Exercise walk-through

The mole ▪ 15.1

eXercise

You must be able to

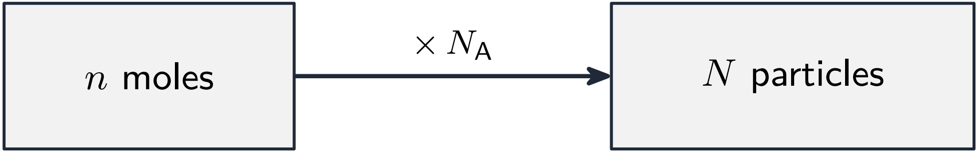
- use the **mole** as the SI unit of amount of substance
- use $N = nN_{\mathrm{A}}$ and find masses of moles and single particles

Method — The mole

Amount of substance is an SI base quantity; its unit is the **mole** (mol). One mole contains N_A particles:

$$N = nN_\mathsf{A}, \qquad N_\mathsf{A} = 6.02 \times 10^{23}\ \mathsf{mol}^{-1}.$$

The **molar mass** M_m is the mass of one mole; one particle has mass $m_0 = M_\mathsf{m}/N_\mathsf{A}$. Always say **what** you are counting (atoms or molecules).



$$N = nN_\mathsf{A}, \quad N_\mathsf{A} = 6.02 \times 10^{23}\ \mathsf{mol}^{-1}$$

Practice 2.1 ▪ 1 mark

State the SI **unit** of amount of substance.

Solution 2.1

Method: The mole

Worked steps

The **mole** (mol) B1.

Practice 2.2 ▪ 1 mark

State the value of the **Avogadro constant**.

Solution 2.2

Worked steps

$N_\mathsf{A} = 6.02 \times 10^{23}\ \mathsf{mol}^{-1}$ **B1**.

Practice 2.3 ▪ 2 marks

How many molecules are there in 2.0 mol of a gas?

Solution 2.3

Method: The mole

Worked steps

$N = nN_{\mathsf{A}} = 2.0 \times 6.02 \times 10^{23} = 1.2 \times 10^{24}$ M1 A1.

Exam-style 3.1 ▪ 1 mark

One mole of oxygen gas (O_2) contains:

A 6.02×10^{23} atoms

B 6.02×10^{23} molecules

C 32 molecules

D 16 molecules

Solution 3.1

Method: The mole

A 6.02×10^{23} atoms

B 6.02×10^{23} molecules ✓

C 32 molecules

D 16 molecules

Worked steps

B — 6.02×10^{23} molecules.

Exam-style 3.2 ▪ 2 marks

A gas sample contains 3.0×10^{24} molecules. Find the number of **moles**.

Solution 3.2

Method: The mole

Worked steps

$n = N/N_A = (3.0 \times 10^{24})/(6.02 \times 10^{23})$ **M1** $= 5.0$ mol **A1**.

Exam-style 3.3 ▪ 2 marks

The molar mass of water is 18 g mol^{-1}. Calculate the mass of **one** water molecule.

Solution 3.3

Method: The mole

Worked steps

$m_0 = M_\mathrm{m}/N_\mathrm{A} = (0.018)/(6.02 \times 10^{23})$ **M1** $= 3.0 \times 10^{-26}$ kg **A1**.

Exam-style 3.4 ▪ 1 mark

A sealed cylinder holds an ideal gas. The Avogadro constant is 6.02×10^{23} mol^{-1}, the molar gas constant is 8.31 J mol^{-1} K^{-1} and the Boltzmann constant is 1.38×10^{-23} J K^{-1}.

(a) **State** what is meant by the **Avogadro constant**.

(b) **State** the relationship between the Avogadro constant N_A, the molar gas constant R and the Boltzmann constant k.

(c) The cylinder holds 0.32 mol of the gas. **Determine** the number of molecules in it.

(d) A second, identical cylinder holds **twice** as many molecules of the same gas at the same temperature T. **Complete** the table, giving each entry in terms of some or all of N, m, T, V, k and N_A, where sample X contains N molecules each of mass m in volume V.

quantity	**sample X**	**sample Y**
pressure	____________	____________
amount of substance	____________	____________
mean kinetic energy per molecule	____________	____________

Exam-style 3.4 ▪ 1 mark

(e) **Explain** why the mean kinetic energy per molecule is the same in both samples, while the internal energies differ.
(f) The temperature of sample X is now varied. In the space below, **sketch** how the root-mean-square speed of its molecules varies with thermodynamic temperature. **Label** both axes.

Solution 3.4

Method: The mole

Worked steps

(a) The number of particles per unit amount of substance — the number of particles in one mole **B1**.

(b) $N_A = \dfrac{R}{k}$ **B1**.

(c) $N = nN_A = 0.32 \times 6.02 \times 10^{23}$ **M1** $= 1.9 \times 10^{23}$ molecules **A1**.

(d) Sample Y has $2N$ molecules in the same volume at the same temperature.

quantity	**sample X**	**sample Y**
pressure	$\dfrac{NkT}{V}$	$\dfrac{2NkT}{V}$
amount of substance	$\dfrac{N}{N_A}$	$\dfrac{2N}{N_A}$
mean kinetic energy per molecule	$\frac{3}{2}kT$	$\frac{3}{2}kT$
internal energy	$\frac{3}{2}NkT$	$3NkT$

Solution 3.4

B1 **B1** **B1** **B1** *for the pressures; for the amounts; for both mean kinetic energies being the same; for the internal energies*

(e) The mean kinetic energy of a molecule is $\frac{3}{2}kT$, which depends **only on the temperature** — and both samples are at T **B1**. Internal energy is the **total** for all the molecules, so twice as many molecules at the same energy each gives twice the internal energy **B1**.

(f) Axes labelled *root-mean-square speed* and *thermodynamic temperature / K* **B1**; a curve from the **origin** rising with a **decreasing** gradient, since $c_{\text{r.m.s.}} \propto \sqrt{T}$ — quadrupling T only doubles the speed **B1**.