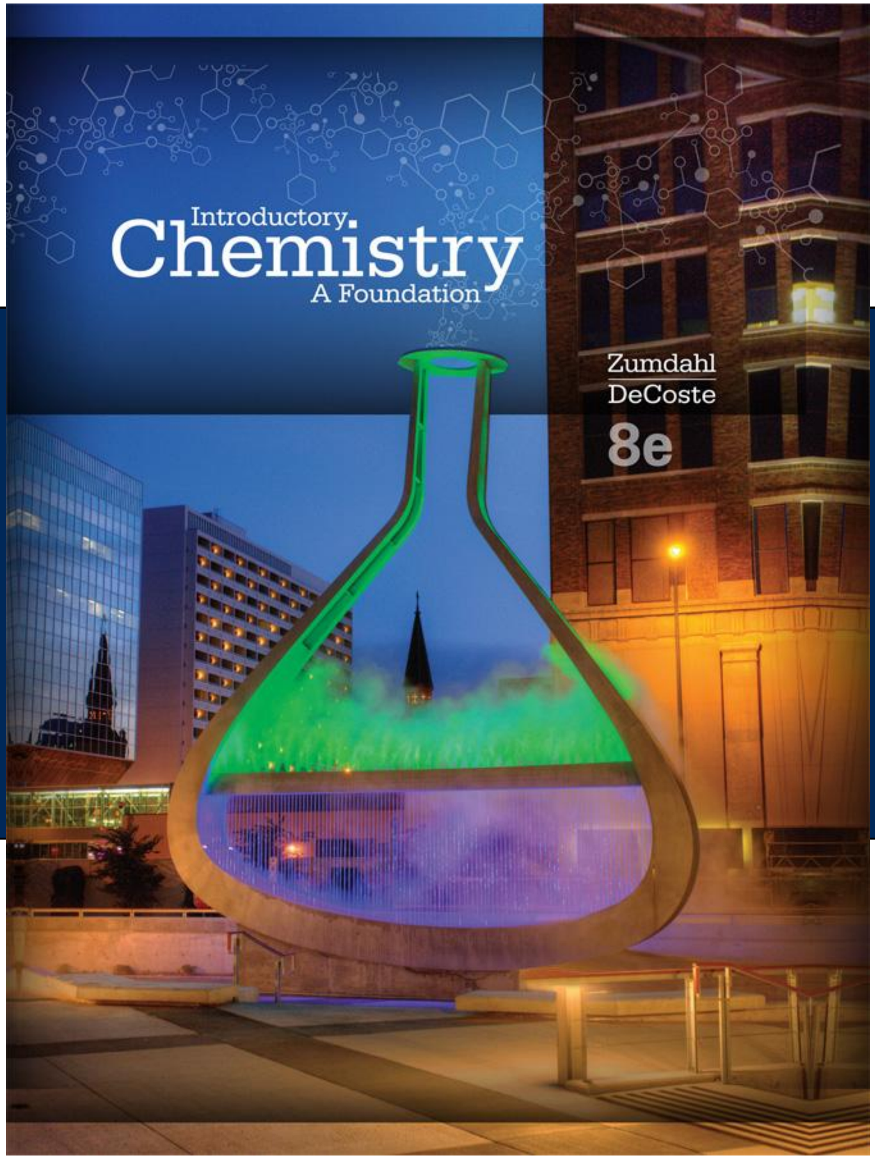


Chapter 13

Gases

Pressure

Why study gases?

- An understanding of real world phenomena.
- An understanding of how science "works."

Pressure

A Gas

- Uniformly fills any container.
- Mixes completely with any other gas.
- Exerts pressure on its surroundings.

Pressure

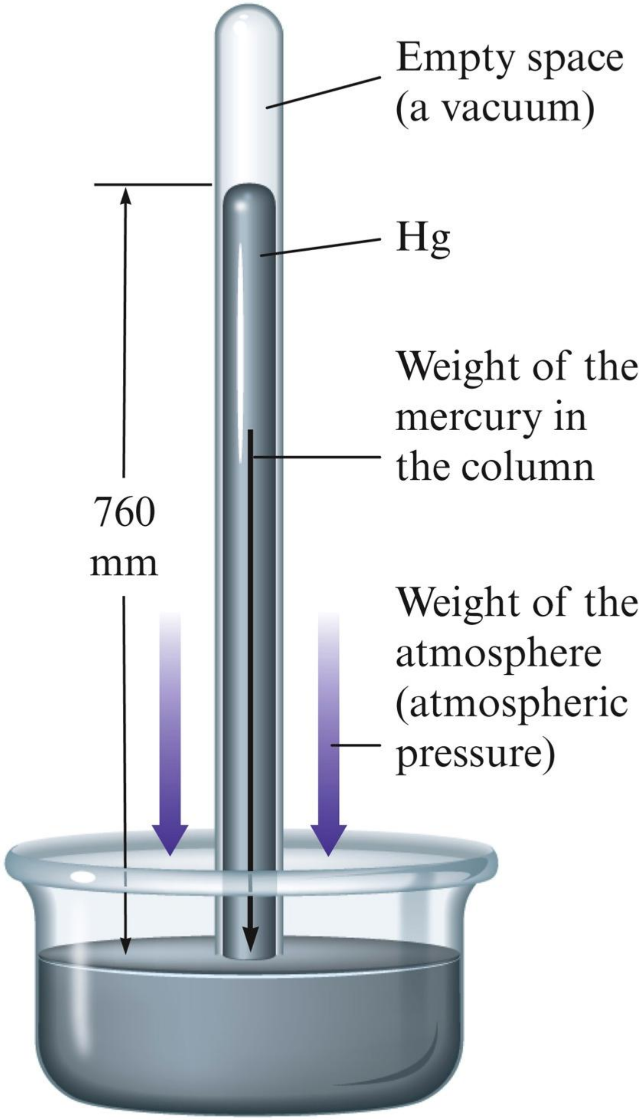
Pressure

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

- SI units = Newton/meter^2 = 1 Pascal (Pa)
- 1 standard atmosphere = 101,325 Pa
- 1 standard atmosphere = 1 atm = 760 mm Hg = 760 torr

Barometer

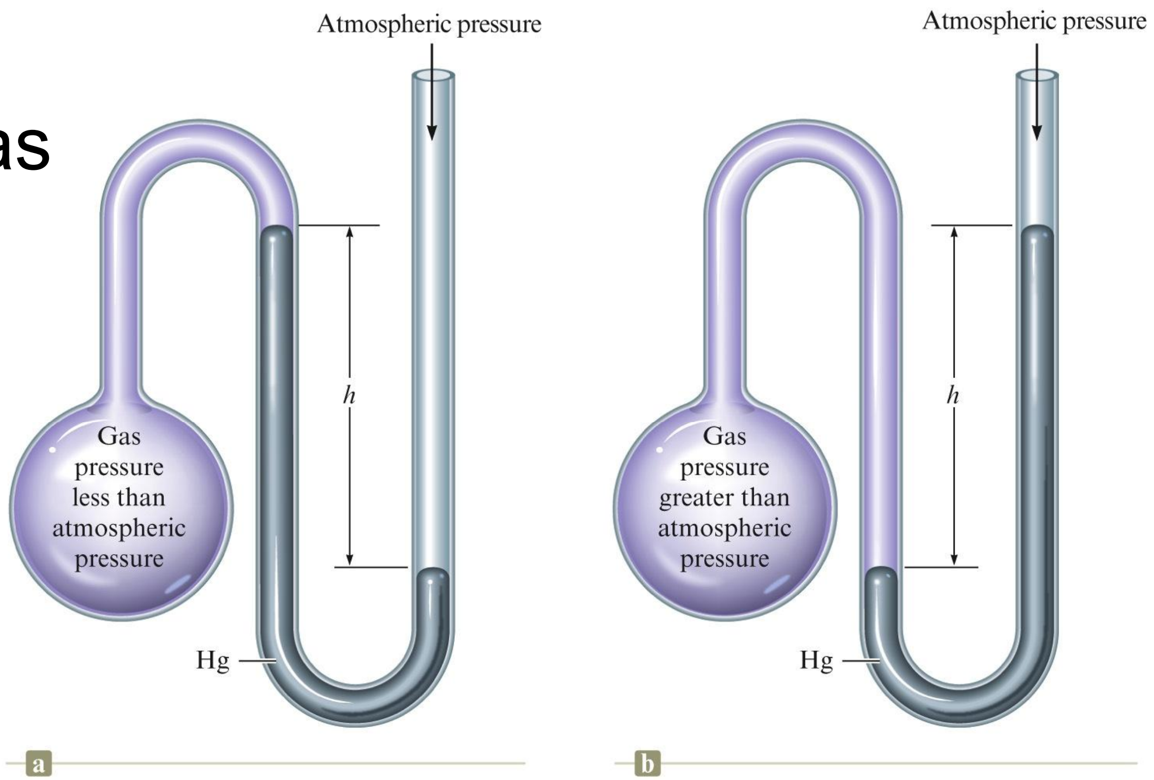
- Device used to measure atmospheric pressure.
- Mercury flows out of the tube until the pressure of the column of mercury standing on the surface of the mercury in the dish is *equal* to the pressure of the air on the rest of the surface of the mercury in the dish.



Pressure

Manometer

- Device used for measuring the pressure of a gas in a container.

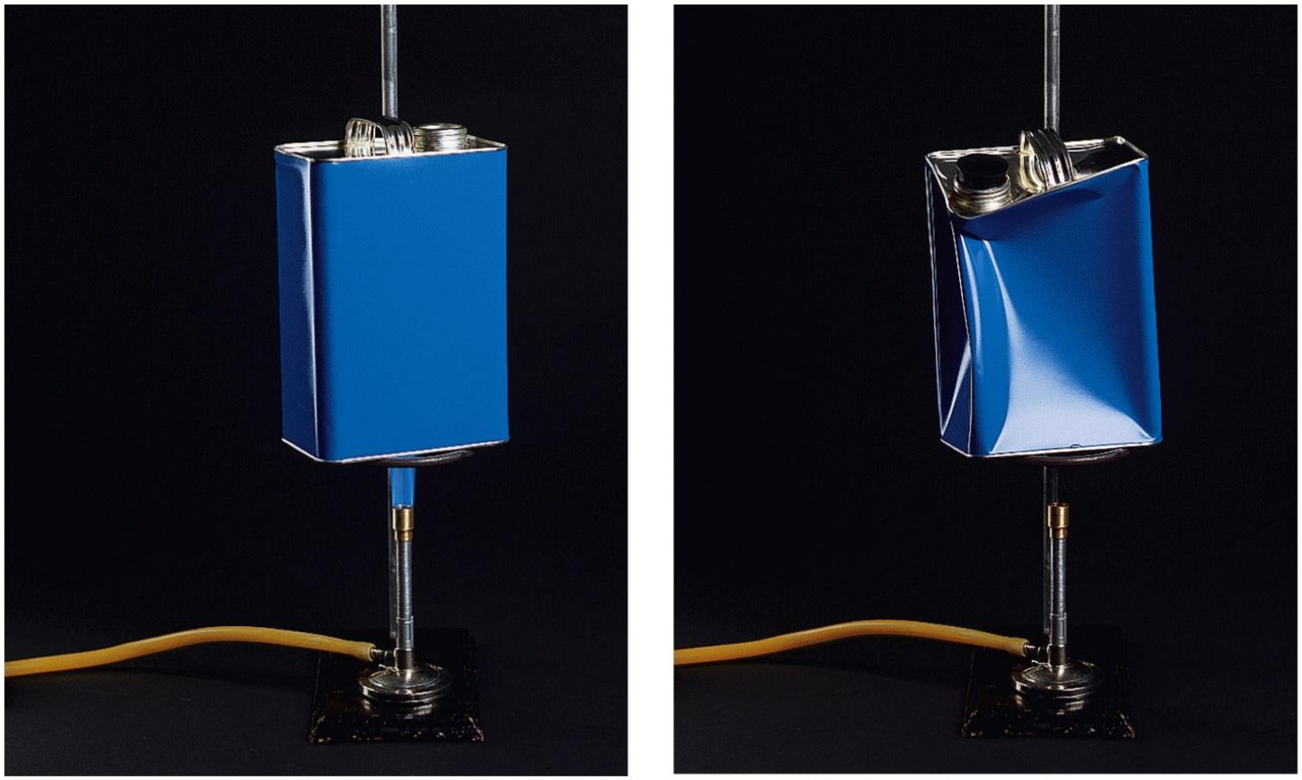


Gas pressure = atmospheric pressure – *h*.

Gas pressure = atmospheric pressure + *h*.

Pressure

Collapsing Can



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a The pressure exerted by the gases in the atmosphere can be demonstrated by boiling water in a can and then turning off the heat and sealing the can.

b As the can cools, the water vapor condenses, lowering the gas pressure inside the can. This causes the can to crumple.

Pressure Conversions: An Example

The pressure of a gas is measured as 2.5 atm. Represent this pressure in both torr and pascals.

Where are we going?

- We want to convert from units of atm to units of torr and units of pascals.

What do we know?

- 2.5 atm

What information do we need?

- Equivalence statements for the units.

Pressure Conversions: An Example

The pressure of a gas is measured as 2.5 atm. Represent this pressure in both torr and pascals.

How do we get there?

$$(2.5\ \cancel{\text{atm}}) \times \left(\frac{760\ \text{torr}}{1\ \cancel{\text{atm}}}\right) = 1.9 \times 10^{3}\ \text{torr}$$

$$(2.5\ \cancel{\text{atm}}) \times \left(\frac{101{,}325\ \text{Pa}}{1\ \cancel{\text{atm}}}\right) = 2.5 \times 10^{5}\ \text{Pa}$$

Exercise

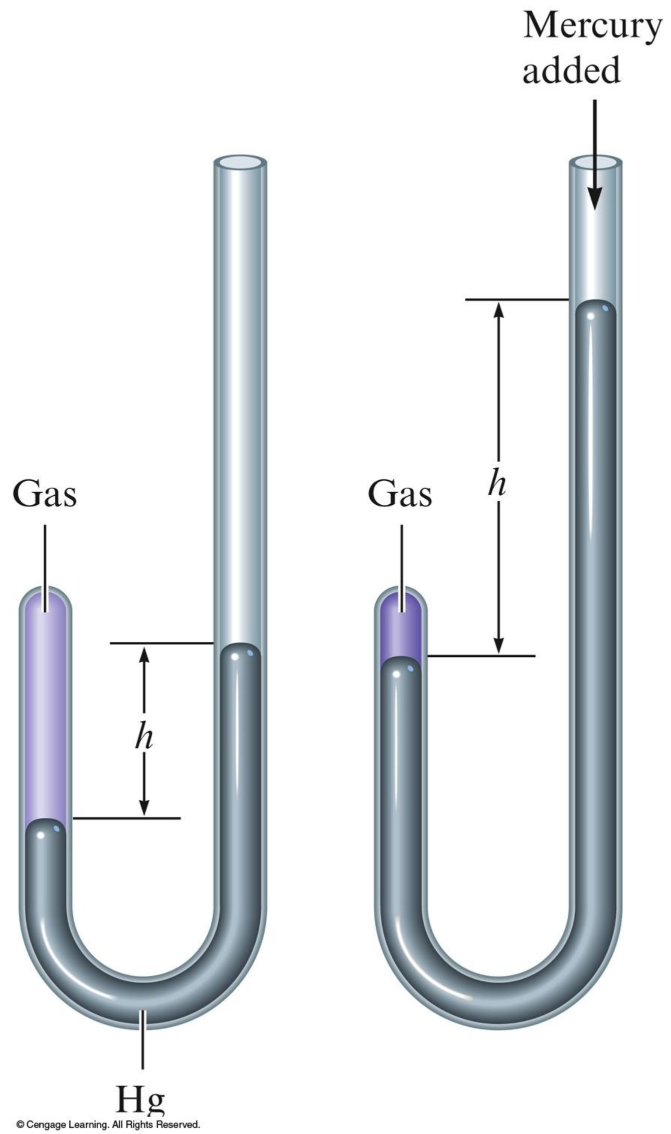
The vapor pressure over a beaker of hot water is measured as 656 torr. What is this pressure in atmospheres?

a) 1.16 atm
b) 0.863 atm
c) 0.756 atm
d) 0.500 atm

$$656 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ atm}} = 0.863 \text{ atm}$$

Pressure and Volume: Boyle's Law

Robert Boyle's Experiment



Pressure and Volume: Boyle's Law

A Sample of Boyle's Observations

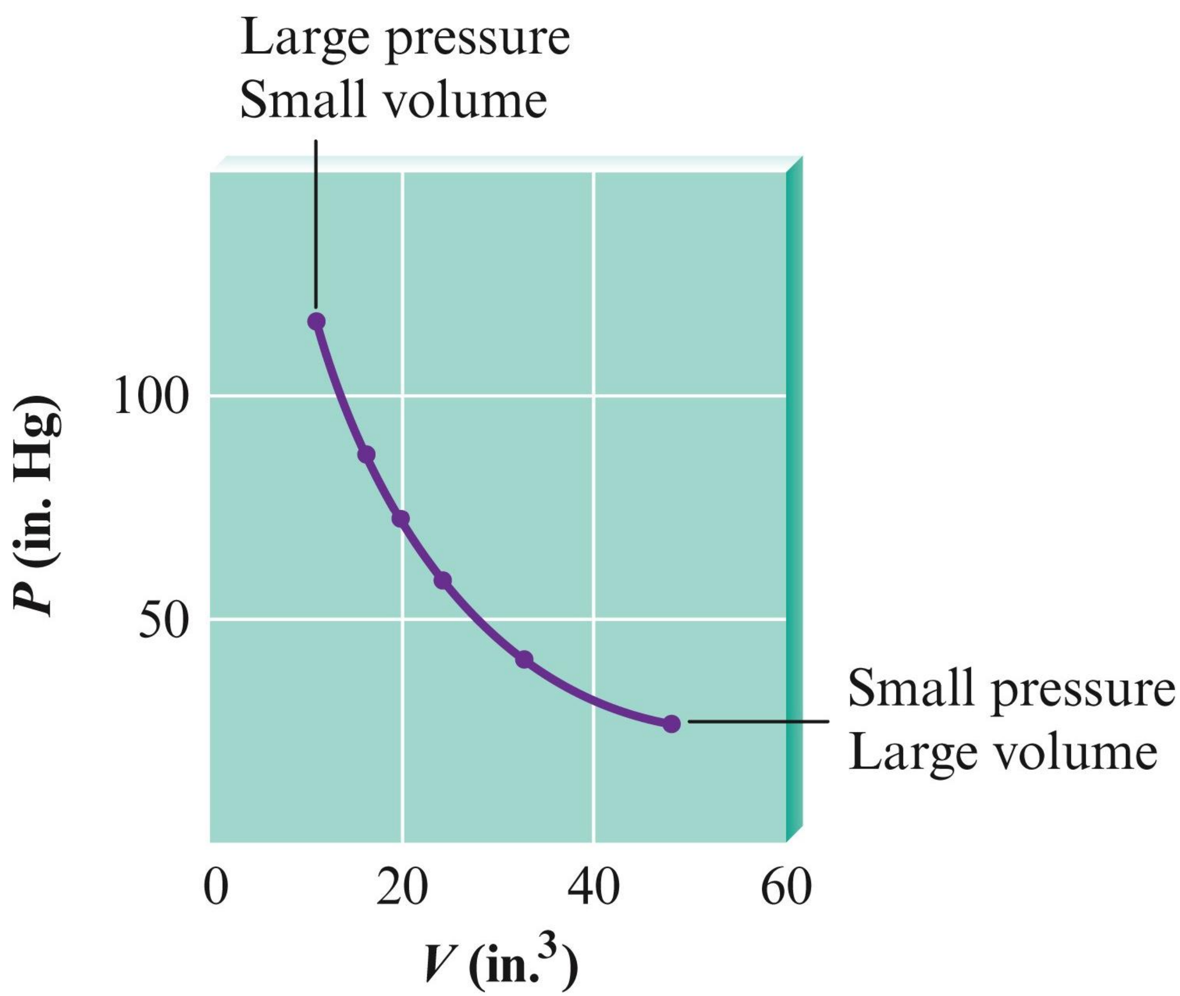
Table 13.1 ▸ A Sample of Boyle's Observations (moles of gas and temperature both constant)

			Pressure × Volume (in. Hg) × (in.^{3})	
Experiment	Pressure (in. Hg)	Volume (in.^{3})	Actual	Rounded*
1	29.1	48.0	1396.8	1.40×10^3
2	35.3	40.0	1412.0	1.41×10^3
3	44.2	32.0	1414.4	1.41×10^3
4	58.2	24.0	1396.8	1.40×10^3
5	70.7	20.0	1414.0	1.41×10^3
6	87.2	16.0	1395.2	1.40×10^3
7	117.5	12.0	1410.0	1.41×10^3

*Three significant figures are allowed in the product because both of the numbers that are multiplied together have three significant figures.

Pressure and Volume: Boyle's Law

Graphing Boyle's Results

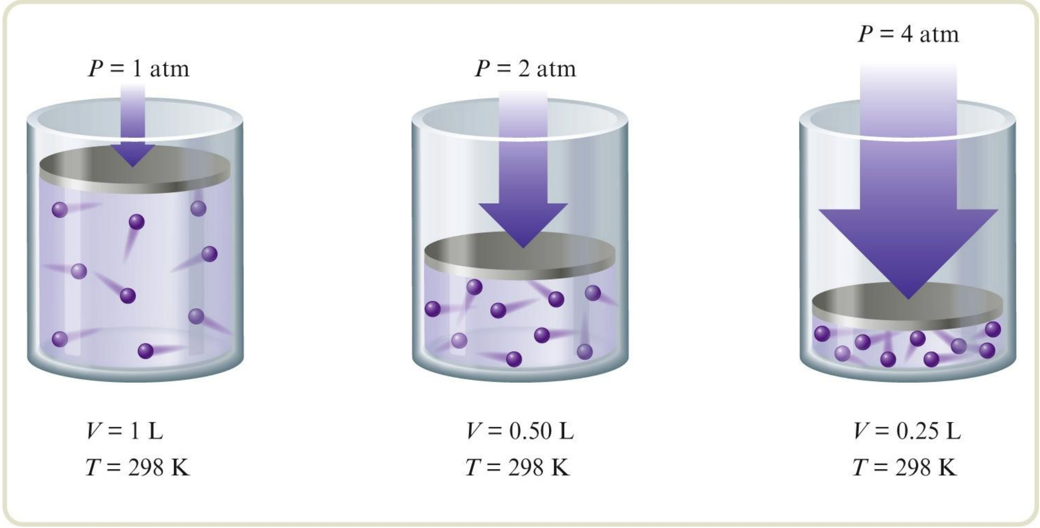


Pressure and Volume: Boyle's Law

Boyle's Law

- Pressure and volume are inversely related (constant *T*, temperature, and *n*, # of moles of gas).
- $PV = k$ (k is a constant for a given sample of air at a specific temperature)

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



Pressure and Volume: Boyle's Law

Exercise

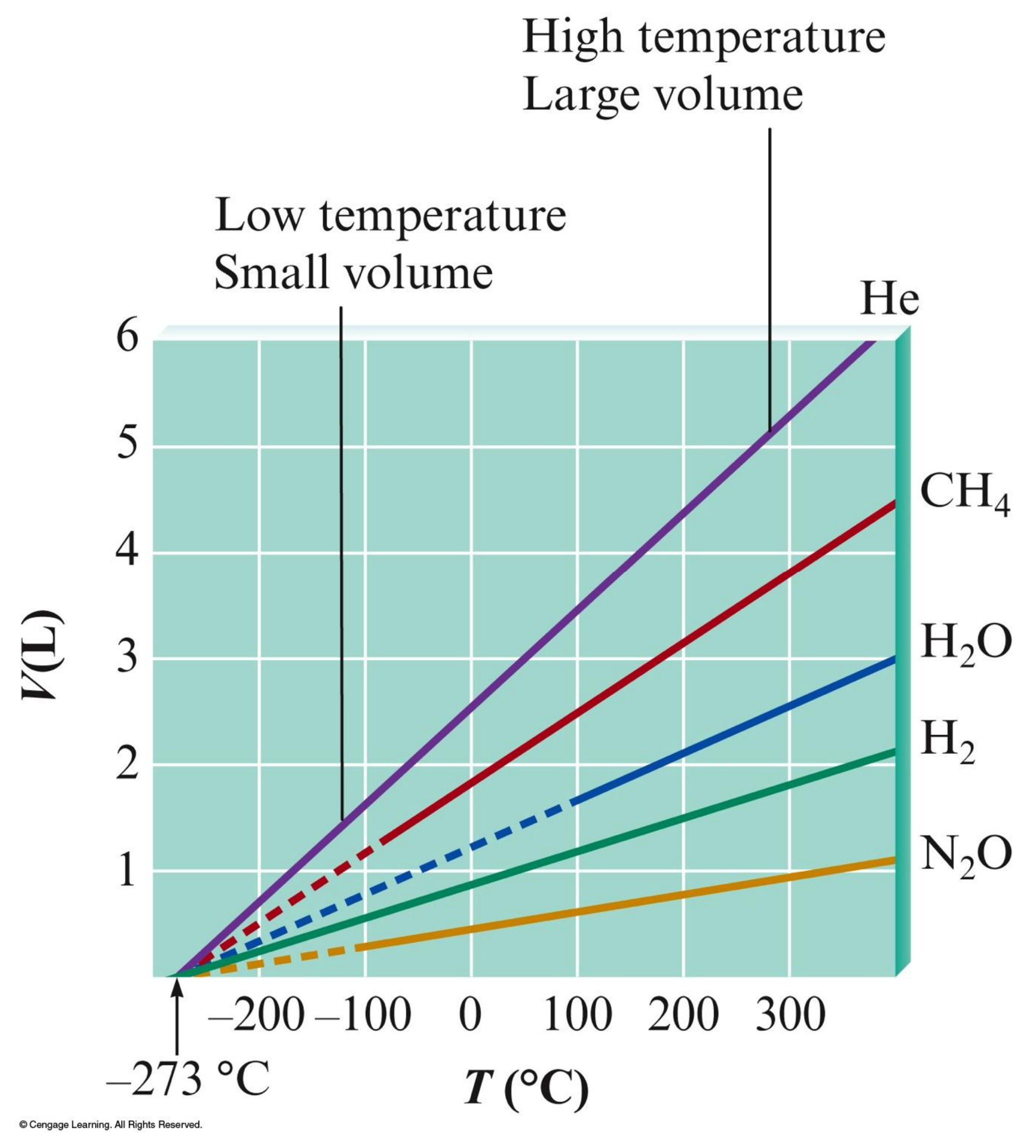
A sample of helium gas occupies 12.4 L at 23°C and 0.956 atm. What volume will it occupy at 1.20 atm assuming that the temperature stays constant?

9.88 L

$$P_1V_1 = P_2V_2$$
$$(0.956 \text{ atm})(12.4 \text{ L}) = (1.20 \text{ atm})(V_2)$$
$$V_2 = 9.88 \text{ L}$$

Volume and Temperature: Charles's Law

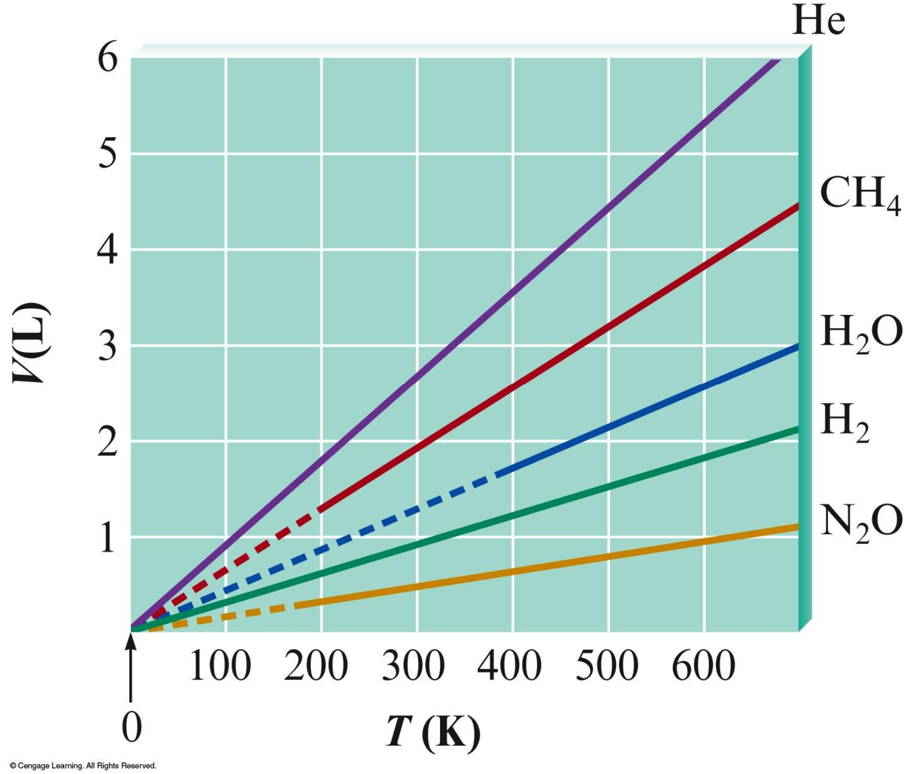
Graphing Data for Several Gases



Volume and Temperature: Charles's Law

Graphing Data for Several Gases

- It is easier to write an equation for the relationship if the lines intersect the origin of the graph.
  - Use absolute zero for the temperature.



Volume and Temperature: Charles's Law

Charles's Law

- Volume and Temperature (in Kelvin) are directly related (constant *P* and *n*).
- $V = bT$ (*b* is a proportionality constant)
- K = °C + 273
- 0 K is called absolute zero.

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

Volume and Temperature: Charles's Law

Exercise

Suppose a balloon containing 1.30 L of air at 24.7°C is placed into a beaker containing liquid nitrogen at –78.5°C. What will the volume of the sample of air become (at constant pressure)?

0.849 L

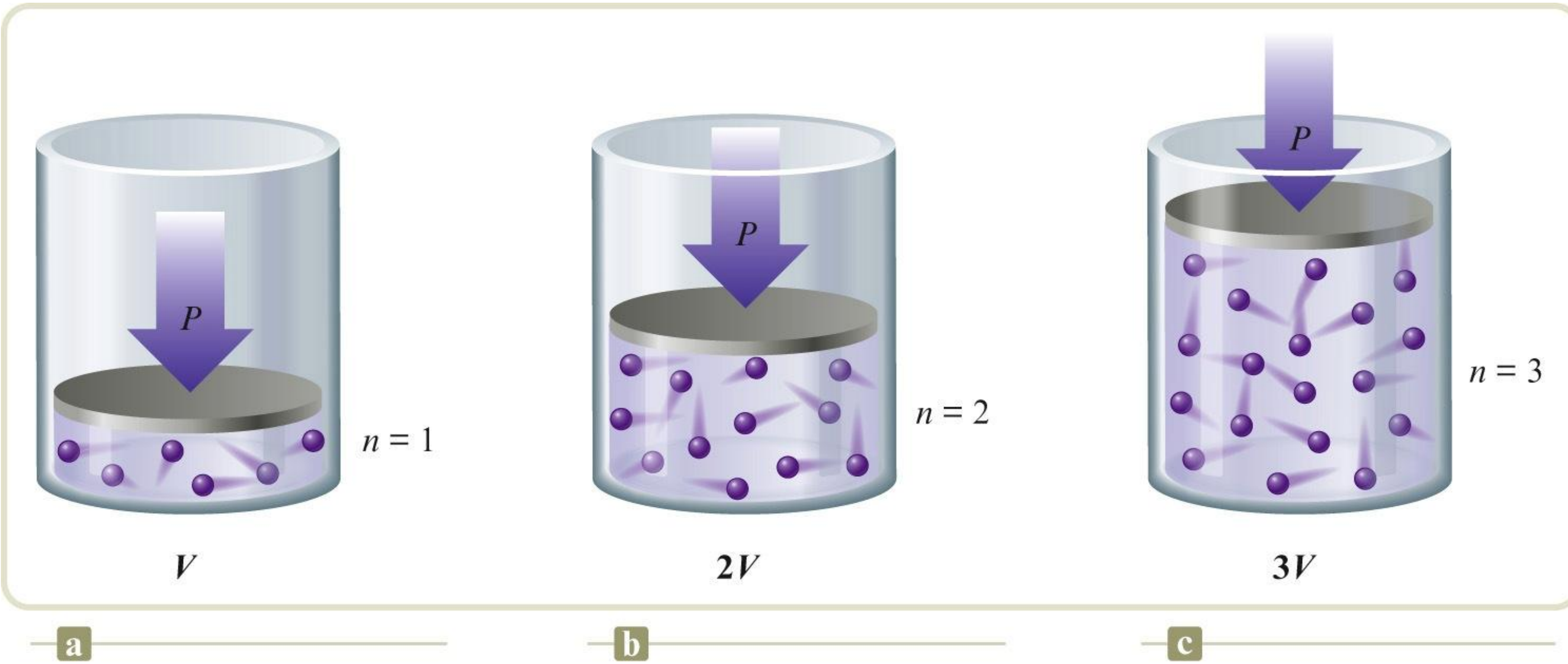
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{(1.30\text{ L})}{(24.7 + 273\text{ K})} = \frac{(V_2)}{(-78.5 + 273\text{ K})}$$

$$V_2 = 0.849\text{ L}$$

Volume and Moles: Avogadro's Law

The Relationship Between Volume and Moles



Volume and Moles: Avogadro's Law

Avogadro's Law

- Volume and number of moles are directly related (constant *T* and *P*).
- $V = an$ (*a* is a proportionality constant)

$$\frac{n_1}{V_1} = \frac{n_2}{V_2}$$

Volume and Moles: Avogadro's Law

Exercise

If 2.45 mol of argon gas occupies a volume of 89.0 L, what volume will 2.10 mol of argon occupy under the same conditions of temperature and pressure?

76.3 L

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

$$\frac{89.0\text{ L}}{2.45\text{ mol}} = \frac{V_2}{2.10\text{ mol}}$$

$$V_2 = 76.3\text{ L}$$

The Ideal Gas Law

- We can bring all of these laws together into one comprehensive law:
  - $V = bT$ (constant P and n)
  - $V = an$ (constant T and P)
  - $V = \frac{k}{P}$ (constant T and n)

$$PV = nRT$$

(where R = 0.08206 L·atm/mol·K, the universal gas constant)

Exercise

An automobile tire at 23° C with an internal volume of 25.0 L is filled with air to a total pressure of 3.18 atm. Determine the number of moles of air in the tire.

3.27 mol

$$n = \frac{PV}{RT} = \frac{(3.18 \text{ atm})(25.0 \text{ L})}{(0.08206 \frac{\text{L atm}}{\text{mol K}})(23 + 273 \text{ K})} = 3.27 \text{ mol}$$

Exercise

What is the pressure in a 304.0 L tank that contains 5.670 kg of helium at 25° C?

114 atm

$$P = \frac{nRT}{V} = \frac{\left(5.670 \text{ kg He} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mol He}}{4.003 \text{ g He}}\right)\left(0.08206 \frac{\text{L atm}}{\text{mol K}}\right)(25 + 273 \text{ K})}{(304.0 \text{ L})} = 114 \text{ atm}$$

Exercise

At what temperature (in °C) does 121 mL of CO_2 at 27°C and 1.05 atm occupy a volume of 293 mL at a pressure of 1.40 atm?

696°C

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \frac{(1.05\text{ atm})(121\text{ mL})}{(27 + 273\text{ K})} = \frac{(1.40\text{ atm})(293\text{ mL})}{T_2}$$

$$T_2 = 969\text{ K} - 273 = 696^\circ\text{C}$$

Dalton's Law of Partial Pressures

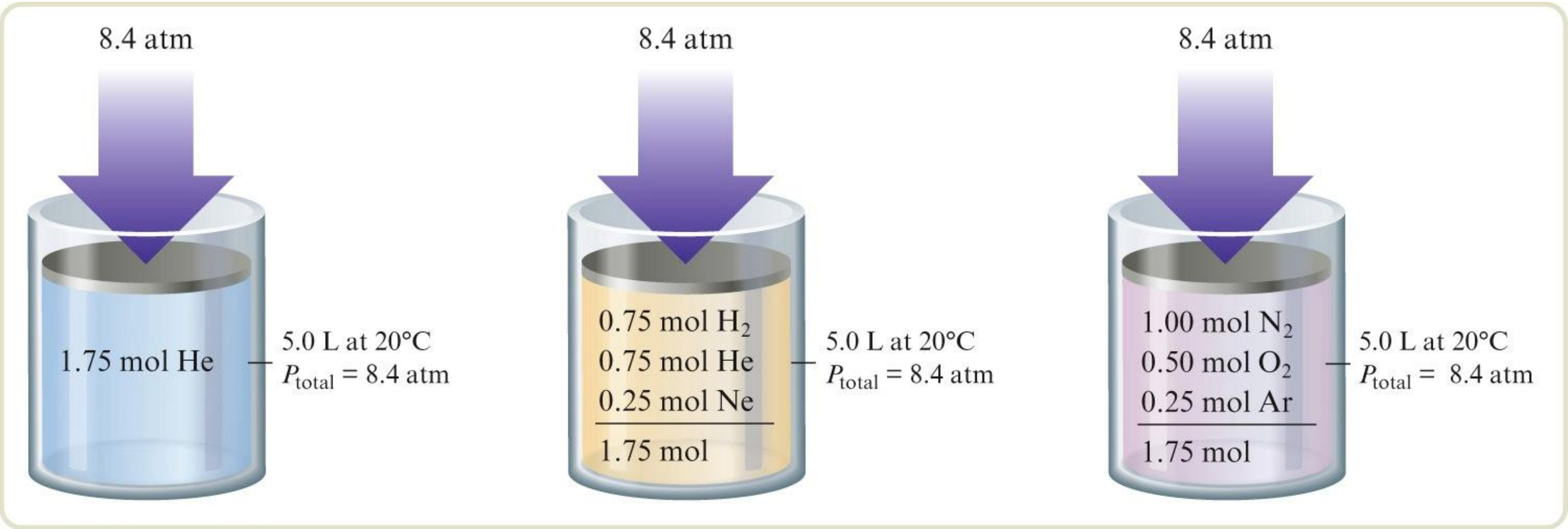
- For a mixture of gases in a container,

$$P_{Total} = P_1 + P_2 + P_3 + \ldots$$

- The total pressure exerted is the sum of the pressures that each gas would exert if it were alone.

Dalton's Law of Partial Pressures

- The pressure of the gas is affected by the number of moles of particles present.
- The pressure is independent of the nature of the particles.



Dalton's Law of Partial Pressures

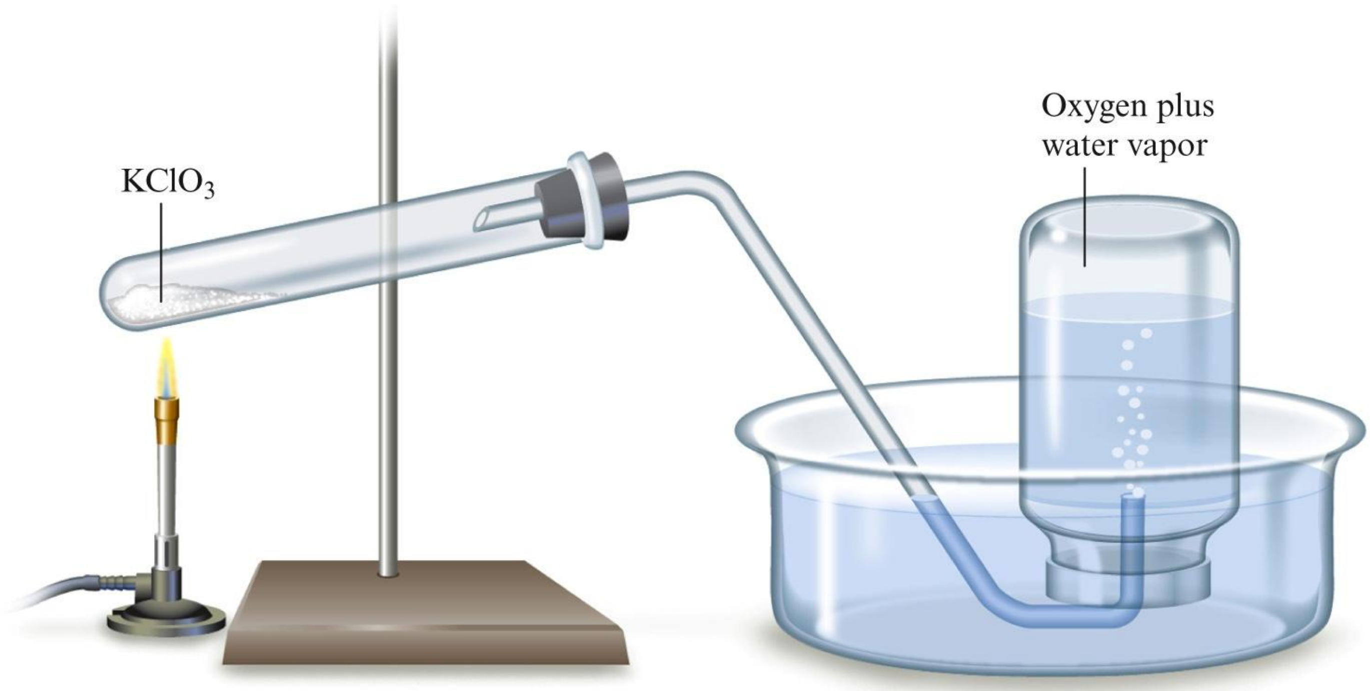
Two Crucial Things We Learn From This Are:

- The volume of the individual particles is not very important.
- The forces among the particles must not be very important.

Dalton's Law of Partial Pressures

Collecting a Gas Over Water

- Total pressure is the pressure of the gas + the vapor pressure of the water.



Dalton's Law of Partial Pressures

Collecting a Gas Over Water

- How can we find the pressure of the gas collected alone?

Table 13.2 ▸ The Vapor Pressure of Water as a Function of Temperature

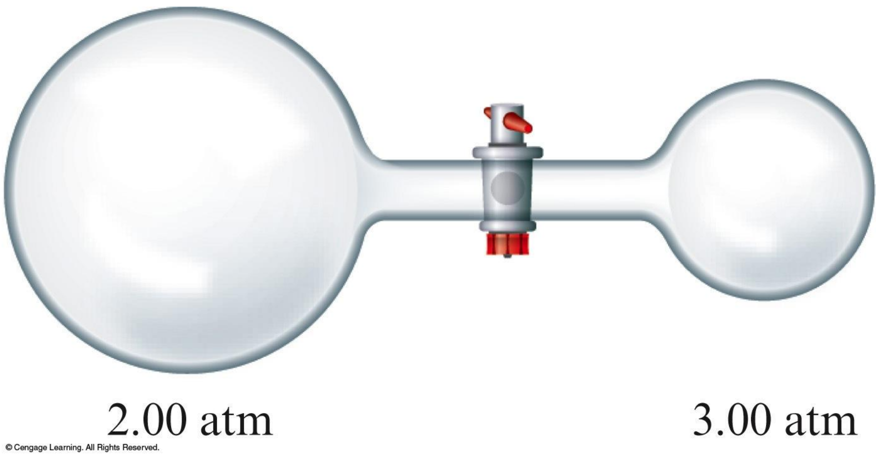
T (°C)	*P* (torr)
0.0	4.579
10.0	9.209
20.0	17.535
25.0	23.756
30.0	31.824
40.0	55.324
60.0	149.4
70.0	233.7
90.0	525.8

Dalton’s Law of Partial Pressures

Exercise

Consider the following apparatus containing helium in both sides at 45° C. Initially the valve is closed.

- After the valve is opened, what is the pressure of the helium gas?



P = 2.25 atm

Dalton's Law of Partial Pressures

Exercise

27.4 L of oxygen gas at 25.0° C and 1.30 atm, and 8.50 L of helium gas at 25.0° C and 2.00 atm were pumped into a tank with a volume of 5.81 L at 25° C.

- Calculate the new partial pressure of oxygen.

  6.13 atm

- Calculate the new partial pressure of helium.

  2.93 atm

- Calculate the new total pressure of both gases.

  9.06 atm

Laws and Models: A Review

Scientific Method

- A law is a generalization of observed behavior.
- Laws are useful – We can predict behavior of similar systems.

Laws and Models: A Review

- A model can never be proved absolutely true.
- A model is an approximation and is destined to be modified.

The Kinetic Molecular Theory of Gases

- So far we have considered "what happens," but not "why."
- In science, "what" always comes before "why."

The Kinetic Molecular Theory of Gases

Postulates of the Kinetic Molecular Theory

1. Gases consist of tiny particles (atoms or molecules).

The Kinetic Molecular Theory of Gases

Postulates of the Kinetic Molecular Theory

2. The particles are so small, compared with the distances between them that the volume (size) of the individual particles can be assumed to be negligible (zero).

The Kinetic Molecular Theory of Gases

Postulates of the Kinetic Molecular Theory

3. The particles are in constant random motion, colliding with the walls of the container. These collisions with the walls cause the pressure exerted by the gas.

The Kinetic Molecular Theory of Gases

Postulates of the Kinetic Molecular Theory

4. The particles are assumed not to attract or to repel each other.

The Kinetic Molecular Theory of Gases

Postulates of the Kinetic Molecular Theory

5. The average kinetic energy of the gas particles is directly proportional to the Kelvin temperature of the gas.

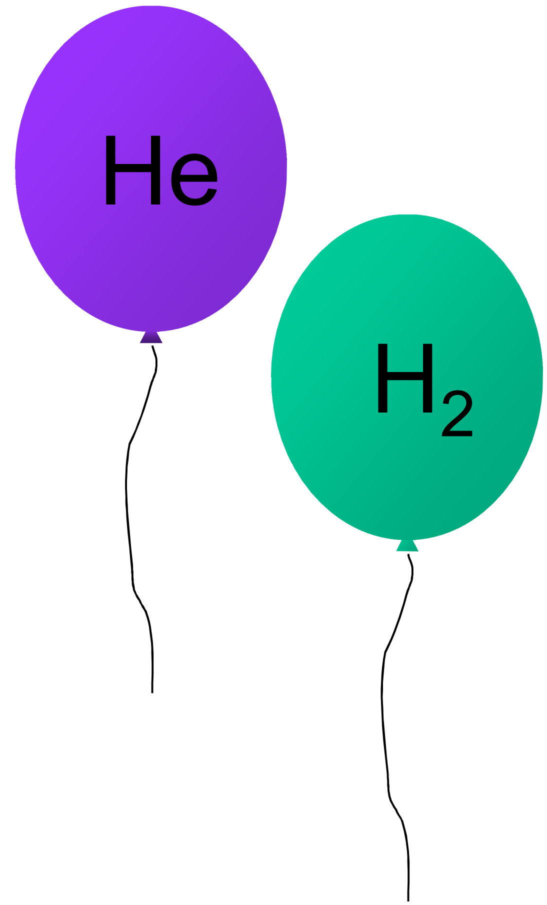
The Implications of the Kinetic Molecular Theory

- Meaning of temperature
  - Kelvin temperature is directly proportional to the average kinetic energy of the gas particles.
- Relationship between Pressure and Temperature
  - Gas pressure increases as the temperature increases because the particles speed up.
- Relationship between Volume and Temperature
  - Volume of a gas increases with temperature because the particles speed up.

The Implications of the Kinetic Molecular Theory

Concept Check

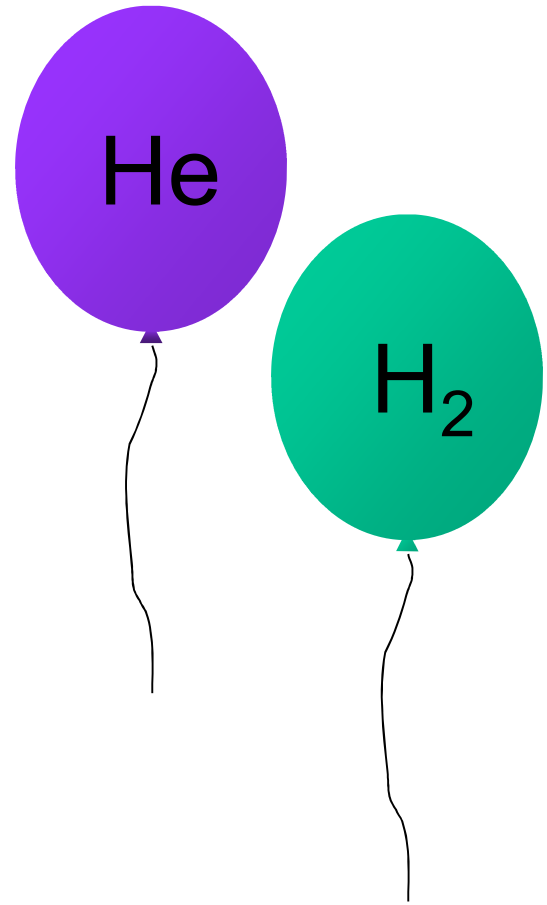
You are holding two balloons of the same volume. One contains helium, and one contains hydrogen. Complete each of the following statements with "different" or "the same" and be prepared to justify your answer.



The Implications of the Kinetic Molecular Theory

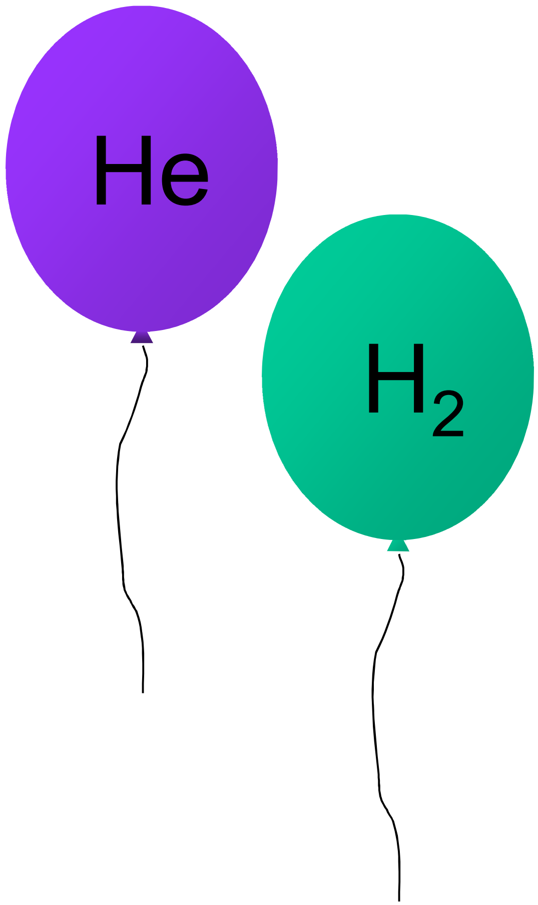
Concept Check

- Complete the following statement with “different” or “the same” and be prepared to justify your answer.
- The pressures of the gas in the two balloons are ___the same___.



Concept Check

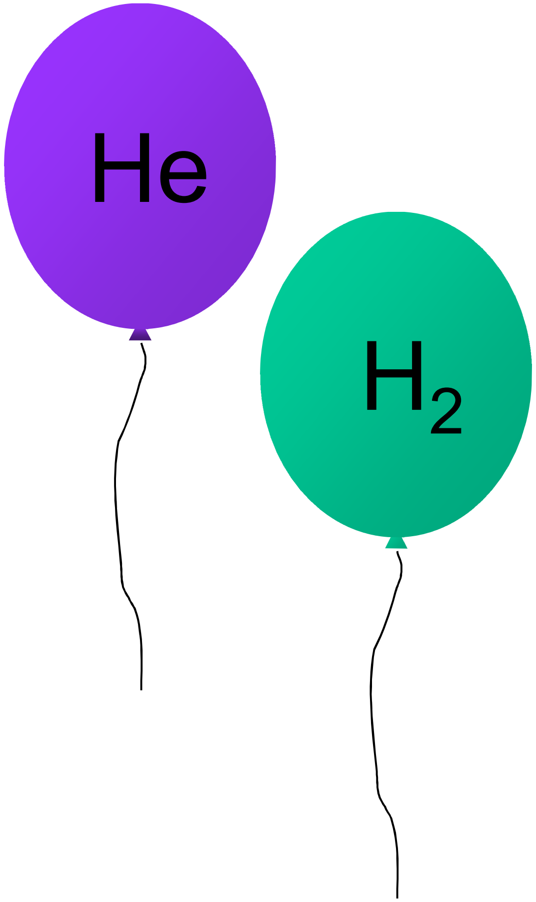
- Complete the following statement with “different” or “the same” and be prepared to justify your answer.
- The temperatures of the gas in the two balloons are __the same__.



The Implications of the Kinetic Molecular Theory

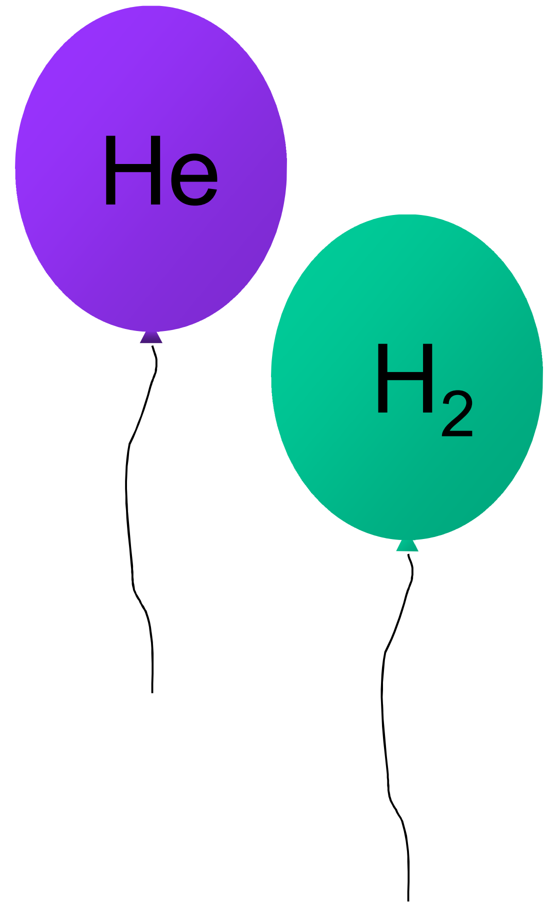
Concept Check

- Complete the following statement with "different" or "the same" and be prepared to justify your answer.
- The numbers of moles of the gas in the two balloons are __the same__.



Concept Check

- Complete the following statement with “different” or “the same” and be prepared to justify your answer.
- The densities of the gas in the two balloons are __different__.

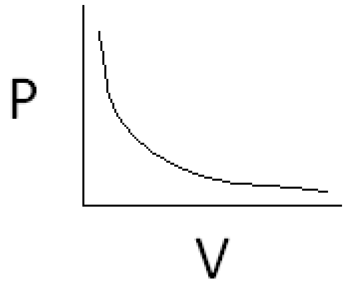


The Implications of the Kinetic Molecular Theory

Concept Check

Sketch a graph of:

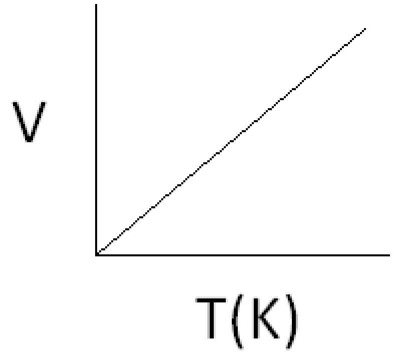
I. Pressure versus volume at constant temperature and moles.



Concept Check

Sketch a graph of:

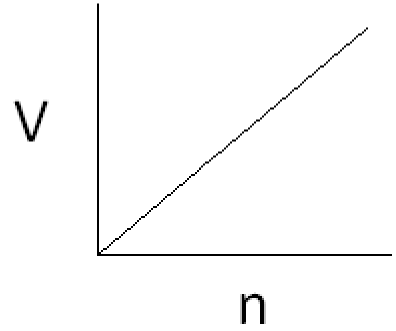
II. Volume vs. temperature (K) at constant pressure and moles.



Concept Check

Sketch a graph of:

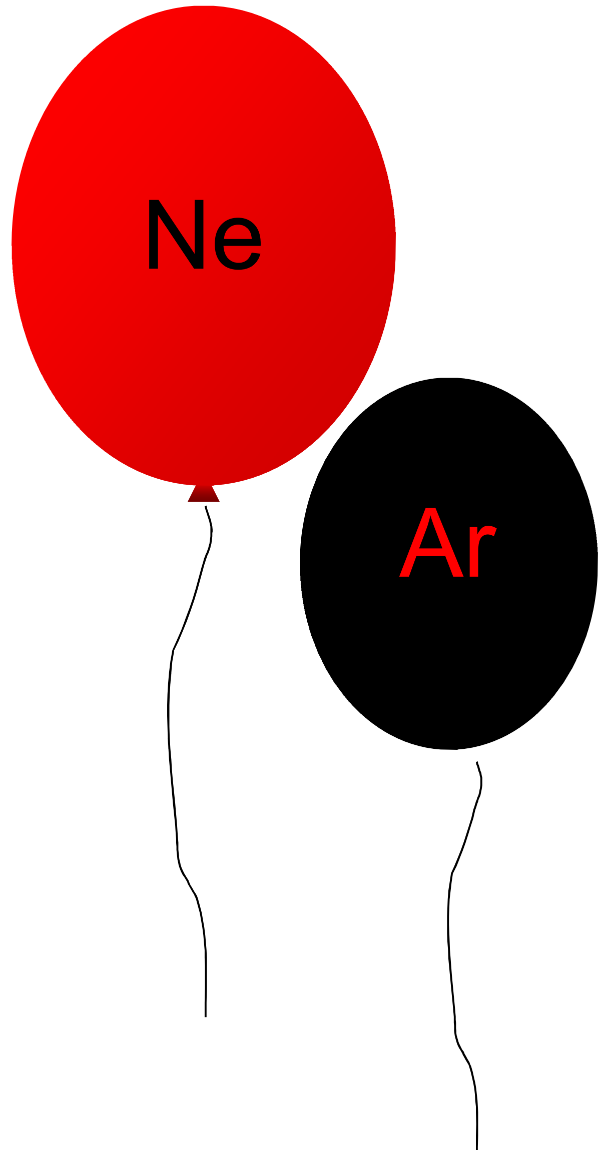
III. Volume vs. moles at constant temperature and pressure.



The Implications of the Kinetic Molecular Theory

Concept Check

$$V_{Ne} = 2V_{Ar}$$

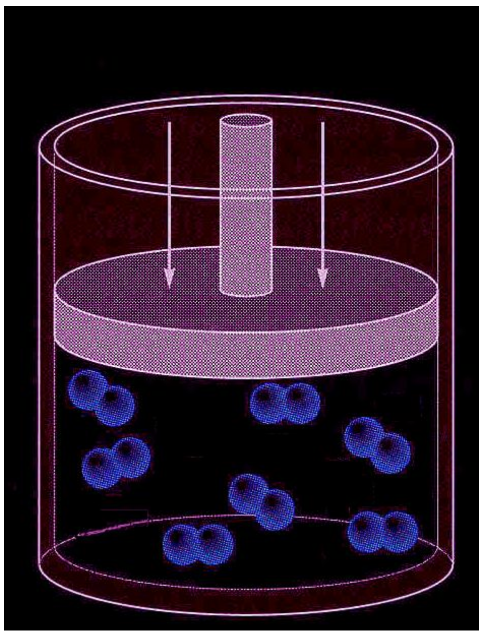


Which of the following best represents the mass ratio of Ne:Ar in the balloons?

a) 1:1
b) 1:2
c) 2:1
d) 1:3
e) 3:1

The Implications of the Kinetic Molecular Theory

Concept Check



- You have a sample of nitrogen gas (N_2) in a container fitted with a piston that maintains a pressure of 6.00 atm. Initially, the gas is at 45°C in a volume of 6.00 L.
- You then cool the gas sample.

Concept Check

Which best explains the final result that occurs once the gas sample has cooled?

a) The pressure of the gas increases.
b) The volume of the gas increases.
c) The pressure of the gas decreases.
d) The volume of the gas decreases.
e) Both volume and pressure change.

Concept Check

The gas sample is then cooled to a temperature of 15°C. Solve for the new condition. (Hint: A moveable piston keeps the pressure constant overall, so what condition will change?)

5.43 L

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

$$\frac{6.00\text{ L}}{(45 + 273)} = \frac{V_2}{(15 + 273)}$$

$$V_2 = 5.43\text{ L}$$

Gas Stoichiometry

Molar Volume of an Ideal Gas

- For 1 mole of an ideal gas at 0° C and 1 atm, the volume of the gas is 22.42 L.

$$V = \frac{nRT}{P} = \frac{(1.000\ \cancel{\text{mol}})(0.08206\ \text{L}\cdot\cancel{\text{atm}}/\cancel{\text{K}}\cdot\cancel{\text{mol}})(273.2\ \cancel{\text{K}})}{1.000\ \cancel{\text{atm}}} = 22.42\ \text{L}$$

- STP = standard temperature and pressure
  - 0° C and 1 atm
  - Therefore, the molar volume is 22.42 L at STP.

Gas Stoichiometry

Exercise

A sample of oxygen gas has a volume of 2.50 L at STP. How many grams of O_2 are present?

3.57 g

$$2.50 \text{ L } O_2 \times \frac{1 \text{ mol } O_2}{22.4 \text{ L } O_2} \times \frac{32.00 \text{ g } O_2}{\text{mol } O_2} = 3.57 \text{ g } O_2$$

Gas Stoichiometry

Exercise

Consider the following reaction:

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

If 15.00 g of solid zinc reacts with 100.0 mL of 4.00 *M* hydrochloric acid, what volume of hydrogen gas is produced at 25° C and 1.00 atm?

a) 0.200 L
b) 4.89 L
c) 5.61 L
d) 9.78 L