POGIL: The ABCs of Gases

Learning Objectives:
- Investigate the relationship between the volume and the pressure of a given sample of a gas at a set temperature.
- Investigate the effect of a temperature change on the volume of a given sample of gas at a constant pressure.
- Investigate the relationship between the quantity of a gas and the given volume at set T and P.
- Apply gas laws to problems involving the temperature, volume, and pressure of a contained gas sample.
- State Avogadro’s hypothesis and use it to answer conceptual problems involving gases.
- Identify, define, and explain: Kelvin, absolute temperature scale, direct relationship, and inverse relationship.


Text Vocabulary:
- Boyle’s law (p142) The volume of a fixed amount of gas is inversely proportional to the gas pressure, at constant temperature.
- Absolute temperature scale (p145) A temperature scale on which absolute zero (0 K) is the lowest temperature, also called the Kelvin temperature scale.
- Absolute zero (p145) Theoretically the lowest possible temperature.
- Kelvin temperature scale (p145) See absolute temperature scale.
- Charles’s law (p146) The volume of a fixed amount of gas is directly proportional to the absolute temperature of the gas when the pressure is held constant.
- Avogadro’s law (p147) At constant temperature and pressure, the volume of a gas is directly proportional to the number of moles of gas present.

Information: Ideal Gases

An ideal gas is a hypothetical gas consisting of identical particles with zero volume and with no intermolecular forces. Additionally, the constituent atoms or molecules undergo perfectly elastic collisions with the walls of the container. An ideal gas can consist of molecules (e.g., carbon dioxide molecules, CO₂) or atoms (e.g., neon atoms, Ne). Real gases do not exhibit these exact properties, although many gases behave as ideal gases at high temperatures and low pressure. The four properties of an ideal gas are:
- Point masses (the volume of a gas particle essentially zero—if infinitely compressed, all the molecules of an ideal gas would occupy a single point of insignificant volume).
- Random motion (constant random motion of gas particles).
- Intermolecular forces (there are NO intermolecular forces).
- Elastic collisions (all collisions are totally elastic).

Model I: Charles’ Law

Charles’ Law is the relationship between the volume and temperature of an ideal gas. Condition: Charles’ Law requires that the pressure and the number of moles of the gas are constant.

Balloon filled with gas at room temperature. Place balloon in refrigerator. Balloon filled with the same amount of gas in a refrigerator.

Give complete answers to all questions. Provide explanations and show work, where necessary.
Key Questions

1. When the pressure and the number of moles of a gas are constant, is the relationship between volume and temperature a direct relationship or an inverse relationship? Explain/justify.

2. The graph to the right depicts the volumes of three different ideally-behaving gases (A, B, and C) as a function of their temperatures. Use a straightedge to determine the temperature at which each gas would have a volume of 0 L. Check this temperature with your teacher.

3. Gas A, gas B, and gas C all share a common point (a set of x,y coordinates) in the plot in question 2. What is this point and what is the significance of this point?

Model II: Absolute Temperature

Whenever the temperature of a gas is needed, it ought to be expressed on the absolute temperature scale. The absolute temperature is defined so that the gas has a volume of zero when the absolute temperature is 0 K. (The unit of temperature in the absolute scale is called Kelvin, K.) You convert between the temperature in °C and K using the formula: \( T_K = T_C + 273 \). Really it is 273.15, but we will use 273 in our calculations with 3 significant figures.

4. A mathematical way to represent Charles’ Law is \( \frac{V_1}{T_1} = \frac{V_2}{T_2} \) where the subscript 1 identifies the initial volume and temperature of the gas and the subscript 2 identifies the final volume and temperature of the gas. The temperature needs to be reported in the absolute scale (Kelvin).

   (a) On a mathematical basis, explain why the temperatures in the above equation must be expressed in Kelvin and not Celsius. (Hint - What temperatures would make the equation invalid and how do these temperatures differ in Celsius and Kelvin?)

   (b) Under what conditions may the above equation be used? (Hint - what may change and what may not?)

5. **Exercise:** An ideally-behaving gas has a volume of 18.25 L at a temperature of 15.9°C. The temperature of the gas is raised to 40.7°C while the number of moles and the pressure of the gas are kept constant. What is the new volume of the gas (in L)? Show all work using units and sig figs.
**Model III: Boyle’s Law**

Recall that \( P = \frac{F}{A} \)

where \( P \) = pressure (in kPa, atm, torr, etc)
\( F \) = force (in N, Newton)
\( A \) = area over which the force is applied (in m\(^2\)).

Common units of pressure:
- 1 atm = 760 mmHg = 760 torr = 101.325 kPa = 14.70 lb/in\(^2\) (psi)

**Boyle’s Law** is the relationship between the volume and pressure of an ideal gas. Condition: Boyle’s Law requires that the temperature and the number of moles of the gas are constant.

1.00 mol of an ideal gas in a cylinder with one movable wall (piston) at a temperature of 25.0\(^\circ\)C under a pressure of 1.00 atm possesses a volume of 24.446L.

1.00 mol of an ideal gas in the same cylinder at the same temperature possesses a volume of 12.233 L.

6. Does Boyle’s Law describe a direct relationship or an inverse between the pressure and the volume of an ideal gas? Explain/justify.

7. A mathematical way to represent Boyle’s Law is \( P_1V_1 = P_2V_2 \) where the subscript 1 identifies the initial volume and pressure of the gas and the subscript 2 identifies the final volume and pressure of the gas. When would it be inappropriate to use the above equation to relate an ideal gas’s pressure to its volume? (Hint - what may change and what may not?)

8. **Exercise:** An ideal gas has a volume of 10.8L at a temperature of 25.0\(^\circ\)C and a pressure of 1.60 atm. The pressure of the gas is reduced to 370.0 mmHg, but the temperature and number of moles of the gas are kept constant. What is the new volume of the gas, in L? Show all work using units and sig figs.
Model IV: Avogadro’s Hypothesis

**Avogadro’s Hypothesis** is the relationship between the volume and quantity of an ideal gas. **Condition:** Avogadro’s Hypothesis requires that the pressure and the temperature of the gas are constant.

9. What variables are changing in the representation of Avogadro’s hypothesis and what variables remain constant?

10. Does Avogadro’s Hypothesis describe a direct relationship or an inverse between the quantity and the volume of an ideal gas? Explain/justify.

A mathematical way to represent Avogadro’s law is

\[ \frac{V_1}{n_1} = \frac{V_2}{n_2} \]

where the subscript 1 identifies the initial volume and quantity (in moles) of the gas and the subscript 2 identifies the final volume and quantity (in moles) of the gas.

11. Exercise: A 4.00g sample of helium has a volume of 24.4L at a temperature of 25.0°C and a pressure of 1.00 atm. The volume of the helium is reduced to 10.4L, but the temperature and pressure of the gas are kept constant. What is the new quantity of the gas, in moles? Show all work using units and sig figs.

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Model V: STP and the Combined Gas Law

**STP** (Standard Temperature and Pressure) = STP

STP conditions: 0°C (273.15K) & 1 atm

At STP, 1 mole of an ideal gas has a volume of 22.4L. *(Remember this relationship from Unit 06: Chemical Quantities.)*
Boyle’s Law, Charles’ Law, and Avogadro’s Hypothesis are used when 2 variables are held constant. One of the remaining two variables is changed and the final variable responds. Frequently, a sample of a gas with a fixed mass has more than one variable that gets changed. In this case, it is appropriate to use the combined gas law.

\[
\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}
\]

12. Use choices (A) through (F) to describe the relationship between the variables in each law listed.

__________ Charles’ Law  
(A) direct relationship between \( V \) and \( P \)  
(B) direct relationship between \( V \) and \( T \)

__________ Boyle’s Law  
(C) direct relationship between \( V \) and \( n \)  
(D) inverse relationship between \( V \) and \( P \)

__________ Avogadro’s Hypothesis  
(E) inverse relationship between \( V \) and \( T \)  
(F) inverse relationship between \( V \) and \( n \)

13. At constant temperature, the volume of a gas expands from 4.25L to 8.75L. If the initial pressure was 120. kPa, what is the final pressure?

14. The volume of a gas was originally 2.50L; its pressure was 104kPa and its temperature was 270.K. The volume of the gas expanded to 5.30L and its pressure decreased to 95.0kPa. What is the temperature of the gas?

\[
P_1 V_1 = P_2 V_2
\]

15. What is the effect of the following on the volume of 1.00 mole of an ideal gas? The pressure changes from 760. torr to 202 kPa and the temperature changes from 37.0°C to 155K, while the moles of gas remain constant. Does the volume of the gas change? If it does, by what factor does the volume of the gas increase or decrease?