### Boyle’s Law

The volume of a gas is inversely proportional to its pressure.

### Charles’ Law

The volume of a gas is directly proportional to its Kelvin temperature.

### Avogadro’s Law

Equal volumes of gas at the same pressure and temperature contain equal numbers of molecules.

### Empirical Gas Laws

- **Boyle’s Law:**
  
  \[ V = \frac{1}{k_1} P \]

- **Charles’ Law:**
  
  \[ V = k_2 T \]

- **Avogadro’s Law:**
  
  Equal volumes of gas at the same pressure and temperature contain equal numbers of molecules.

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**Example 1:**

If a scuba diver fills her lungs to their full capacity of 5 litres when 10 m below the surface, what volume would her lungs acquire if she rose quickly to the surface? Assume the pressure at 10 m is twice standard atmospheric pressure. What one word of advice should the diver heed as she rises?

**Solution:**

Boyle’s Law: \[ V = \frac{P_1}{P_2} V_1 \]

Given: \( P_1 = 2 \text{ atm} \) at 10 m, \( P_2 = 1 \text{ atm} \) at the surface, \( V_1 = 5 \text{ L} \)

\[ V = \frac{2}{1} \times 5 = 10 \text{ L} \]

**Advice:** 

Be cautious of decompression sickness (The bends).

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**Example 2:**

A balloon at 27 °C has a volume of 3 L. What will be the volume of the balloon if the air inside is cooled to -173 °C?

**Solution:**

Charles’ Law: \[ V = k_2 T \]

Given: \( T_1 = 300 \text{ K} \) at 27 °C, \( T_2 = -146 \text{ K} \) at -173 °C

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

\[ V_2 = \frac{T_2}{T_1} V_1 = \frac{-146}{300} \times 3 = 1.44 \text{ L} \]

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**Example 3:**

A bike tyre is filled with air to a pressure of 300 kPa at 27 °C. After riding for several hours the temperature of the tyres increases to 47 °C. What will the pressure gauge read?

**Solution:**

Boyle’s Law: \[ \frac{P_1}{P_2} = \frac{V_1}{V_2} \]

Given: \( P_1 = 300 \text{ kPa} \) at 27 °C, \( T_1 = 300 \text{ K} \), \( T_2 = 320 \text{ K} \)

\[ \frac{P_2}{300} = \frac{300}{320} \]

\[ P_2 = \frac{300 	imes 320}{300} = 320 \text{ kPa} \]

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**Example 4:**

A balloon at 27 °C has a volume of 3 L. What will be the volume of the balloon if the air inside is cooled to -173 °C?

**Solution:**

Charles’ Law: \[ V = k_2 T \]

Given: \( T_1 = 300 \text{ K} \) at 27 °C, \( T_2 = -146 \text{ K} \) at -173 °C

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

\[ V_2 = \frac{T_2}{T_1} V_1 = \frac{-146}{300} \times 3 = 1.44 \text{ L} \]

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**Example 5:**

A bike tyre is filled with air to a pressure of 300 kPa at 27 °C. After riding for several hours the temperature of the tyres increases to 47 °C. What will the pressure gauge read?

**Solution:**

Boyle’s Law: \[ \frac{P_1}{P_2} = \frac{V_1}{V_2} \]

Given: \( P_1 = 300 \text{ kPa} \) at 27 °C, \( T_1 = 300 \text{ K} \), \( T_2 = 320 \text{ K} \)

\[ \frac{P_2}{300} = \frac{300}{320} \]

\[ P_2 = \frac{300 	imes 320}{300} = 320 \text{ kPa} \]
Ideal Gas Equation

\[ PV = nRT \]

- Pressure
- Volume
- Number of moles
- Gas constant

Universal gas constant \( R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1} \)

(R has different values with different, but equally valid, units – later)

Gas Behaviour at Standard Temperature and Pressure (STP)

Example

Volume of 1.00 g of CH\(_4\) at \( P = 120 \text{ kPa} \) and \( T = 30 \degree \text{C} \)?

\[ PV = nRT \]

Example cont’d

<table>
<thead>
<tr>
<th>( P )</th>
<th>( V )</th>
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PV = nRT from Kinetic Theory

- Pressure arises from the force experienced on vessel wall by gas molecules bouncing off it

\[ PV = nRT \]

Follow derivation not examinable:
- momentum of gas molecule = mass \( \times \) velocity = \( mv \)
- change in momentum from bouncing off wall: \( \Delta p = 2mv \)

Improved Derivation: Distribution Of Molecular Speeds

In actuality, not all molecules have same velocities

To learn: trends in this figure
- molecules have spread of velocities
- higher temperature = faster molecules