5.5 Charles's Law

- At constant pressure (*P*) the volume (*V*) of a fixed amount of gas is proportional to its absolute temperature (*T*)

$V = k'T$ $\quad$ **$k' \rightarrow$ constant (depends on P)**

$$\frac{V}{T} = k' \qquad T\uparrow \Leftrightarrow V\uparrow$$

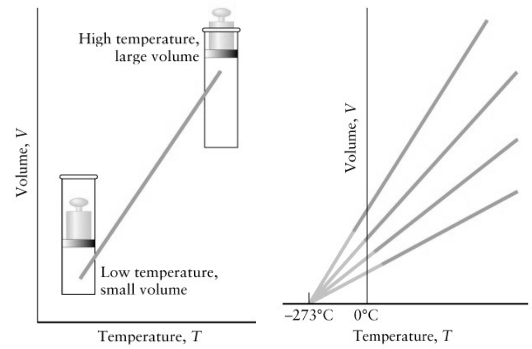

Fig. 5.10, 5.11

- Assume two states of a gas at constant ***P***
  - state 1 → T_1, V_1
  - state 2 → T_2, V_2

$$\frac{V_1}{T_1} = k' \qquad \frac{V_2}{T_2} = k' \qquad \Rightarrow \qquad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Example: A balloon is filled with 5.0 L He gas at 15ºC. The temperature is changed to 35ºC. What is the new volume of the balloon?

T_1 = 15ºC = 288 K $\quad$ **V_1 = 5.0 L**

T_2 = 35ºC = 308 K $\quad$ **V_2 = ?**

$$V_2 = \frac{V_1 T_2}{T_1} = \frac{5.0 \text{ L} \times 308 \text{ K}}{288 \text{ K}} = 5.3 \text{ L}$$

- At constant volume (*V*) the pressure (*P*) of a fixed amount of gas is proportional to its absolute temperature (*T*)

$P = k''T$

$k'' \rightarrow$ constant (depends on V)

$$\frac{P}{T} = k'' \qquad T\uparrow \Leftrightarrow P\uparrow$$

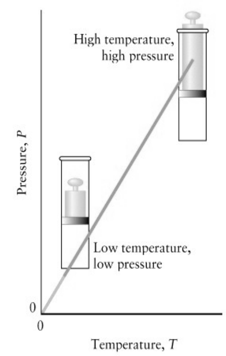

Fig. 5.12

- Assume two states of a gas at constant ***V***
  - state 1 → T_1, P_1
  - state 2 → T_2, P_2

$$\frac{P_1}{T_1} = k'' \qquad \frac{P_2}{T_2} = k'' \qquad \Rightarrow \qquad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Example: A cylinder containing N_2 gas at 15ºC and 50 atm is moved to a new location at 35ºC. What is the new pressure in the cylinder?

T_1 = 15ºC = 288 K $\quad$ **P_1 = 50 atm**

T_2 = 35ºC = 308 K $\quad$ **P_2 = ?**

$$P_2 = \frac{P_1 T_2}{T_1} = \frac{50 \text{ atm} \times 308 \text{ K}}{288 \text{ K}} = 53 \text{ atm}$$

5.6 Avogadro's Law

- At constant temperature (*T*) and pressure (*P*) the volume (*V*) of a gas is proportional to its amount (*n*)

$V = k'''n$ $\quad$ **$k''' \rightarrow$ constant (depends on T, P)**

$$\frac{V}{n} = k''' \qquad n\uparrow \Leftrightarrow V\uparrow$$

- Molar volume (V_m) - the volume of one mole of a substance

V_m = V/n

- Avogadro's principle - equal number of moles of different gases occupy the same volume at constant T and P (molar volumes of gases are very similar)
- Assume two states of a gas at constant $\boldsymbol{T}$ and $\boldsymbol{P}$
  - state 1 → V_1, n_1
  - state 2 → V_2, n_2

$$\frac{V_1}{n_1} = k''' \qquad \frac{V_2}{n_2} = k''' \qquad \Rightarrow \qquad \frac{V_1}{n_1} = \frac{V_2}{n_2}$$

5.7 The Ideal Gas Law

$$V = k\frac{1}{P} \qquad \text{Boyle's Law}$$

$$V = k'T \qquad \text{Charles's Law}$$

$$V = k'''n \qquad \text{Avogadro's Law}$$

Combination of the three laws:

$$V = R\frac{nT}{P} \qquad R \text{ – proportionality constant}$$

$\boldsymbol{PV = nRT}$ → **ideal gas law**

$\boldsymbol{R}$ → **gas constant**

- Ideal gases - obey the ideal gas law
- Real gases behave as ideal gases at low pressures (in the limit of zero pressure)
- $\boldsymbol{R}$ is determined experimentally
  - $R = 0.08206$ L·atm/mol·K
  - $R = 8.314$ J/mol·K
- Assume two states of a gas
  - state 1 → P_1, V_1, n_1, T_1
  - state 2 → P_2, V_2, n_2, T_2

$$\frac{P_1V_1}{n_1T_1} = R \qquad \frac{P_2V_2}{n_2T_2} = R \qquad \Rightarrow \qquad \frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

- **Example:** A 5.0 L gas sample at 1.0 atm and 10ºC is moved to a 2.0 L container and heated to 300ºC. What is the new pressure?

P_1 = 1.0 atm V_1 = 5.0 L T_1 = 10ºC = 283 K

P_2 = ? V_2 = 2.0 L T_2 = 300ºC = 573 K

$n_1 = n_2$

$$\frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2} \qquad \Rightarrow \qquad P_2 = \frac{P_1V_1}{n_1T_1} \times \frac{n_2T_2}{V_2}$$

$$P_2 = \frac{P_1V_1T_2}{T_1V_2} = \frac{1.0 \text{ atm} \times 5.0 \text{ L} \times 573 \text{ K}}{283 \text{ K} \times 2.0 \text{ L}} = 5.1 \text{ atm}$$

- **Example:** A 3.0 g sample of methane, CH_4, is placed in a 2.0 L container at 22ºC. What is the pressure in the container?

$PV = nRT$

V = 2.0 L T = 22ºC = 295 K

moles of CH_4 (n):

$$n = 3.0 \text{ g CH}_4 \times \left(\frac{1 \text{ mol CH}_4}{16.0 \text{ g CH}_4}\right) = 0.19 \text{ mol CH}_4$$

$$P = \frac{nRT}{V} = \frac{0.19 \text{ mol} \times 0.08206 \ \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}} \times 295 \text{ K}}{2.0 \text{ L}} = 2.3 \text{ atm}$$

5.8 The Molar Volume of Ideal Gases

$$V_m = \frac{V}{n} = \frac{nRT / P}{n} = \frac{RT}{P}$$

- Standard temperature and pressure (STP)

P = 1.000 atm; T = 0ºC = 273.15 K

- $\boldsymbol{V_m}$ at STP:

$$V_m = \frac{RT}{P} = \frac{0.08206 \ \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}} \times 273.15 \text{ K}}{1.000 \text{ atm}} = 22.41 \ \frac{\text{L}}{\text{mol}}$$