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Structure 1.5


25
Mn
Manganese
54.938045
16
S
Sulfur
32.065
J
6
C
Carbon
12.0107
2
He
Helium
4.002602
25
Mn
Manganese
54.938045

Ideal gases

Ideal gases vs real gases

An ideal gas is a hypothetical gas that obeys the gas laws and the kinetic-molecular theory.

- Particles of an ideal gas are in constant, random, straight-line motion.
- Collisions between particles of an ideal gas are elastic; total kinetic energy is conserved.
- The volume occupied by the particles of an ideal gas is negligible relative to the volume of the container.
- There are no intermolecular forces acting between particles of an ideal gas.
- The average kinetic energy of the particles of an ideal gas is directly proportional to the absolute temperature in kelvin.

Ideal gases vs real gases

A real gas is a gas that deviates from ideal gas behaviour.

- Real gases have a finite, measurable volume.
- Real gases have intermolecular forces that act between the particles.

Real gases exhibit nearly ideal behaviour at relatively high temperatures and low pressures.

They deviate the most from ideal behaviour at low temperatures and high pressures.

Ideal gases vs real gases

For one mole of an ideal gas, the product of PV/RT is equal to one (regardless of the temperature or pressure).

$$n = \frac{1.00 \times 10^{5}\ \text{Pa} \times 0.0227\ \text{m}^{3}}{8.31\ \text{J K}^{-1}\ \text{mol}^{-1} \times 273\ \text{K}} = 1.00\ \text{mol}$$

Real gases exhibit nearly ideal behaviour at relatively high temperatures and low pressures.

Real gases deviate the most from ideal gas behavior at high pressures and low temperatures.

Ideal gases vs real gases

For one mole of an ideal gas, the product of PV/RT is always equal to one.

$$n = \frac{PV}{RT}$$

$$n = \frac{1.00 \times 10^5\ \mathrm{Pa} \times 0.0227\ \mathrm{m^3}}{8.31\ \mathrm{J\ K^{-1}\ mol^{-1}} \times 273\ \mathrm{K}} = 1.00\ \mathrm{mol}$$

For real gases the product of PV/RT ≠ 1.

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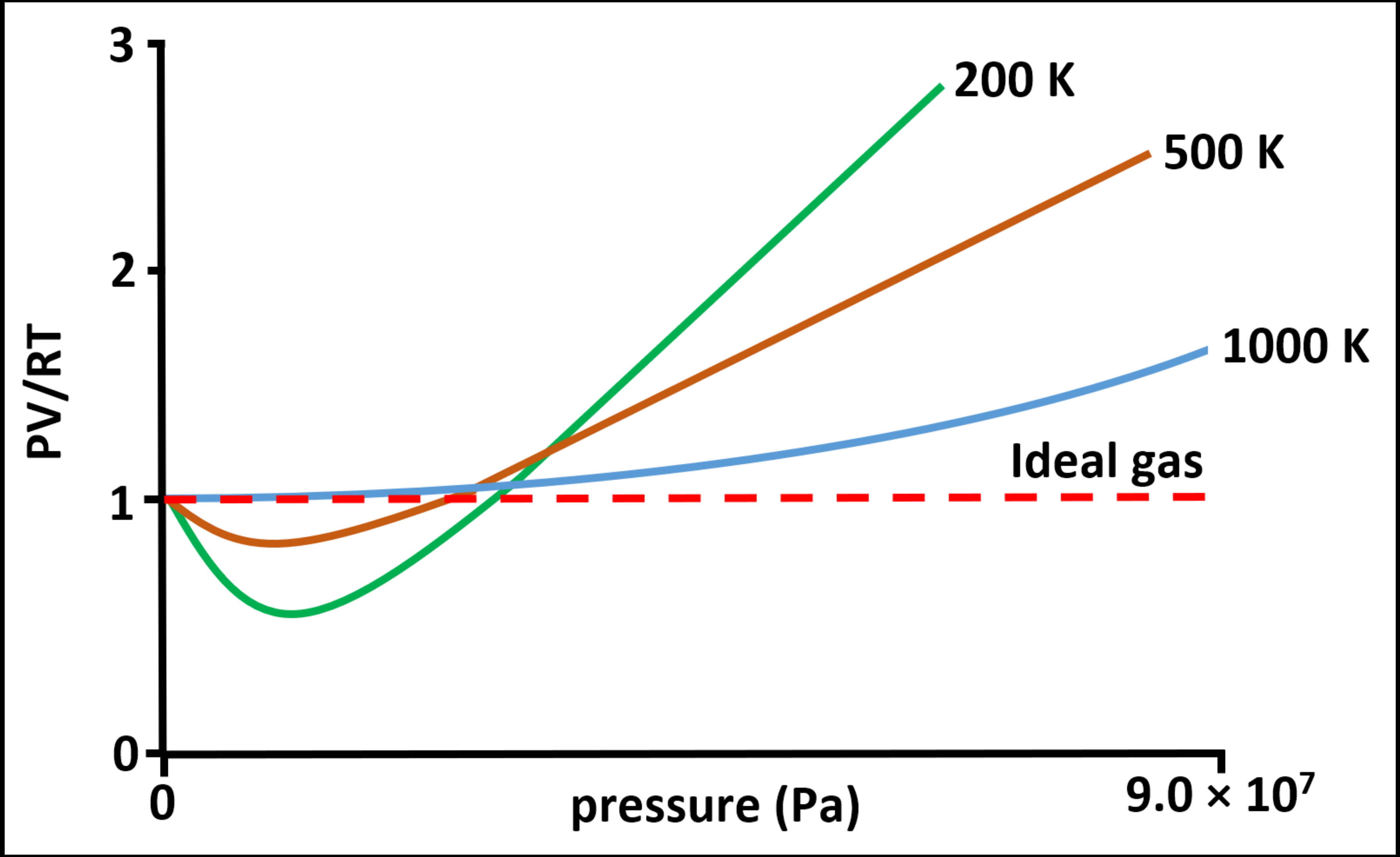
Ideal gases vs real gases

Deviation of nitrogen gas from ideal gas behavior.

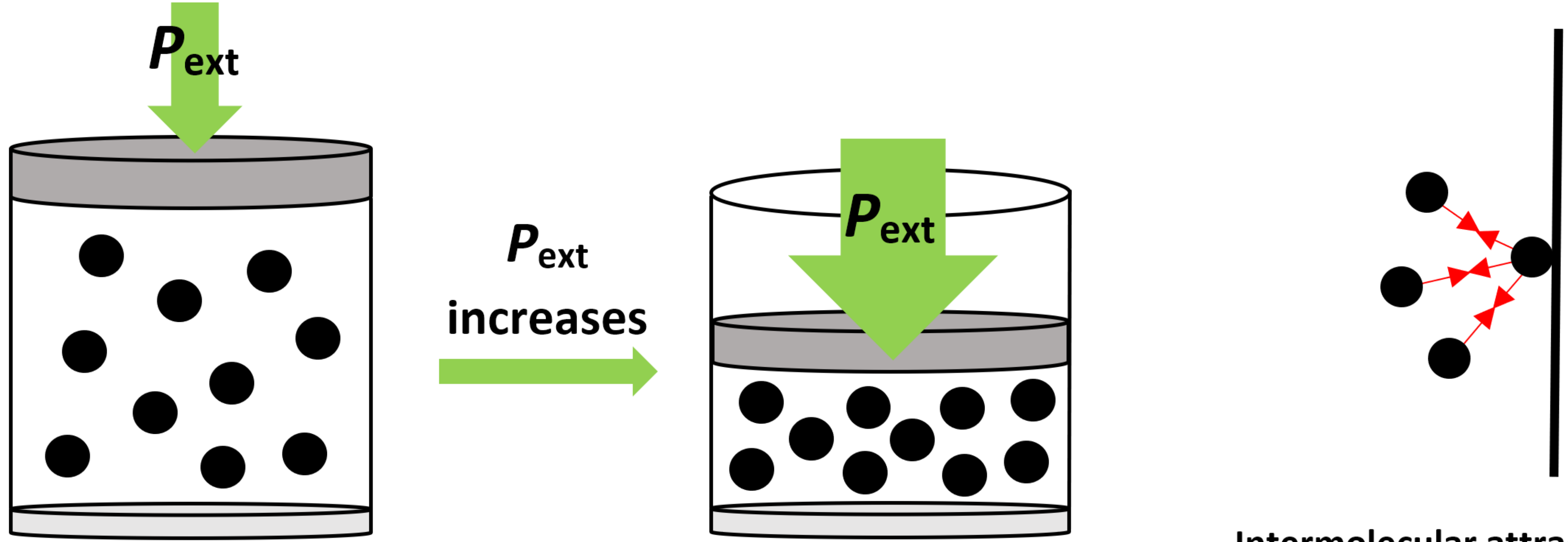


$$\frac{PV}{RT} > 1$$

$$\frac{PV}{RT} < 1$$

Ideal gases vs real gases

At moderately high pressures, the values of PV/RT are less than one, mainly because of the effects of intermolecular forces.



Lower P_{ext}; particles are too far apart for intermolecular forces to act

Moderately high P_{ext}; particles are now close enough for intermolecular forces to act

Intermolecular attractions reduce the force of the collisions with the container wall which results in a lower pressure

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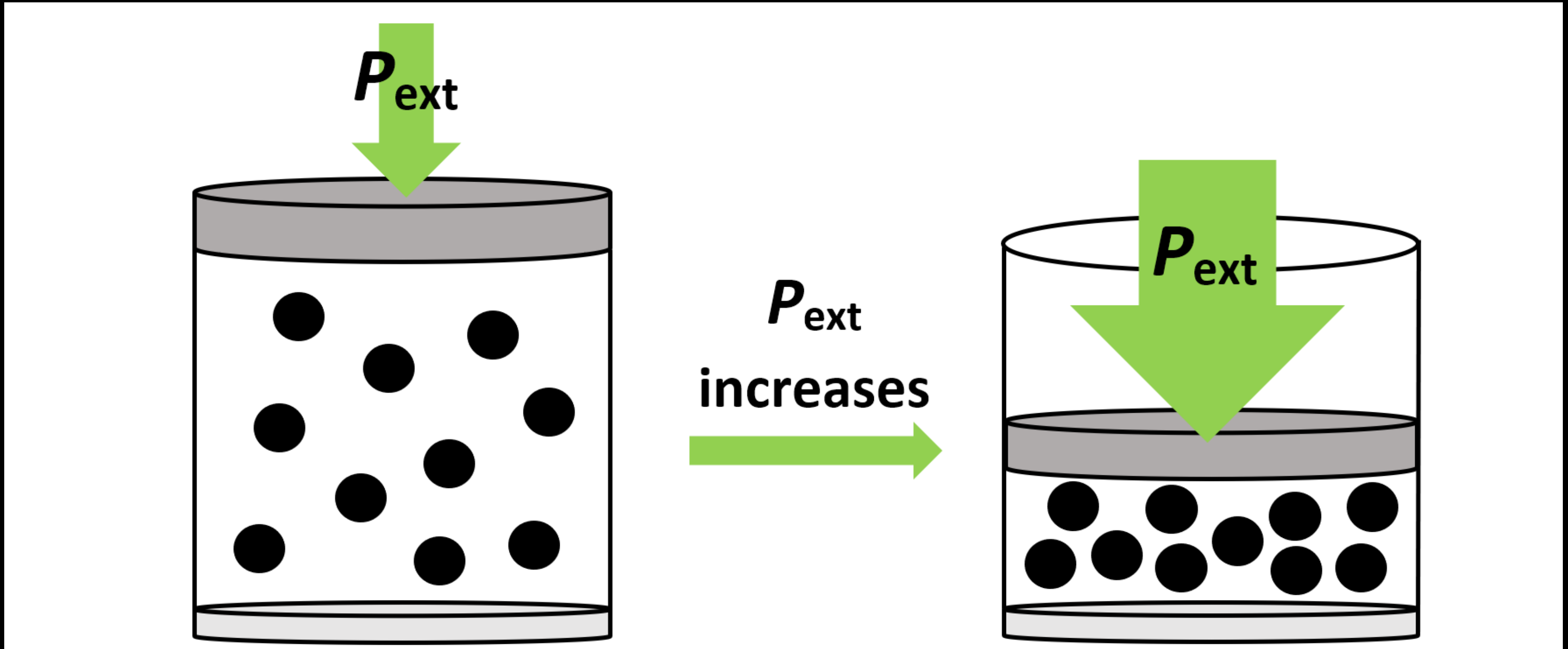
Ideal gases vs real gases

At very high pressures, the values of PV/RT are greater than one, mainly because of the effects of molecular volume.



Lower P_{ext}; the volume occupied by the gas particles is negligible compared to the volume of the container

Very high P_{ext}; the volume occupied by the gas particles becomes significant

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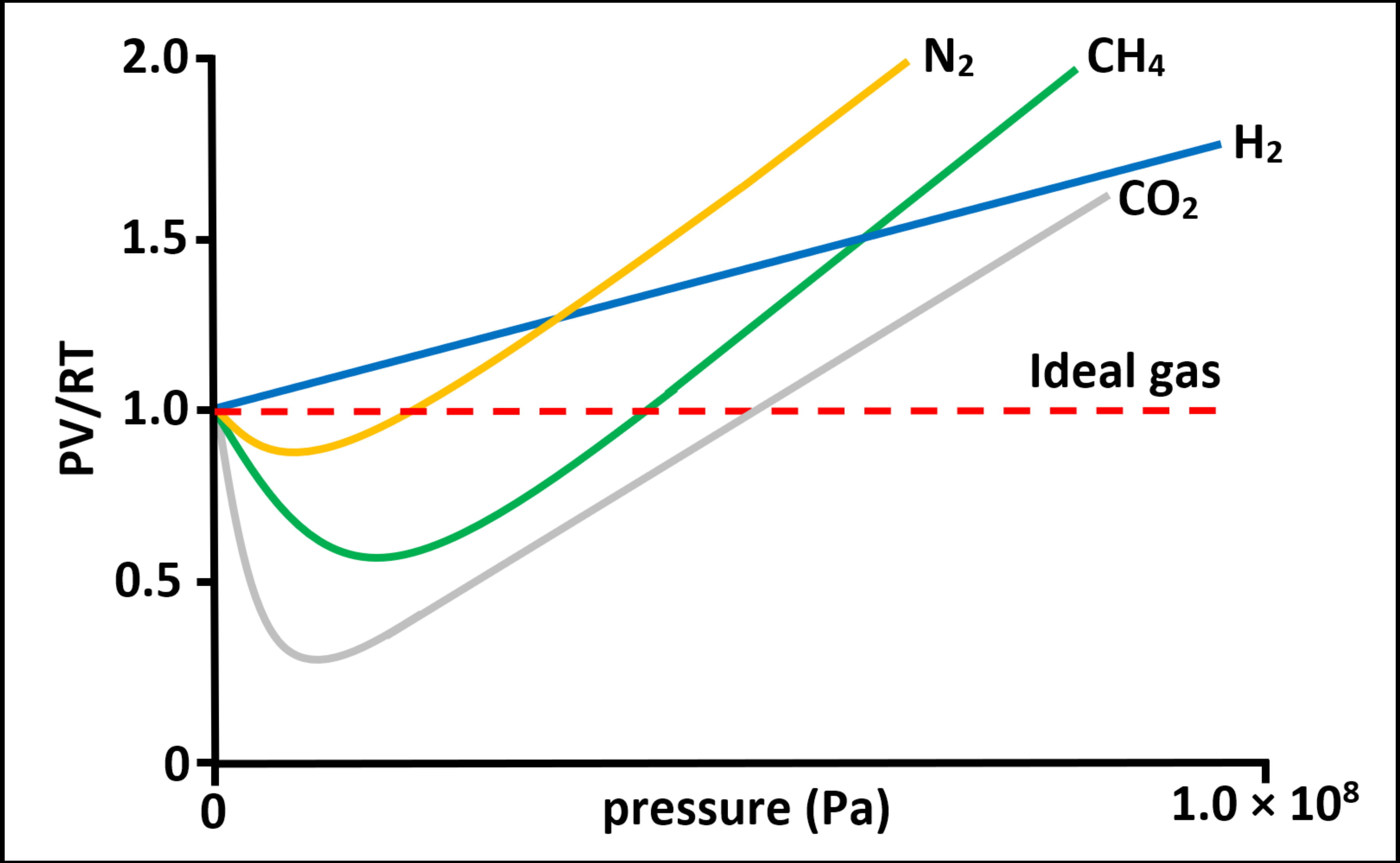
Ideal gases vs real gases

Deviation of different gases from ideal gas behaviour.



$$\frac{PV}{RT} > 1$$

$$\frac{PV}{RT} < 1$$

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Ideal gases vs real gases

Ideal gases	Real gases
Ideal gases behave ideally at all temperatures and pressures	Real gases deviate the most from ideal behaviour at low temperatures and high pressures
The volume occupied by an ideal gas is assumed to be negligible	Real gases have a finite, measurable volume
Ideal gases have no intermolecular forces acting between the particles	Real gases have intermolecular forces acting between their particles
Ideal gases obey the ideal gas law $PV = nRT$	Real gases obey the van der Waals equation $P = \frac{RT}{V - b} - \frac{a}{V^2}$

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Molar volume of a gas

Molar volume of a gas

The molar volume of a gas (V_m) is the volume occupied by one mole of an ideal gas.

$$\mathbf{STP : 273\ K\ \ and\ \ 1.00 \times 10^5\ Pa}$$

$$V = \frac{1.00 \times 8.31 \times 273}{1.00 \times 10^5} = 0.0227\ \mathrm{m^3}$$

$$V_m = 0.0227\ \mathrm{m^3 mol^{-1}}\ \mathrm{or}\ \ 22.7\ \mathrm{dm^3\ mol^{-1}}$$

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Molar volume of a gas

The molar volume of a gas (V_m) is the volume occupied by one mole of an ideal gas.

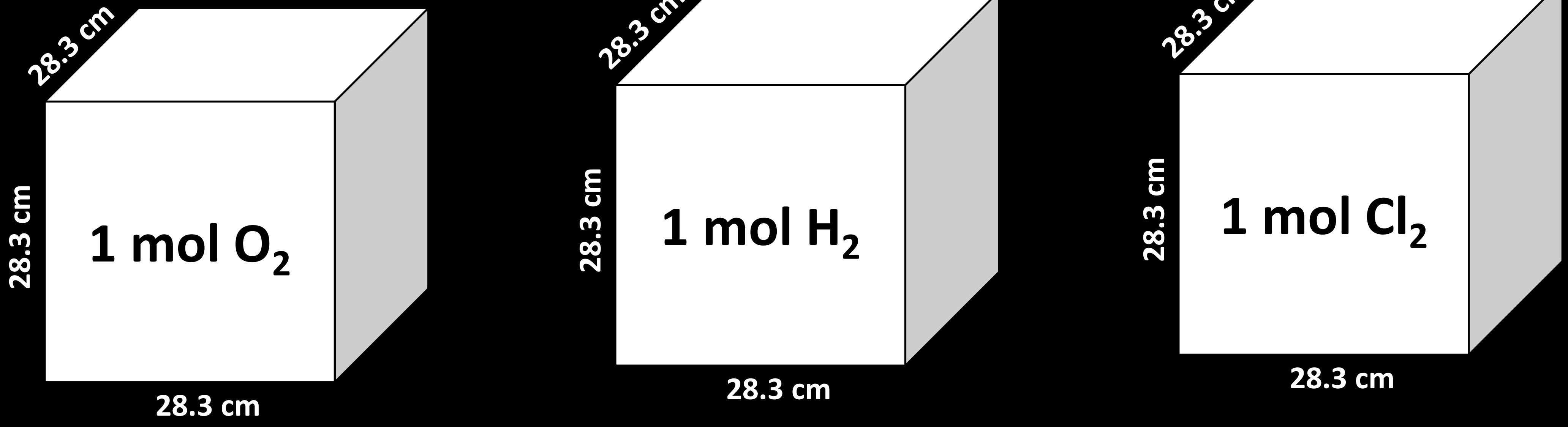
$$\mathbf{STP: 273\ K\ \ and\ \ 1.00 \times 10^5\ Pa}$$

$$V_m\,(\mathrm{m^3\ mol^{-1}}) = \frac{0.0227\ \mathrm{m^3}}{1\ \mathrm{mol}}$$

$$V_m = 0.0227\ \mathrm{m^3\ mol^{-1}}\ or\ \ 22.7\ \mathrm{dm^3\ mol^{-1}}$$

Molar volume of a gas

Under conditions of STP one mole of any gas occupies a volume of 0.0227 m^3 (22.7 dm^3).



22.7 dm^3 22.7 dm^3 22.7 dm^3

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Molar volume of a gas

$$V\,(\mathrm{dm^3}) = n\,(\mathrm{mol}) \times V_m\,(22.7\ \mathrm{dm^3})$$

$$V = n \times 22.7$$

$$n\,(\mathrm{mol}) = \frac{V\,(\mathrm{dm^3})}{V_m\,(22.7\ \mathrm{dm^3})}$$

$$n = \frac{V}{22.7}$$

Molar volume of a gas

Calculate the volume (in dm^3) occupied by 0.250 mol of N_2 at STP.

$$V = n \times 22.7$$

$$V = 0.250 \times 22.7$$

$$V = 5.68\ \mathrm{dm}^3$$

Molar volume of a gas

Calculate the volume (in cm^3) occupied by 0.00619 mol of CO_2 at STP.

$$V = n \times 22.7$$

$$V = 0.00619 \times 22.7$$

$$V = 0.141\ \text{dm}^3$$

$$0.141\ \text{dm}^3 \times \frac{1000\ \text{cm}^3}{1\ \text{dm}^3} = 141\ \text{cm}^3$$

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Molar volume of a gas

Calculate the amount (in mol) of N_2 in a 0.742 dm^3 sample.

$$n = \frac{V}{22.7}$$

$$n = \frac{0.742}{22.7}$$

$$n = 0.0327 \text{ mol}$$

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Molar volume of a gas

Calculate the amount (in mol) of CH_4 in a 2.36 cm^3 sample.

$$2.36\ \mathrm{cm^3} \times \frac{1\ \mathrm{dm^3}}{1000\ \mathrm{cm^3}} = 2.36 \times 10^{-3}\ \mathrm{dm^3}$$

$$n = \frac{V}{22.7} \qquad n = \frac{2.36 \times 10^{-3}}{22.7}$$

$$n = 1.04 \times 10^{-4}\ \mathrm{mol}$$

Molar volume of a gas

Determine the volume of H_2 (in cm^3) produced at STP when 2.00 g of Mg is reacted with excess $HCl_{(aq)}$.

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$

$$n(\mathrm{Mg}) = \frac{2.00}{24.31} = 0.0823\ \mathrm{mol}$$

Ratio of Mg to H_2 is 1:1

0.0823 mol Mg will produce 0.0823 mol H_2

Molar volume of a gas

$$n(\mathrm{H_2}) = 0.0823\ \mathrm{mol}$$

$$V = n \times 22.7$$

$$V = 0.0823 \times 22.7$$

$$V = 1.87\ \mathrm{dm^3}$$

$$1.87\ \mathrm{dm^3} \times \frac{1000\ \mathrm{cm^3}}{1\ \mathrm{dm^3}} = 1.87 \times 10^3\ \mathrm{cm^3}$$

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The gas laws part 1

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The gas laws

$$P \propto \frac{1}{V}$$

$$V \propto T$$

$$P \propto T$$

$$V \propto n$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

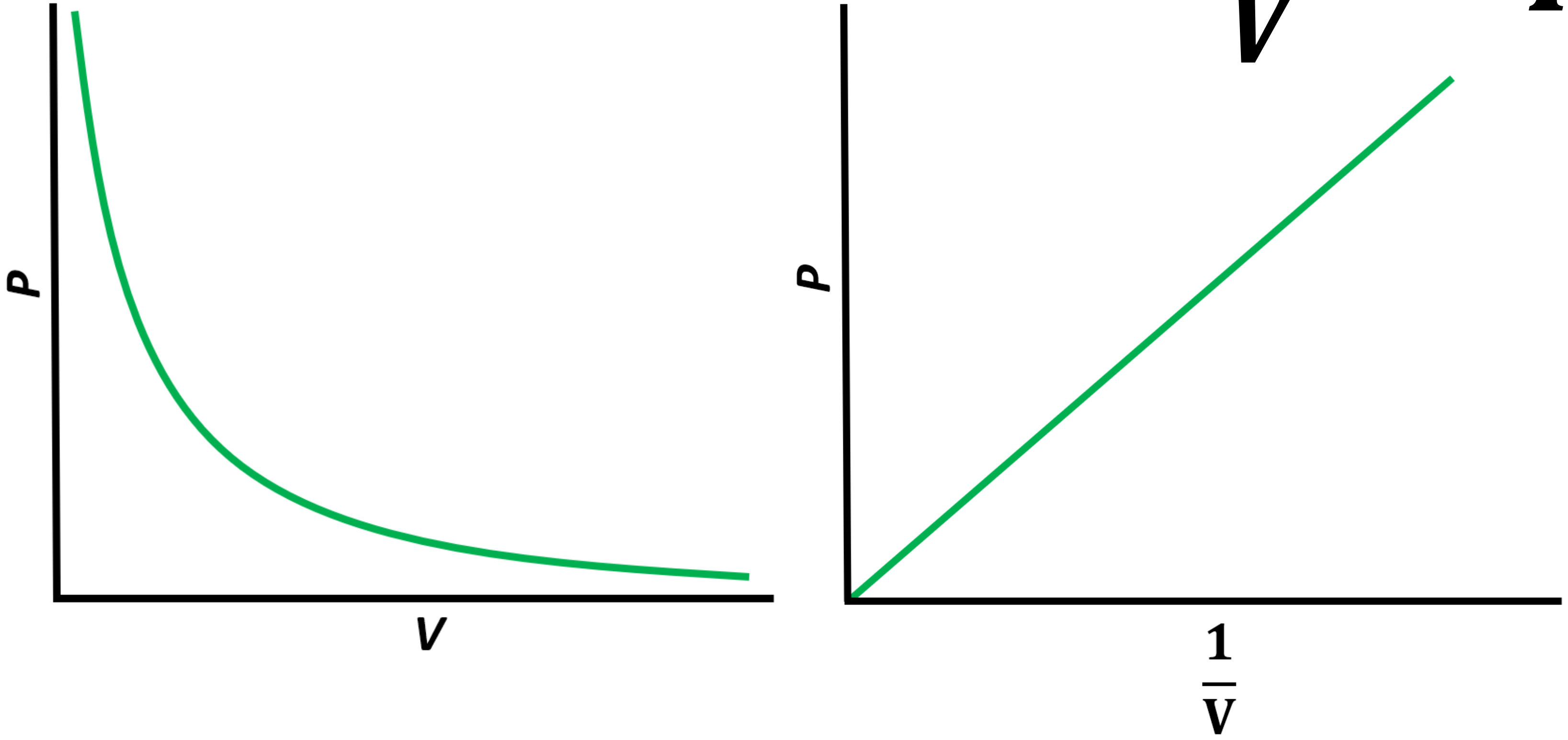
The gas laws

Boyle's law - the volume occupied by a gas is inversely proportional to its pressure (at constant *n* and *T*).

$$PV = k$$

$$P \propto \frac{1}{V}$$

$$P_1V_1 = P_2V_2$$

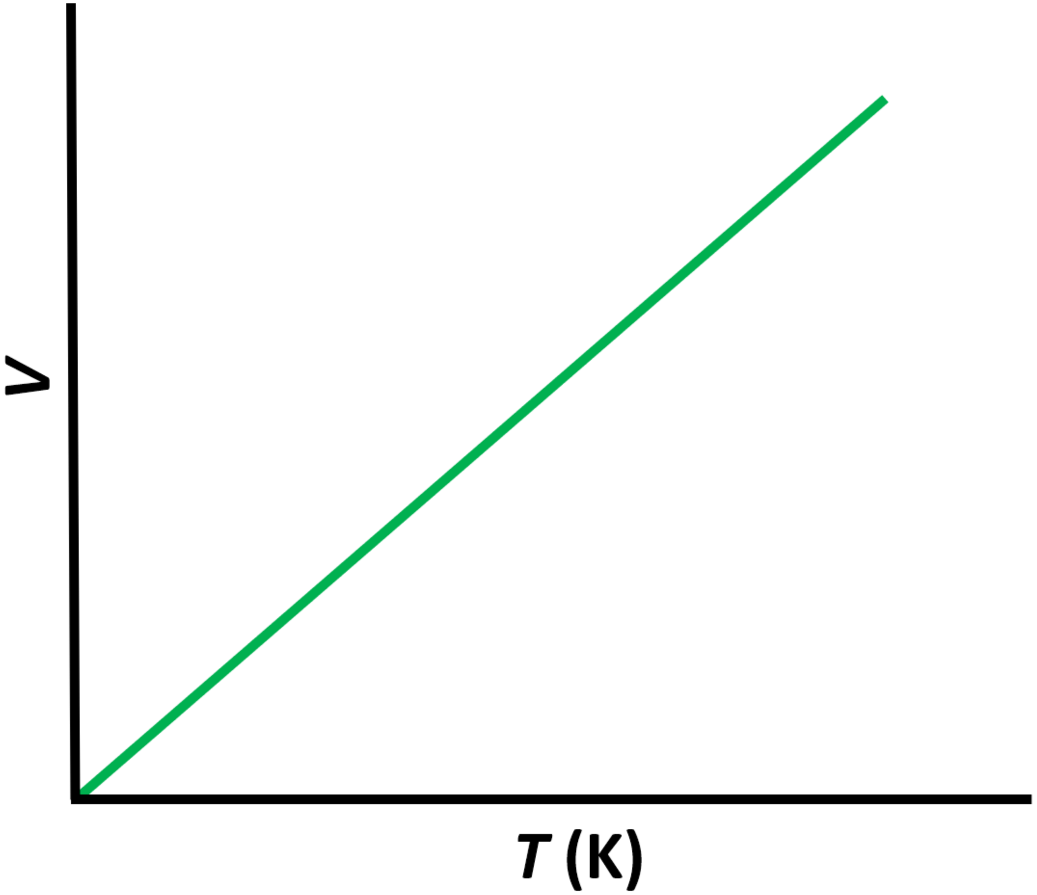


The gas laws

Charles's law - the volume occupied by a gas is directly proportional to its absolute temperature (at constant *n* and *P*).

$$V \propto T \qquad \frac{V}{T} = k$$

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



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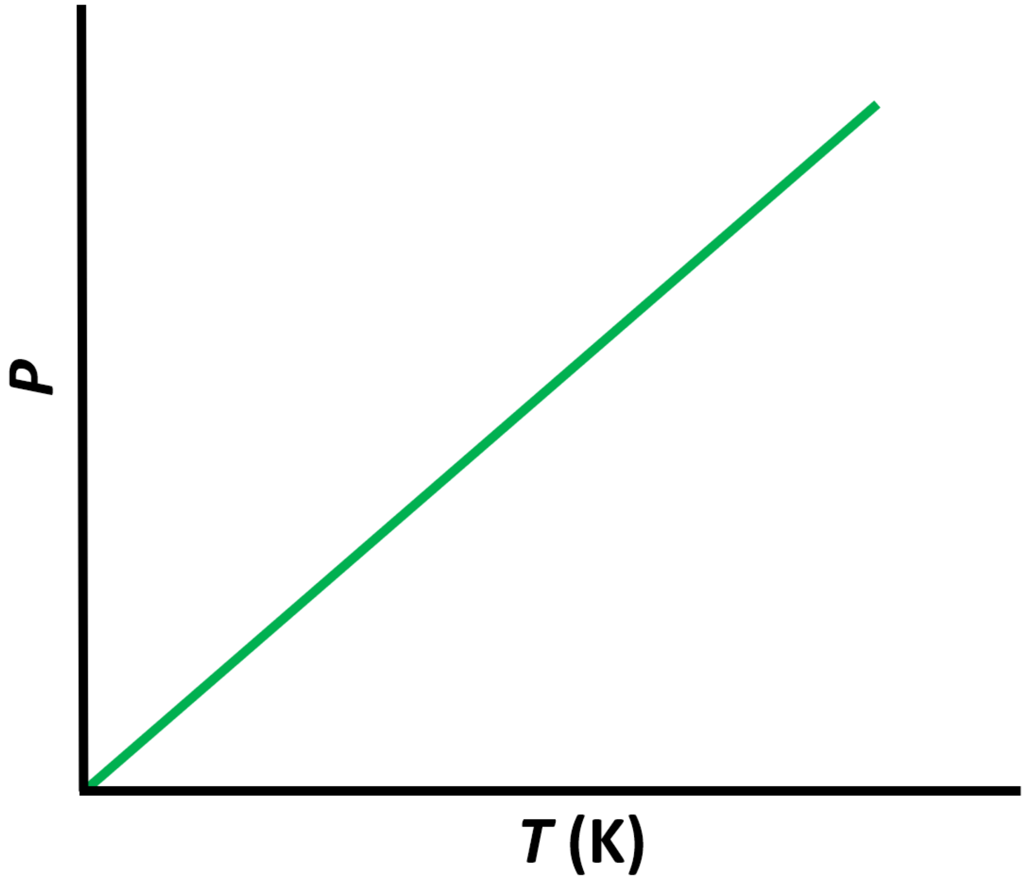
The gas laws

Gay Lussac's law - the pressure exerted by a gas is directly proportional to its absolute temperature (at constant *n* and *V*).

$$P \propto T \quad \frac{P}{T} = k$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

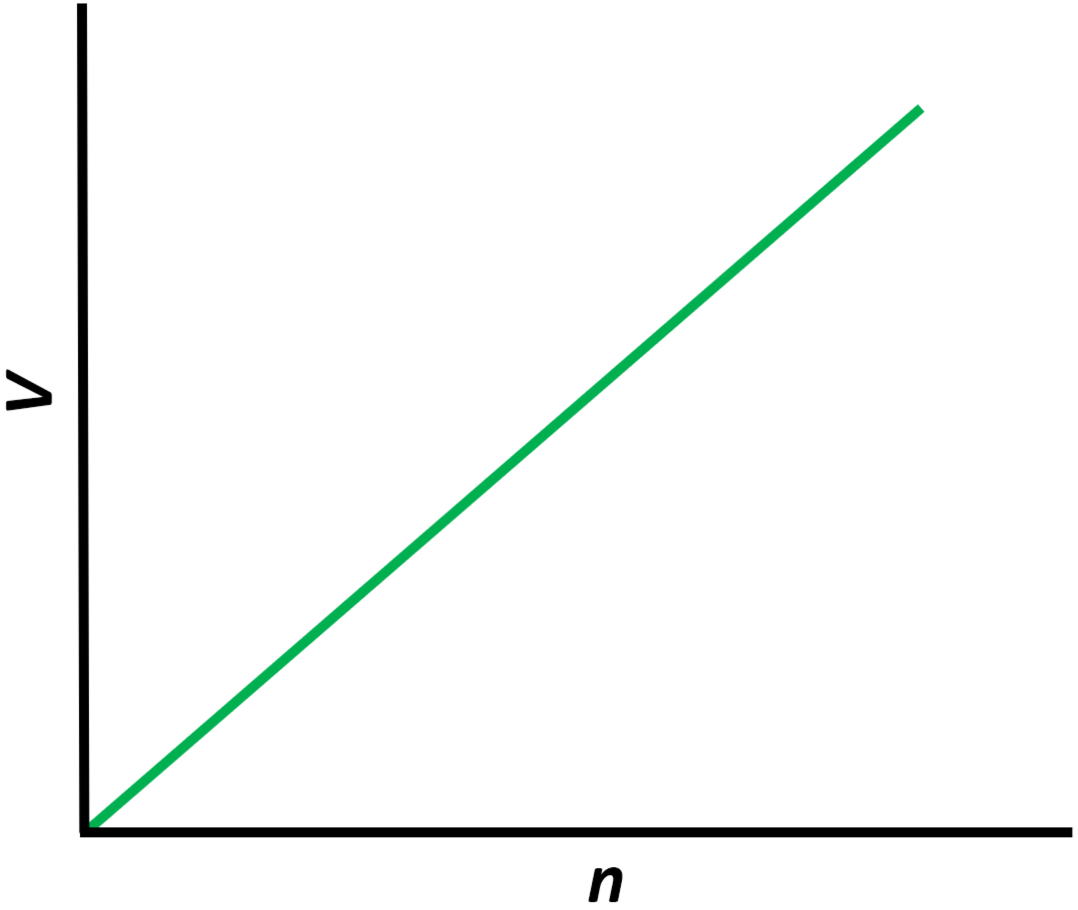


The gas laws

Avogadro's law - the volume occupied by a gas is directly proportional to the amount (in mol) of gas (at constant *P* and *T*).

$$V \propto n \qquad \frac{V}{n} = k$$

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



The gas laws

The Combined gas law combines Boyle's law, Charles's law and Gay-Lussac's law.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad \frac{P_1V_1}{T_1} = k$$

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The gas laws part 2

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The gas laws

$$P \propto \frac{1}{V}$$

$$V \propto T$$

$$P \propto T$$

$$V \propto n$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

The gas laws

A sample of gas has a volume of 15.0 cm^3 at a pressure of 575 kPa. Assuming that temperature remains constant, what volume will the gas occupy at a pressure of 968 kPa?

$$P_1V_1 = P_2V_2$$

$$V_2 = \frac{P_1V_1}{P_2}$$

$$V_2 = \frac{575 \times 15.0}{968}$$

$$V_2 = 8.91\ \mathrm{cm}^3$$

The gas laws

A sample of gas has a volume of 32.0 dm^3 at a temperature of 256 K. Assuming that pressure remains constant, what volume will the gas occupy at a temperature of 391 K?

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

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

$$V_2 = \frac{32.0 \times 391}{256}$$

$$V_2 = 48.9\ \mathrm{dm}^3$$

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The gas laws

A sample of gas has a pressure of 73.9 kPa at a temperature of 347 K. Assuming that volume remains constant, what will be the pressure of the gas at a temperature of 602 K?

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$P_2 = \frac{73.9 \times 602}{347}$$

$$P_2 = \frac{P_1 T_2}{T_1}$$

$$P_2 = 128\ \mathrm{kPa}$$

The gas laws

A sample contains 5.13 mol of gas with a volume of 1.28 m^3. Assuming that temperature and pressure remain constant, what volume will the gas occupy if 3.49 mol of gas are added?

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

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

$$V_2 = \frac{1.28 \times 8.62}{5.13}$$

$$V_2 = 2.15\ \mathrm{m}^3$$

The gas laws

A sample of gas has a volume of 1.54 m^3 at a temperature of 447 K and a pressure of 12.0 kPa. If the temperature and pressure are changed to 561 K and 15.7 kPa respectively, what volume will the gas occupy?

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$V_2 = \frac{1.54 \times 12.0 \times 561}{447 \times 15.7}$$

$$V_2 = \frac{V_1P_1T_2}{T_1P_2}$$

$$V_2 = 1.48\ \mathrm{m}^3$$

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Ideal gas equation

Ideal gas equation

$$V \propto \frac{1}{P} \qquad V \propto T \qquad V \propto n$$

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

$$PV = nRT$$

Ideal gas equation

$$PV = nRT$$

P is pressure (Pa)

V is volume (m^3)

n is amount (mol)

R is the gas constant ($8.31\ \mathrm{J\ K^{-1}\ mol^{-1}}$)

T is temperature (K)

Ideal gas equation

$$n = \frac{PV}{RT}$$

$$V = \frac{nRT}{P}$$

$$P = \frac{nRT}{V}$$

$$T = \frac{PV}{nR}$$

Ideal gas equation

Unit conversions

Temperature in kelvin (K): °C + 273

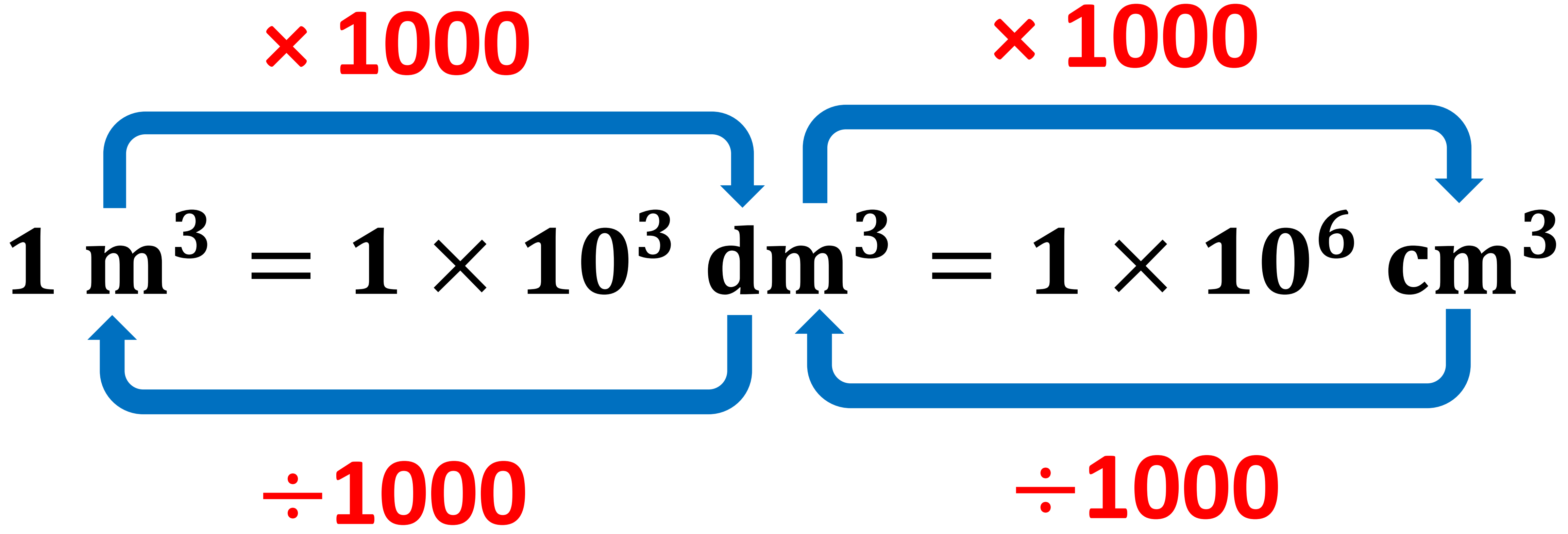
25°C = 298 K

Pressure in Pa: 1.00×10^5 Pa = 100 kPa

$1\ \text{cm}^3 = 1 \times 10^{-3}\ \text{dm}^3 = 1 \times 10^{-6}\ \text{m}^3$

$1\ \text{m}^3 = 1 \times 10^{3}\ \text{dm}^3 = 1 \times 10^{6}\ \text{cm}^3$

Ideal gas equation



× 1000

× 1000

$$1\ \mathrm{m}^3 = 1 \times 10^3\ \mathrm{dm}^3 = 1 \times 10^6\ \mathrm{cm}^3$$

÷1000

÷1000

Ideal gas equation

Calculate the volume (in dm^3) occupied by 0.500 mol of gas at 1.50×10^5 Pa and 25.0 °C.

$$V = \frac{nRT}{P} \qquad V = \frac{0.500 \times 8.31 \times 298}{150000}$$

$$V = 8.25 \times 10^{-3}\ \mathrm{m}^3 = 8.25\ \mathrm{dm}^3$$

Ideal gas equation

Calculate the pressure (in kPa) of 0.200 mol of gas that occupies a volume of 10.0 dm³ at 20.0 °C.

$$P = \frac{nRT}{V} \quad P = \frac{0.200 \times 8.31 \times 293}{0.0100}$$

$$P = 4.87 \times 10^4\ \text{Pa} = 48.7\ \text{kPa}$$

Ideal gas equation

Calculate the amount (in mol) of gas that occupies a volume of 20.0 dm^3 at 50.0 ^{o}C and 85.0 kPa.

$$n = \frac{PV}{RT} \qquad n = \frac{85000 \times 0.0200}{8.31 \times 323}$$

$$n = 0.633\ \text{mol}$$

Ideal gas equation

1.10 g of an unknown gas occupies a volume of 567 cm^3 at STP. Calculate the molar mass of the gas.

$$M = \frac{mRT}{PV} \qquad M = \frac{1.10 \times 8.31 \times 273}{1.00 \times 10^{5} \times 5.67 \times 10^{-4}}$$

$$M = 44.0\ \text{g mol}^{-1}$$