Counting particles by mass: the mole

Structure 1.4 · SL and HL

How do you count grains of rice?

> Chemists count atoms by weighing them.

- A shop sells rice by mass, not by counting grains.
- At 0.02 g a grain, 1 kg holds about 50 000 grains.
- This unit: the mole $\rightarrow$ **molar mass** $\rightarrow$ formulae $\rightarrow$ solutions $\rightarrow$ gases.

The mole

- One mole contains exactly $6.02214076 \times 10^{23}$ specified elementary entities.
- State whether the entities are atoms, molecules, ions or formula units.

$$N = n \times N_A$$

Course calculations use rounded $N_a = 6.02 \times 10^{23}\ \text{mol}^{-1}$.

Count molecules and atoms in water

1. **Molecules.** $0.500 \times 6.02 \times 10^{23} = 3.01 \times 10^{23}$ molecules
2. **Atoms.** $3 \times 3.01 \times 10^{23}$

Decision

9.03×10^{23} atoms

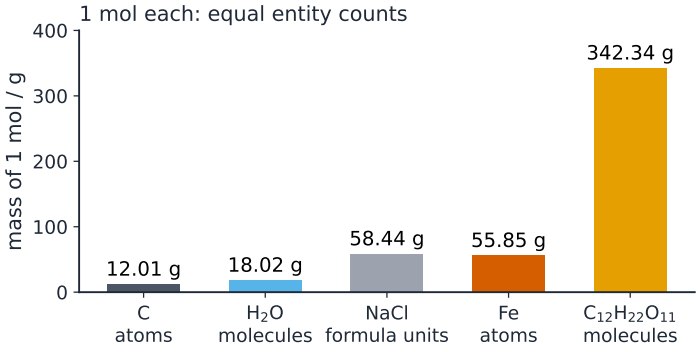
Relative atomic mass



$$A_r = \frac{(75 \times 35) + (25 \times 37)}{100} = 35.5$$

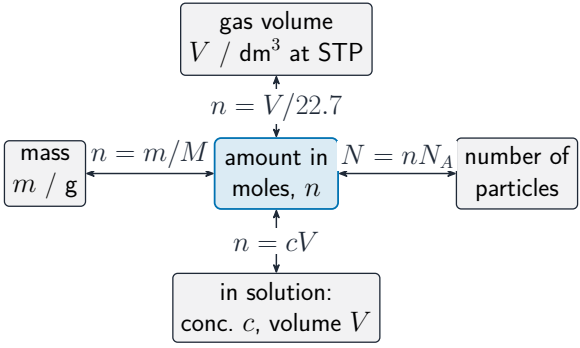
The diagram uses rounded illustrative inputs; the booklet value for Cl is 35.45.

Molar mass



Equal amounts count equal specified entities; masses differ.

The mole map



Use the equation for the correct direction of each conversion.

CO_2: mass to molecules

1. **Molar mass.** $12.01 + 2 \times 16.00 = 44.01$ g mol^{-1}
2. **Moles.** $4.4/44.01$ =0.0999773... mol; retain guard digits
3. **Molecules.** n$\times$N$_a$ =6.018632...$\times 10^{22}$ molecules

Decision

6.0×10^{22} molecules

Empirical and molecular formulae

Compound	Molecular	Empirical
ethane	C_2H_6	CH_3
glucose	$C_6H_{12}O_6$	CH_2O
benzene	C_6H_6	CH

Finding an empirical formula

Element	**% by mass**	**÷ A_r**	**÷ smallest**
C	40.0	3.33	1
H	6.7	6.7	2
O	53.3	3.33	1

Use the evidence

CH_2O; $M_r = 180$ fits $180/30 = 6$ times, so $C_6H_{12}O_6$.

Check: water of crystallization

Your turn

Using unrounded amounts, the ratio is 4.98259… . Which integer x is consistent?

A. 2

B. 4

C. 5

D. 9

Concentration

- Divide cm^3 by 1000 to get dm^3.
- Multiply by M to get g dm^{-3}.

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

5.85/58.44/0.250 =0.4004107... mol/dm^3, reported 0.400; use final **solution** volume.

Dilution

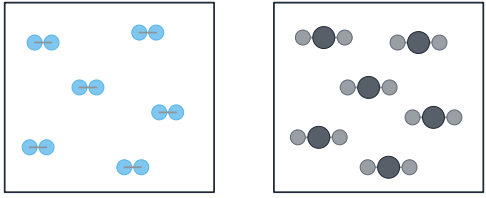
- In simple dilution without reaction/loss, **solute** amount is conserved.
- 25.0 cm^3 stock at 2.00 $\mathrm{mol/dm}^3$ made up to 500 cm^3 final **solution**.

$$c_1 V_1 = c_2 V_2$$

$c_2 = 2.00 \times 25.0/500 = 0.100$ mol dm^{-3}

Avogadro's law

ideal model: same V, T and p



hydrogen, H_2 carbon dioxide, CO_2

same **number**: 6 molecules in each model volume

> The booklet molar volume 22.7 dm^3/mol applies at its stated STP.

Complete methane combustion: dry-gas volumes

1. **Methane.** 20 cm^3 CH_4; compare dry gases at common T,p
2. **Oxygen.** CH_4:O_2 =1:2, so 2×20 =40 cm^3 O_2
3. **Water.** Condensed liquid excluded; hot or wet water vapour needs separate treatment

Decision

20 cm^3 of CO_2

$MgSO_4$ hydrate: interpret the water-loss ratio

1. **Residue.** 4.80−2.46 =2.34 g; n =2.34/120.38 mol
2. **Water.** n =2.46/18.02 mol
3. **Ratio.** Water/salt =7.02294... , consistent with x=7

Decision

Use constant mass and check decomposition, spitting and incomplete drying.

From percentages to a formula

element	% by mass	$\div A_r$ $\rightarrow$ moles	$\div$ smallest (3.33)	ratio
C	40.0	$40.0/12 = 3.33$	1.0	1
H	6.7	$6.7/1 = 6.7$	2.0	2
O	53.3	$53.3/16 = 3.33$	1.0	1

empirical formula CH_2O; $M_r = 180$ gives $180/30 = 6$
molecular formula $C_6H_{12}O_6$

With $M_r = 180$: $C_6H_{12}O_6$

Final volume is not solvent added

1. **Stock.** 10.0 cm^3 at 0.500 mol/dm^3 contains 0.00500 mol
2. **Dilute.** c_2 =0.00500/0.250 =0.0200 mol/dm^3
3. **Interpret.** 250 cm^3 is the final **solution** volume, not water added

Decision

Conserve the amount in the aliquot and use the stated final volume.

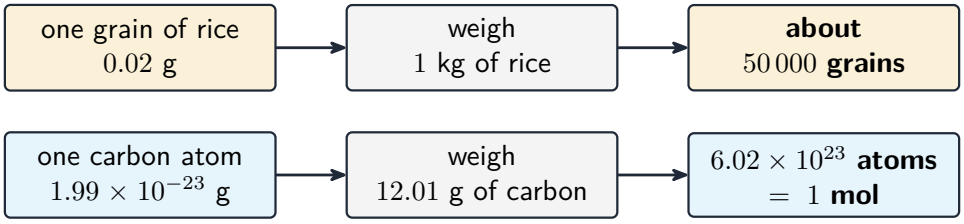
A formula unit is not the total ion count

1. **Input.** 0.200 mol $CaCl_2$; assume complete dissociation
2. **Calcium.** 0.200 mol Ca^{2+}
3. **Chloride.** $2\times0.200 = 0.400$ mol Cl^-
4. **Total.** 0.600 mol ions

Decision

State the entity before multiplying by N_a.

Counting by weighing



mass of one particle$\text{number} = \text{total mass} \div \text{mass of one}$

So 12.01 g holds 6.02×10^{23} atoms: one mole

Preparing a standard solution

Concentration depends on the final **solution** volume and complete transfer.

- Use suitable known-purity **solute** and accurate weighing.
- Dissolve, transfer quantitatively and rinse into the volumetric flask.
- At calibration temperature, make to the mark at eye level and mix.

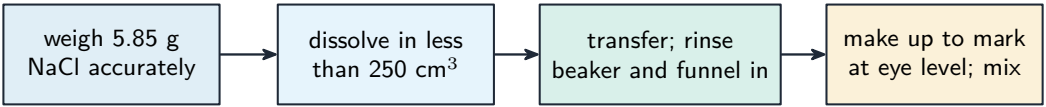
Track each serial-dilution aliquot

1. **First.** 10.0 cm^3 made up to 100.0 cm^3: factor 0.100
2. **Second.** 10.0 cm^3 of that made up to 250.0 cm^3: factor 0.0400
3. **Result.** $0.200 \times 0.100 \times 0.0400 = 0.000800$ mol/dm^3

Decision

The whole first flask is not transferred to the second flask.

Making a standard solution



$n = 5.85/58.44 = 0.100$ mol; $c = 0.100/0.250 = 0.400$ mol dm^{-3}

250 cm^3 of *solution*, not 250 cm^3 of water added

0.400 mol dm^{-3}

Exam tips

> Do not turn a fractional ratio into a whole number by arbitrary rounding.

- Say which particle you count.
- Use data booklet A_r values; round only the final answer.
- Divide cm^3 by 1000 before $c = n/V$.

Check yourself

Try these

Calculate the mass of 3.01×10^{23} molecules of O_2.

Find the formula of a hydrocarbon with 85.6% C and $M_r = 56.12$.

Find the concentration of 2.00 g of NaOH in 500 cm^3.

Find the volume of O_2 needed to burn 50 cm^3 of propane.