CHEMICAL FORMULAE (ANSWERS)

ionic bonds = electrons have been transferred between atoms, resulting in oppositely charged ions that attract each other. Contain cations and anions.

covalent bonds = two atoms share some of their electrons.

Atomic element = one atom e.g. Ne, Xe

Molecular element = elements whose particles are multi-atom molecules (e.g. Cl₂, H₂, P₄).

compounds are generally represented with a chemical formula. Molecular compounds contain non-metals (e.g. H₂O, HCl) and ionic compounds contain cations and anions (e.g. NaCl, Na₂SO₄).

Empirical formula = the kinds of elements found in the compound and the ratio of their atoms.

Molecular formula = the kinds of elements found in the compound and the numbers of their atoms.

Structural formula = the kinds of elements found in the compound, the numbers of their atoms, order of atom attachment, and the kind of attachment.

Models show the 3-dimensional structure along with all the other information given in structural formula.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Empirical formula</th>
<th>Molecular formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. propane</td>
<td>C₃H₈</td>
<td>C₃H₈</td>
</tr>
<tr>
<td>2. benzene</td>
<td>CH</td>
<td>C₆H₆</td>
</tr>
</tbody>
</table>

WRITING IONIC FORMULAS

Write the formula of a compound made from aluminum ions and oxide ions

1. Write the symbol for the metal cation and its charge $\text{Al}^{3+}$ Group 3A
2. Write the symbol for the nonmetal anion and its charge $\text{O}^2$ Group 6A
3. Charge (without sign) becomes subscript for other ion $\text{Al}_{3+}^{2-}$

4. Reduce subscripts to smallest whole number ratio $\text{Al}_2\text{O}_3$

5. Check that the total charge of the cations cancels the total charge of the anions
$\text{Al} = (2)\cdot(+3) = +6$; $\text{O} = (3)\cdot(-2) = -6$

✓ If cation is:
  ➢ metal with invariant charge = metal name
  ➢ metal with variable charge = metal name(charge)
  ➢ polyatomic ion = name of polyatomic ion

✓ If anion is:
  ➢ nonmetal = stem of nonmetal name + ide
  ➢ polyatomic ion = name of polyatomic ion
e.g. Cu$\text{SO}_4$ = copper(II) sulphate; Cu$_2$O = copper(I) oxide; CrO$_3$ = chromium (VI) oxide; K$_2$Cr$_2$O$_7$ = potassium chromate(VI).

Metals with invariant charge see table 3.2, p. 89 (e.g. Na$^+$, Ca$^{2+}$); metals that form cations with different charges; common monoatomic anions (e.g. Cl$^-$, chloride, O$^{2-}$ = oxide); common polyatomic ions (e.g. CH$_3$COO$^-$ or C$_2$H$_3$O$_2^-$ = acetate; NO$_3^-$ = nitrate, SO$_4^{2-}$ = sulphate).

elements in the same column form similar polyatomic ions

same number of O’s and same charge

ClO$_3^-$ = chlorate \ BrO$_3^-$ = bromate

if the polyatomic ion starts with H, add hydrogen- prefix before name and add 1 to the charge: CO$_3^{2-}$ = carbonate \ HCO$_3^-$ = hydrogen carbonate.

-ate ion: chlorate = ClO$_3^-$
-ate ion + 1 O $\Rightarrow$ same charge, per- prefix, perchlorate = ClO$_4^-$
-ate ion – 1 O $\Rightarrow$ same charge, -ite suffix, chlorite = ClO$_2^-$
-ate ion – 2 O $\Rightarrow$ same charge, hypo- prefix, -ite suffix, hypochlorite = ClO$^-$

Writing Formula for Ionic Compounds Containing Polyatomic Ion: Iron(III) phosphate

1. Write the symbol for the cation and its charge Fe$^{3+}$
2. Write the symbol for the anion and its charge PO$_4^{3-}$
3. Charge (without sign) becomes subscript for other ion $\text{Fe}_3\text{PO}_4^{3-}$ $\text{Fe}_3\text{(PO}_4)_3$
4. Reduce subscripts to smallest whole number ratio $\text{FePO}_4$
5. Check that the total charge of the cations cancels the total charge of the anions
$\text{Fe} = (1)\cdot(+3) = +3$; $\text{PO}_4 = (1)\cdot(-3) = -3$

hydrates = crystalline ionic compounds containing a specific number of waters for each formula unit e.g. CuSO$_4$.6H$_2$O = copper(II) sulphate hexahydrate (blue colour). After heating, it becomes CuSO$_4$ (anhydrous copper(II) sulphate - colourless).
**Naming Molecular Compounds**

E.g. Naming $\text{BF}_3$

1. Name the first element: boron
2. Name the second element with an –ide: fluorine $\Rightarrow$ fluoride
3. Add a prefix to each name to indicate the subscript monoboron, trifluoride
4. Write the first element with prefix, then the second element with prefix
5. Drop prefix mono from first element: **boron trifluoride**

1 = mono- *not used on first nonmetal*, 2 = di-, 3 = tri-, 4 = tetra-, 5 = penta-, 6 = hexa-, 7 = hepta-, 8 = octa-, 9 = nona-, 10 = deca-.

**acids** = molecular compounds that form $\text{H}^+$ when dissolved in water

to indicate the compound is dissolved in water (aq) is written after the formula
not named as acid if not dissolved in water

**binary acids** have $\text{H}^+$ cation and nonmetal anion: contain only two different elements (e.g. $\text{HCl(aq)} = \text{hydrochloric acid}$)

**oxyacids** have $\text{H}^+$ cation and polyatomic anion: contain oxygen (e.g. $\text{H}_2\text{SO}_4$ sulphuric acid, $\text{H}_2\text{SO}_3$ sulphurous acid, $\text{HNO}_3$, nitric acid).

**Naming Binary Acids**

write a hydro prefix
follow with the nonmetal name
change ending on nonmetal name to –ic
write the word acid at the end of the name

**Naming Oxyacids**

if polyatomic ion name ends in –ate, then change ending to –ic suffix
if polyatomic ion name ends in –ite, then change ending to –ous suffix

write word acid at end of all names

**PRACTICE EXAMPLE ONE**

Name the following compounds;

- a) KCl  
- b) $\text{HCl}$  
- c) $\text{HCl(aq)}$  
- d) $\text{Na}_2\text{CO}_3$  
- e) $\text{NaHCO}_3$  
- f) $\text{CO}$  
- g) $\text{CO}_2$
- h) $\text{SO}_2$  
- i) $\text{SO}_3$  
- j) $\text{PCl}_5$  
- k) $\text{H}_2\text{SO}_4$  
- l) $\text{NaClO}$  
- m) $\text{ICl}_3$  
- n) $\text{NH}_4\text{Cl}$
- o) $\text{FeSO}_4$  
- p) $\text{Fe}_2(\text{SO}_4)_3$  
- q) $\text{Cu}_2\text{O}$  
- r) $\text{CoSO}_4.7\text{H}_2\text{O}$  
- s) $\text{KMnO}_4$  
- t) $\text{MnO}_2$  
- u) $\text{H}_2\text{SO}_3$

- a) potassium chloride  
- b) hydrogen chloride  
- c) hydrochloric acid  
- d) sodium carbonate  
- e) sodium hydrogen carbonate  
- f) carbon monoxide  
- g) carbon dioxide  
- h) sulphur dioxide  
- i) sulphur trioxide  
- j) phosphorous pentachloride  
- k) sulphuric acid  
- l) sodium hypochlorite  
- m) iodine trichloride  
- n) ammonium chloride  
- o) iron(II) sulphate  
- p) iron(III) sulphate  
- q) copper(I) oxide  
- r) cobalt(II) sulphate heptahydrate  
- s) potassium manganate(VII)  
- t) manganese(IV) oxide  
- u) sulphurous acid.
**Formula Mass** = the mass of an individual molecule or formula unit; also known as **molecular mass** or **molecular weight** = sum of the masses of the atoms in a single molecule or formula unit.

mass of 1 molecule of H₂O = 2(1.01 amu H) + 16.00 amu O = **18.02 amu**

The relative masses of molecules can be calculated from atomic masses. Since 1 mole of H₂O contains 2 moles of H and 1 mole of O. Molar Mass = 1 mole H₂O = 2(1.01 g H) + 16.00 g O = **18.02 g**/mole or **gmol⁻¹**.

**Percent composition** = % of each element in a compound by mass = \[
\frac{\text{part}}{\text{whole}} \times 100\% \quad \text{or} \quad \frac{\text{mass of element}}{\text{molar mass}} \times 100\%.
\]

Benzaldehyde is 79.2% carbon. What mass of benzaldehyde contains 19.8 g of C?

Solution: 100g benzaldehyde contains 79.2 g carbon

\[
19.8 \text{ g C} \times \frac{100 \text{g benzaldehyde}}{79.2 \text{ g C}} = 25.0 \text{ g benzaldehyde}
\]

**FINDING AN EMPIRICAL FORMULA & MOLECULAR FORMULA**

1. convert the percentages to grams
2. assume you start with 100 g of the compound
3. skip if already grams
4. convert grams to moles
5. use molar mass of each element
6. write a pseudoformula using moles as subscripts
7. divide all by smallest number of moles
8. if result is within 0.1 of whole number, round to whole number
9. multiply all mole ratios by number to make all whole numbers
10. if ratio 0.5, multiply all by 2; if ratio 0.33 or 0.67, multiply all by 3; if ratio 0.25 or 0.75, multiply all by 4; etc.
11. skip if already whole numbers

- The **molecular formula** is a multiple of the **empirical formula**
- To determine the molecular formula you need to know the empirical formula and the **molar mass** of the compound

Laboratory analysis of aspirin determined the following mass percent composition. C = 60.00%, H = 4.48%, O = 35.53%. Find the empirical formula. If the molar mass is 180.17 g/mol, then workout the molecular formula.

Solution: in 100 g of aspirin there are 60.00 g C, 4.48 g H, and 35.53 g O.

1 mole C = 12.01 g C, 1 mole H = 1.008 g H, 1 mole O = 16.00 g O.
Pseudoformula: $C_{4.996}H_{4.44}O_{2.220}$

$\frac{2.220}{4.996} = 0.444$ mole C
$\frac{2.220}{4.44} = 0.222$ mole H
$\frac{2.220}{2.220} = 1.000$ mole O

$= C_{2.25}H_{2.0}O_1 \times 4$ (make whole numbers) $\iff C_9H_8O_4$

As $C_9H_8O_4 = n = 1 = 180.17$, then there is no need to multiply so this is the molecular formula.

PRACTICE EXAMPLE TWO

Find the empirical formulae of the following compounds which contained:

(a) 5.85 g K; 2.10 g N; 4.80 g O
(b) 3.22 g Na; 4.48 g S; 3.36 g O
(c) 22.0% C; 4.6% H; 73.4% Br (by mass)

(a) $\_\_KNO_2$

(b) $\_\_Na_2S_2O_3$

(c) $\_\_C_2H_5Br$

a) $\frac{5.85}{39.1} = 0.15$ mole K; $\frac{2.1}{14.01} = 0.15$ mole N; $\frac{4.8}{16} = 0.3$ K$_{0.15}$N$_{0.15}$O$_{0.3}$

$= KNO_2$

b) $\frac{3.22}{22.99} = 0.14$ mole Na; $\frac{4.48}{32.07} = 0.16$ mole S; $\frac{3.36}{16} = 0.21$ = Na$_{0.14}$S$_{0.16}$O$_{0.21}$ = Na$_2$S$_2$O$_3$

Assume 100g so $\frac{22}{12.01} = 1.83$ mole C; $\frac{4.6}{1.01} = 4.55$ mole H; $\frac{73.4}{79.9} = 1.09$ mole Br

$C_{1.83}H_{4.55}Br_{1.09} = C_2H_5Br$

Benzopyrene has a molar mass of 252 g and an empirical formula of $C_5H_3$. What is its molecular formula? ($C = 12.01, H=1.01$).

$5 x 12.01 = 60.05$ g
$3 x 1.01 = 3.03$ g
$63.08 = 63.08$ so molecular formula = $4 x (C_5H_3)$ = $C_{20}H_{12}$

$[\text{ans} = C_{20}H_{12}]$

A compound containing 40% carbon, 6.73% hydrogen and 52.28% oxygen was shown to have a molar mass of 60.06 g mol$^{-1}$ by mass spectrometry. Use this information to work out its molecular formula.
\[
\begin{align*}
40/12.01 &= C = 3.33; \quad 6.73/1.01 = 6.66 \text{ H}; \quad 16/52.28 = 3.27 \text{ O. } CH_2O = 30.03 \text{ so } n = 60.02/30.03 = 2 \text{ so molecular formula } = 2 \times (CH_2O) = C_2H_4O_2
\end{align*}
\]

\[
\text{COMBUSTION ANALYSIS}
\]

Menthol, the substance we can smell in mentholated cough drops, is composed of C, H, and O. A 0.1005 g sample of menthol is combusted, producing 0.2829 g of CO\(_2\) and 0.1159 g of H\(_2\)O. \textbf{What is the empirical formula for menthol?} (x is a multiplication operator).

\[
\begin{align*}
0.2829 \text{ g of CO}_2 \times \frac{1 \text{ mol CO}_2}{44.0 \text{ g CO}_2} &= 0.006430 \text{ mol CO}_2 \times \frac{1 \text{ mol C}}{1 \text{ mol CO}_2} = 0.006430 \text{ mol C} \\
0.1159 \text{ g of H}_2O \times \frac{1 \text{ mol H}_2O}{18.0 \text{ g H}_2O} &= 0.006439 \text{ mol H}_2O \times \frac{2 \text{ mol H}}{1 \text{ mol H}_2O} = 0.01288 \text{ mol H}
\end{align*}
\]

Now we need to convert the moles to grams of these elements

\[
\begin{align*}
0.006430 \text{ mol C} \times \frac{12.0 \text{ g C}}{1 \text{ mol C}} &= 0.07716 \text{ g C} \\
0.001288 \text{ mol H} \times \frac{1.0 \text{ g H}}{1 \text{ mol H}} &= 0.01288 \text{ g H}
\end{align*}
\]

Find the mass of Oxygen by subtracting the C and H from the total mass of the sample

\[
\text{Total= mass C + mass H + mass O} = 0.1005 \text{ g} = 0.07716 \text{ g C} + 0.01288 \text{ g H} + \text{mass O}
\]

mass O = 0.01046 g O

Convert to moles of O

\[
0.01046 \text{ g O} \times \frac{1 \text{ mol O}}{16.0 \text{ g O}} = 0.0006538 \text{ mol O}
\]

Finally find the mole ratio by dividing by the smallest quantity
0.006430 mol C / 0.0006538 = 9.83 ≈ 10
0.01288 mol H / 0.0006538 = 19.70 ≈ 20
0.0006538 mol O / 0.0006538 = 1

Empirical Formula C_{10}H_{20}O

**PRACTICE EXAMPLE THREE**

a) Upon combustion, a compound containing only carbon and hydrogen produced 1.60 g CO₂ and 0.819 g H₂O. Calculate the empirical formula.

Ans = C₂H₅

\[
\frac{1.60}{44.01} = 0.0364 \text{ moles CO}_2 = 0.0364 \text{ moles C}; \frac{0.819}{18.02} = 0.0454 \text{ moles H}_2O = 2 \times 0.0454 = 0.0908 \text{ moles H so } C_{0.0364}H_{0.0908} = CH_{2.5} = C_2H_5 \text{ (make whole number)}
\]

b) Upon combustion, a 0.8009 g sample of compound containing carbon, hydrogen, and oxygen produced 1.6004 g CO₂ and 0.6551 g H₂O. Calculate the empirical formula of the compound.

\[
\frac{1.6004}{44.01} = 0.0364 \text{ moles CO}_2; \frac{0.6551}{18.01} = 0.0364 \text{ moles H}_2O.
\]

= 0.0364 moles C; 2 x 0.0364 = 0.0728 moles H so mass C and H = 0.0364 x 12.01 = 0.437 g C and 0.0728 x 1.008 = 0.0734 g H; Mass O = 0.8009 - (0.437 + 0.0734) = 0.2905 g O. So moles O = 0.2905 / 16 = 0.0182 moles O = C_{0.0364}H_{0.0728}O_{0.0182} = C_2H_4O

**CHEMICAL REACTIONS**

CH₄(g) + 2O₂(g) → CO₂(g) + 2 H₂O(g)

- this equation is balanced, meaning that there are equal numbers of atoms of each element on the reactant and product sides
- to obtain the number of atoms of an element, multiply the subscript by the coefficient
- symbols used to indicate state after chemical
  - (g) = gas; (l) = liquid; (s) = solid
  - (aq) = aqueous = dissolved in water
Organic compounds are composed of carbon and hydrogen and sometimes a few other elements. Many organic compounds contain carbon, hydrogen, oxygen and/or nitrogen. Organic compounds may be divided into hydrocarbons containing carbon and hydrogen (e.g. methane CH₄, ethene, C₂H₄) and functionalised hydrocarbons containing carbon, hydrogen and at least one other element - usually a non-metal (e.g. ethanol, C₂H₅OH, ethanoic or acetic acid CH₃CO₂H). They contain covalent bonding. Carbon covalently bonded to a metal is also known, such as a transition metal (organometallic compound e.g. CH₃CH₂MgCl ethylmagnesium chloride).

Name of hydrocarbon = base name (number of C atoms) + suffix (number of multiple bonds)

Base names: C = 1 = meth-, 2 = eth-, 3 = prop-, 4 = but-, 5 = pent-, 6 = hex-, 7 = hept-, 8 = oct-, 9 = non-, 10 = dec-. E.g. C = 3 = propane.

C-C = alkane e.g. CH₃CH₂CH₂ = propane
C=C = alkene e.g. CH₂=CHCH₃ = propene
C≡C = alkyne e.g. HC≡CCH₃

Family = a group of compounds with the same functional group:

alcohol
CH₃CH₂-OH (ethanol)
ether
CH₃CH₂-O-CH₂CH₃ (diethyl ether)
aldehyde
H₃C-CHO (ethanal)
ketone
H₃C-C-CH₃ (propanone or acetone)
carboxylic acid
H₃C-COOH (ethanoic or acetic acid)
ester
H₃C-C-CH₂OCH₃ (methyl ethanoate)
amine
H₃CCH₂-N-H (ethyl amine)

amide
(e.g. protein linkage)
(N-methylpropanamide)