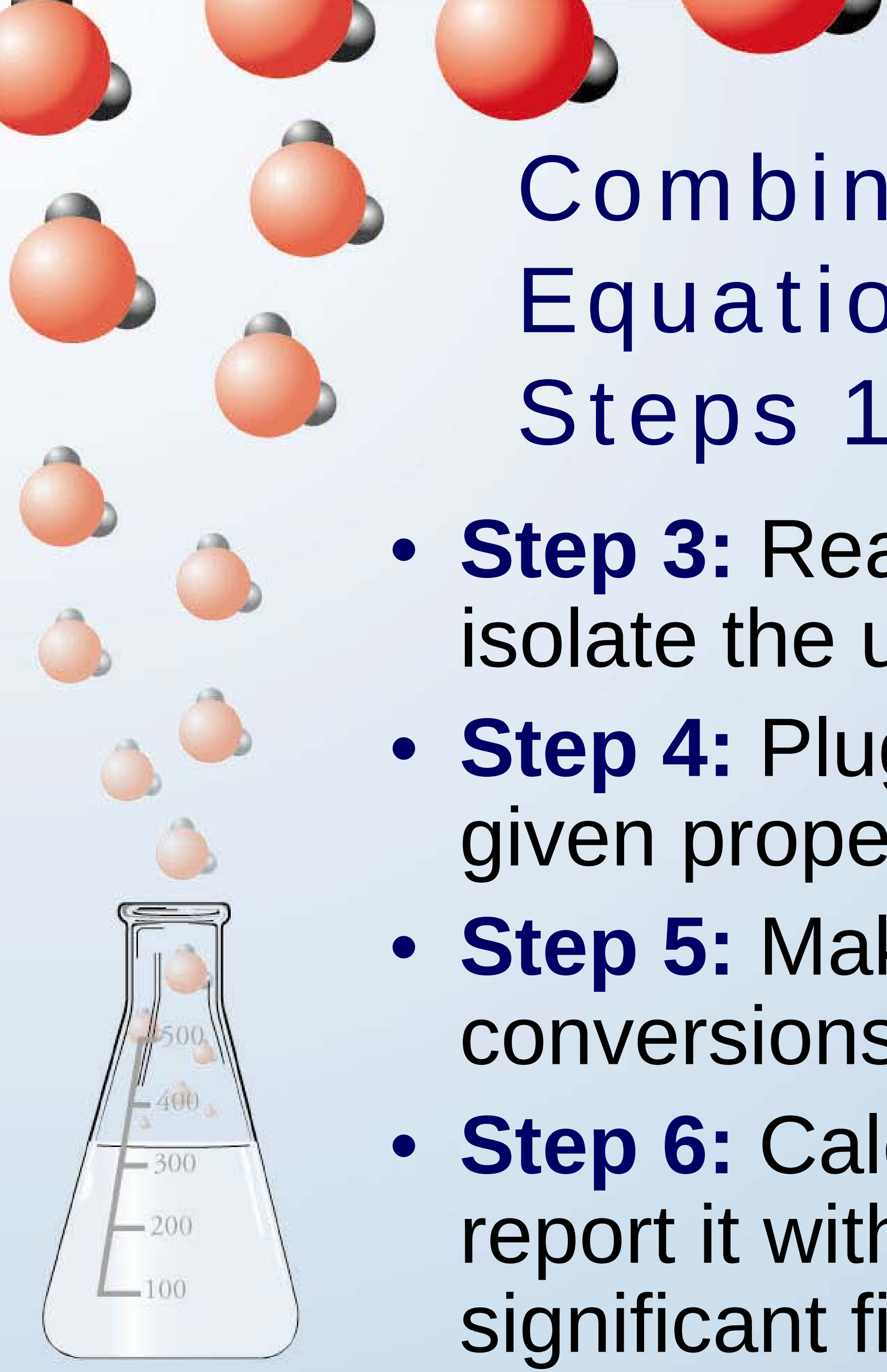
- **Tip-off –** The problem requires calculating a value for a gas property that has changed. In other words, you are asked to calculate a new pressure, temperature, moles (or mass), or volume of gas given sufficient information about the initial and other final properties.

Combined Gas Law Equation Problem Steps 1 and 2



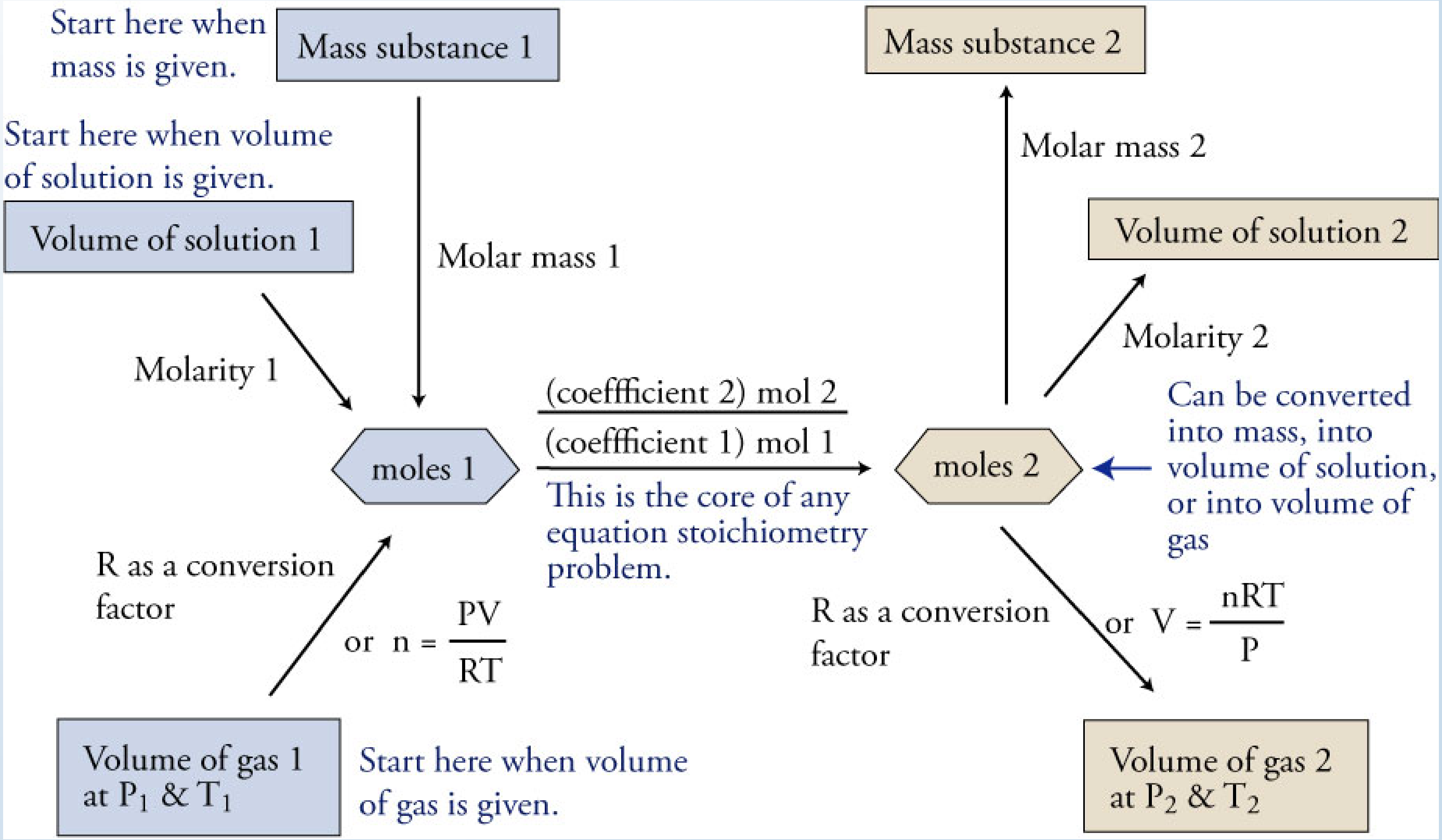
- **Step 1:** Assign the variables P, T, n, and V to the values you are given and to the unknown value. Use the subscripts 1 and 2 to show initial or final conditions.
- **Step 2:** Write out the combined gas law equation, but eliminate the variables for any constant properties. (You can assume that the properties not mentioned in the problem remain constant.)

Combined Gas Law Equation Problem Steps 1 and 2



- **Step 3:** Rearrange the equation to isolate the unknown property.
- **Step 4:** Plug in the values for the given properties.
- **Step 5:** Make any necessary unit conversions and cancel your units.
- **Step 6:** Calculate your answer and report it with the correct units and significant figures.

Equation Stoichiometry



Start here when mass is given.

Mass substance 1

Molar mass 1

Start here when volume of solution is given.

Volume of solution 1

Molarity 1

moles 1

$$\frac{\text{(coeffficient 2) mol 2}}{\text{(coeffficient 1) mol 1}}$$

This is the core of any equation stoichiometry problem.

moles 2

Can be converted into mass, into volume of solution, or into volume of gas

Mass substance 2

Molar mass 2

Volume of solution 2

Molarity 2

R as a conversion factor

or $n = \frac{PV}{RT}$

Volume of gas 1 at P_1 & T_1

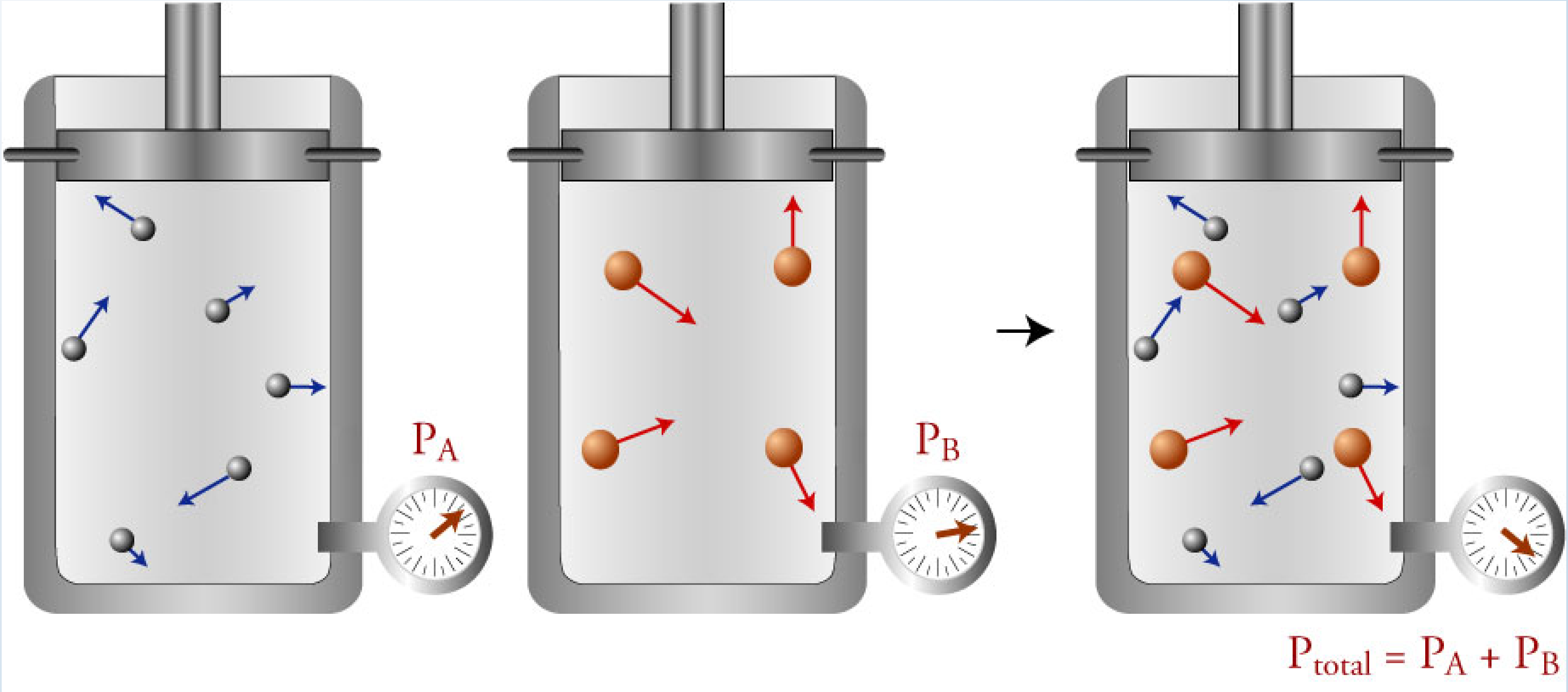
Start here when volume of gas is given.

R as a conversion factor

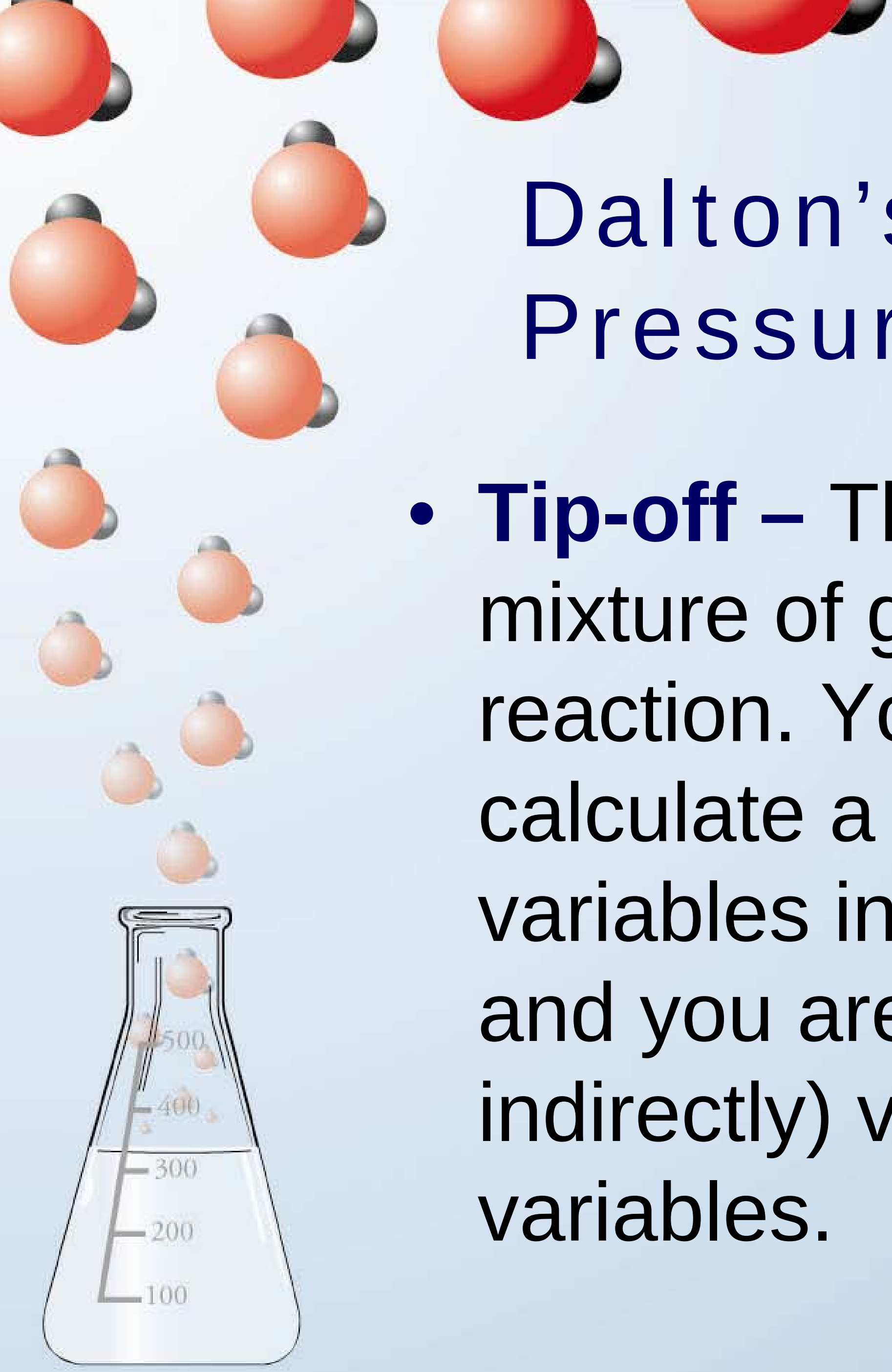
or $V = \frac{nRT}{P}$

Volume of gas 2 at P_2 & T_2

Dalton’s Law of Partial Pressures



Dalton's Law of Partial Pressures Problems

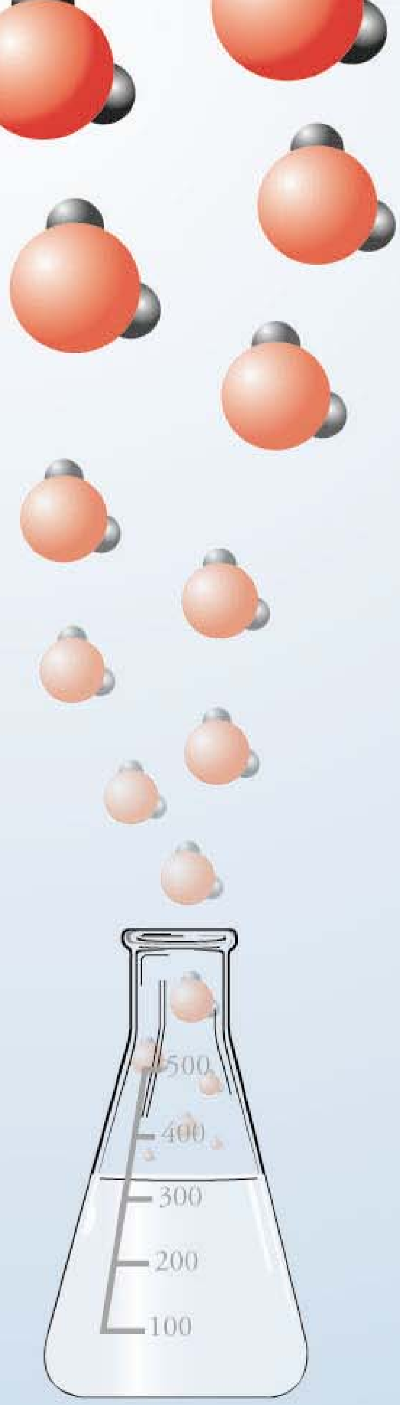


- **Tip-off –** The problem involves a mixture of gases and no chemical reaction. You are asked to calculate a value for one of the variables in the equations below, and you are given (directly or indirectly) values for the other variables.

Dalton's Law of Partial Pressures Problem Steps 1 & 2

- **Step 1:** Assign variables to the values that are given and the value that is unknown.
- **Step 2:** From the following equations, choose the one that best fits the variables assigned in Step 1.

$$P_{\text{total}} = \Sigma P_{\text{partial}} \quad \text{or} \quad P_{\text{total}} = (\Sigma n_{\text{each gas}})\frac{RT}{V}$$



Dalton's Law of Partial Pressures Problem Steps 3-6

- **Step 3:** Rearrange the equation to solve for your unknown.
- **Step 4:** Plug in the values for the given properties.
- **Step 5:** Make sure that the equation yields the correct units. Make any necessary unit conversions.
- **Step 6:** Calculate your answer and report it with the correct units and significant figures.