States of Matter
Lesson 4.4

CHEMISTRY 2 HONORS

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The Gas Laws

The Pressure-Volume Relationship: Boyle’s Law

- Weather balloons are used as a practical consequence to the relationship between pressure and volume of a gas.
- As the weather balloon ascends, the volume increases.
- As the weather balloon gets further from the earth’s surface, the atmospheric pressure decreases.
- Boyle’s Law: the volume of a fixed quantity of gas is inversely proportional to its pressure (assuming all other variables are unchanged).
- Boyle used a manometer to carry out the experiment.

The Pressure-Volume Relationship: Boyle's Law

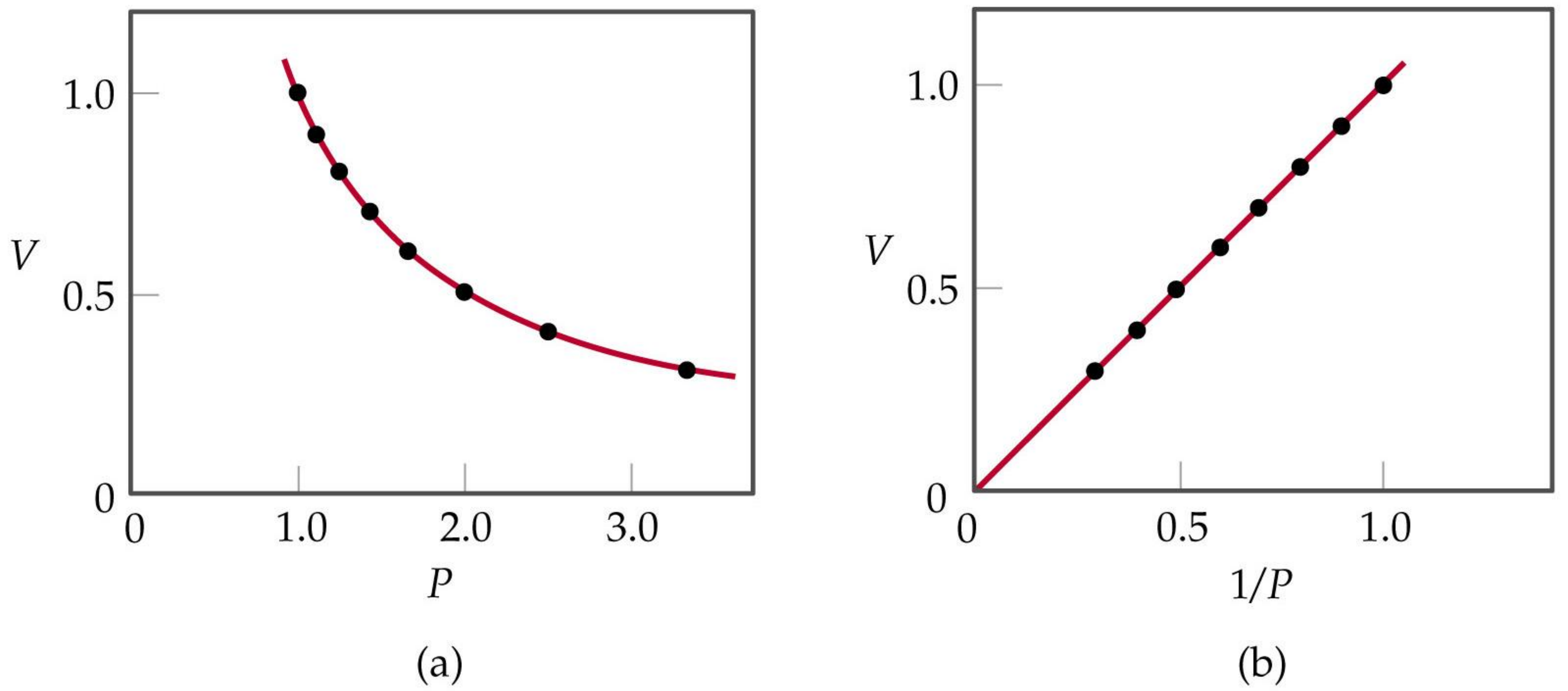
- Mathematically:

$$V = \text{constant} \times \frac{1}{P} \qquad PV = \text{constant}$$

- A plot of V versus P is a hyperbola.
- Similarly, a plot of V versus 1/P must be a straight line passing through the origin.

$$P_1V_1 = P_2V_2$$

The Pressure-Volume Relationship: Boyle's Law



Examples

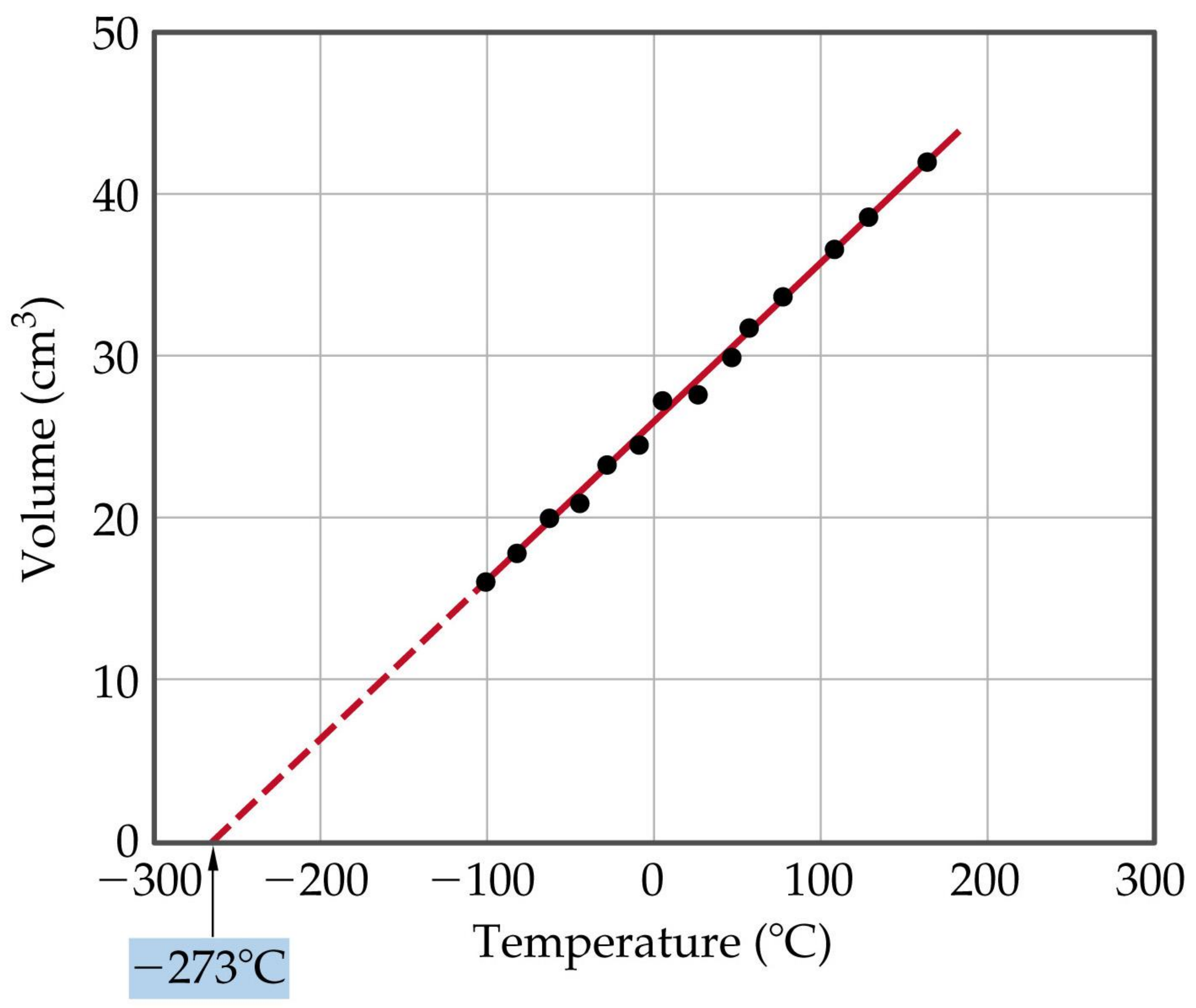
1. A gas that occupies 2.84 L has a pressure of 88.6 kPa. What would be the pressure of the gas sample if it only occupied 1.66 L (assuming the same temperature)?

2. A 10.0-L sample of argon gas has a pressure of 0.885 atm. At what volume would the sample have a pressure of 6.72 atm?

The Temperature-Volume Relationship: Charles's Law

- We know that hot air balloons expand when they are heated.
- Charles's Law: the volume of a fixed quantity of gas at constant pressure increases as the temperature increases (assuming all other factors are constant).
- Mathematically: $V = \text{constant} \times T$ $\quad \frac{V}{T} = \text{constant}$

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


50
40
30
20
10
0
Volume (cm^3)
−300
−200
−100
0
100
200
300
Temperature (°C)
−273°C

- A plot of V versus T is a straight line.
- When T is measured in °C, the intercept on the temperature axis is -273.15°C.
- We define absolute zero, 0 K = -273.15°C.
- Note the value of the constant reflects the assumptions: amount of gas and pressure.

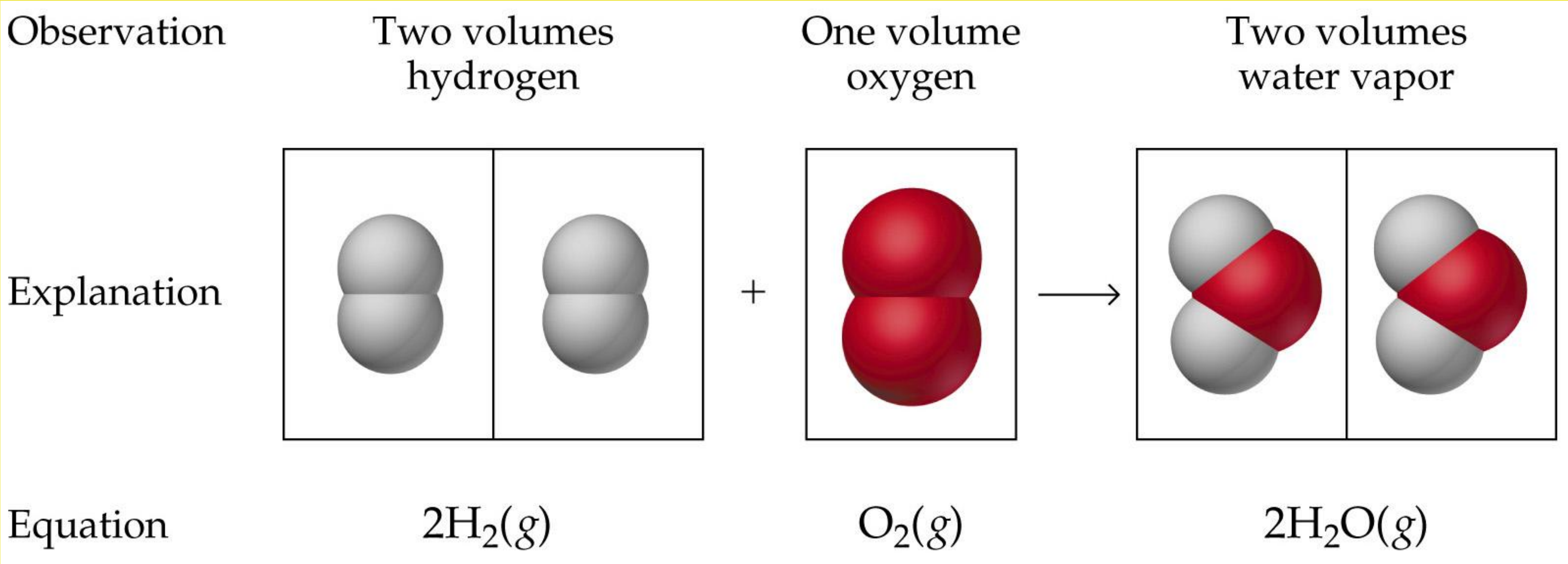
Examples

1. A gas sample occupies a volume of 1.89 L at 25 C. What would be the volume of the sample at 75°C?

2. A sample of carbon dioxide in a 5.00-L container has a temperature of 56.9°C. At what temperature will this sample of CO_2 occupy a volume of 3.00 L?

The Quantity-Volume Relationship: Avogadro's Law

- Gay-Lussac's Law of combining volumes: at a given temperature and pressure, the volumes of gases which react are ratios of small whole numbers.



- Avogadro’s Hypothesis: equal volumes of gas at the same temperature and pressure will contain the same number of molecules.
- Avogadro’s Law: the volume of gas at a given temperature and pressure is directly proportional to the number of moles of gas.

- Mathematically:

$$V = \text{constant} \times n \qquad \frac{n_1}{V_1} = \frac{n_2}{V_2}$$

- We can show that 22.4 L of any gas at 0°C contain 6.02×10^{23} gas molecules.

The Ideal Gas Equation

- Consider the three gas laws.
- Boyle's Law: $V \propto \frac{1}{P}$ (constant n, T)
- Charles's Law: $V \propto T$ (constant n, P)
- Avogadro's Law: $V \propto n$ (constant P, T)
- We can combine these into a general gas law:

$$V \propto \frac{nT}{P}$$

The Ideal Gas Equation

- If R is the constant of proportionality (called the **gas constant**), then

$$V = R\left(\frac{nT}{P}\right)$$

- The **ideal gas equation** is:

$$PV = nRT$$

- R = 0.08206 L·atm/mol·K = 8.314 J/mol·K

  = 62.4 L·mm Hg/mol·K = 8.314 L·kPa/mol·K

- We define STP (standard temperature and pressure) = 0°C, 273.15 K, 1 atm.
- Volume of 1 mol of gas at STP is:

$$PV = nRT$$

$$V = \frac{nRT}{P} = \frac{(1\,\text{mol})(0.08206\,\text{L}\cdot\text{atm/mol}\cdot\text{K})(273.15\,\text{K})}{1.000\,\text{atm}} = 22.41\,\text{L}$$

Examples

1. What is the volume of a 15.0-g sample of neon gas at 130.0 kPa and 39 C?

2. At what temperature will 2.85 moles of hydrogen gas occupy a volume of 0.58 L at 1.00 atm?

Relating the Ideal-Gas Equation and the Gas Laws

- If $PV = nRT$ and n and T are constant, then PV = constant and we have Boyle's law.
- Other laws can be generated similarly.
- In general, if we have a gas under two sets of conditions, then

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

Examples

1. A gas sample occupies a volume of 0.685 L at 38 C and 0.775 atm. What will be the temperature of the sample if it occupies 0.125 L at 1.25 atm?

2. A sample of nitrogen gas in a 2.00 L container has a pressure of 1800.6 mmHg at 25 C. What would be the pressure on the sample in a 1.00 L container at 125 C?