A-LEVEL PHYSICS • EXERCISE SHEET

15.1 The mole

Name: ______________ Class: __________ Date: ____________ **Total: 21 marks**

KEY WORDS mole 摩尔 • amount of substance 物质的量 • avogadro constant 阿伏伽德罗常量 • molecule 分子 • molar mass 摩尔质量

Objective

Build the skills to answer exam questions on **the mole** and the Avogadro constant.

You must be able to:

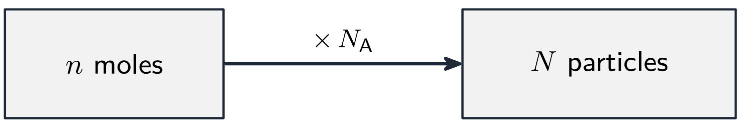
- use the **mole** as the SI unit of amount of substance
- use $N = nN_A$ and find masses of moles and single particles

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ The mole

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



$$N = nN_A, \quad N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$$

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The **molar mass** M_m is the mass of one mole; one particle has mass $m_0 = M_m/N_A$. Always say **what** you are counting (atoms or molecules).

2 Practice

Now apply the methods above.

2.1 State the SI **unit** of amount of substance. [1]

2.2 State the value of the **Avogadro constant**. [1]

2.3 How many molecules are there in 2.0 mol of a gas? [2]

3 Exam-style questions

3.1 One mole of oxygen gas (O_2) contains: [1]

- **A** 6.02×10^{23} atoms
- **B** 6.02×10^{23} molecules
- **C** 32 molecules
- **D** 16 molecules

3.2 A gas sample contains 3.0×10^{24} molecules. Find the number of **moles**. [2]

3.3 The molar mass of water is 18 g mol^{-1}. Calculate the mass of **one** water molecule. [2]

3.4 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**. [1]

(b) **State** the relationship between the Avogadro constant N_A, the molar gas constant R and the Boltzmann constant k. [1]

(c) The cylinder holds 0.32 mol of the gas. **Determine** the number of molecules in it. [2]

(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. [4]

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

(e) **Explain** why the mean kinetic energy per molecule is the same in both samples, while the internal energies differ. [2]

(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. [2]

Solutions

2.1 The **mole** (mol).

2.2 $N_\mathrm{A} = 6.02 \times 10^{23}\ \mathrm{mol}^{-1}$.

2.3 $N = nN_\mathrm{A} = 2.0 \times 6.02 \times 10^{23} = 1.2 \times 10^{24}$.

3.1 **B** — 6.02×10^{23} molecules.

3.2 $n = N/N_\mathrm{A} = (3.0 \times 10^{24})/(6.02 \times 10^{23}) = 5.0$ mol.

3.3 $m_0 = M_\mathrm{m}/N_\mathrm{A} = (0.018)/(6.02 \times 10^{23}) = 3.0 \times 10^{-26}$ kg.

3.4 (a) The number of particles per unit amount of substance — the number of particles in one mole.
(b) $N_\mathrm{A} = \dfrac{R}{k}$.
(c) $N = nN_\mathrm{A} = 0.32 \times 6.02 \times 10^{23} = 1.9 \times 10^{23}$ molecules.
(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	$\dfrac{N}{N_\mathrm{A}}$	$\dfrac{2N}{N_\mathrm{A}}$
mean kinetic energy per molecule	$\frac{3}{2}kT$	$\frac{3}{2}kT$
internal energy	$\frac{3}{2}NkT$	$3NkT$

(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. Internal energy is the **total** for all the molecules, so twice as many molecules at the same energy each gives twice the internal energy.
(f) Axes labelled *root-mean-square speed* and *thermodynamic temperature / K*; a curve from the **origin** rising with a **decreasing** gradient, since $c_{\mathrm{r.m.s.}} \propto \sqrt{T}$ — quadrupling T only doubles the speed.