

2.3 FORMULAE

Learning outcomes

Candidates should be able to:

- 1 write formulae of ionic compounds from ionic charges and oxidation numbers (shown by a Roman numeral), including:
 - (a) the prediction of ionic charge from the position of an element in the Periodic Table
 - (b) recall of the names and formulae for the following ions: NO_3^- , CO_3^{2-} , SO_4^{2-} , OH^- , NH_4^+ , Zn^{2+} , Ag^+ , HCO_3^- , PO_4^{3-}
- 2 (a) write and construct equations (which should be balanced), including ionic equations (which should not include spectator ions)
 - (b) use appropriate state symbols in equations
- 3 define and use the terms empirical and molecular formula
- 4 understand and use the terms anhydrous, hydrated and water of crystallisation
- 5 calculate empirical and molecular formulae, using given data

Some common ions

OH^- , NO_3^- , CO_3^{2-} , SO_4^{2-} , HCO_3^- , PO_4^{3-} , NH_4^+ , Zn^{2+} , Ag^+

1. There are many naturally occurring hydrated compounds that contain the anion PO_4^{3-} . Name the anion PO_4^{3-} . [1]

1. Which pair of formulae is correct?

- A Ag_2CO_3 and $(\text{NH}_4)_3\text{NO}_3$
 B K_2HCO_3 and $\text{Zn}_3(\text{PO}_4)_2$
 C AgHCO_3 and K_3PO_4
 D ZnCO_3 and $(\text{NH}_4)_2\text{PO}_4$

2. Which pair of formulae is correct?

- A Ca_2SO_4 and MgCl_2
 B Na_2HCO_3 and $\text{Zn}_3(\text{PO}_4)_2$
 C NH_4HCO_3 and K_2SO_4
 D ZnNO_3 and $(\text{NH}_4)_2\text{OH}$

3. Compound Q contains 40% carbon by mass. What could Q be?

- a. glucose, $\text{C}_6\text{H}_{12}\text{O}_6$
 b. starch, $(\text{C}_6\text{H}_{10}\text{O}_5)_n$
 c. sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$

4. Compounds J and K each contain 40% carbon by mass. What could J and K be?

	J	K
A	a hexose, $\text{C}_6\text{H}_{12}\text{O}_6$	starch, $(\text{C}_6\text{H}_{10}\text{O}_5)_n$
B	a pentose, $\text{C}_5\text{H}_{10}\text{O}_5$	a hexose, $\text{C}_6\text{H}_{12}\text{O}_6$
C	a pentose, $\text{C}_5\text{H}_{10}\text{O}_5$	sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$
D	starch, $(\text{C}_6\text{H}_{10}\text{O}_5)_n$	sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$

5. Which sodium compound contains 74.2% by mass of sodium?

A sodium carbonate

B sodium chloride

C sodium hydroxide

D sodium oxide

Writing balanced equations

[Balancing Chemical Equations \(colorado.edu\)](http://colorado.edu)

Use above link to play games related to balancing equations.

2. HI reacts with oxygen to form iodine and water.

Construct an equation for the reaction of HI with oxygen.

[1]

3. Magnesium and lithium both form nitrides with N_2 . These compounds both contain the N^{3-} ion.

Write an equation for the reaction of magnesium with N_2 to form magnesium nitride.

[1]

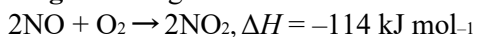
4. Bismuth reduces water to form bismuth oxide, Bi_2O_3 . A colourless gas that ignites with a squeaky pop also forms. Construct an equation for the reduction of water by bismuth.

[1]

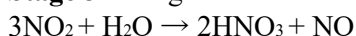
5. Nitric acid can be made in a 3-stage process.

Stage 1 Ammonia is oxidised by oxygen from the air, to form nitrogen monoxide and water. This reaction is carried out at 10–13 atmospheres pressure and 900°C in the presence of a platinum catalyst.

Stage 2 Nitrogen monoxide reacts with more oxygen to form nitrogen dioxide.



Stage 3 Nitrogen dioxide reacts with water to make nitric acid and nitrogen monoxide.



Write an equation to show the reaction occurring in stage 1.

[1]

6. Silicon shows the same type of bonding and structure as diamond.

Silicon reacts with magnesium to form Mg_2Si .

Solid Mg_2Si reacts with dilute hydrochloric acid to form gaseous SiH_4 and a solution of magnesium chloride.

Construct an equation for this reaction. Include state symbols.

[2]

7. Sodium oxide and silicon(IV) oxide react to form sodium silicate(IV), Na_2SiO_3 .

Sodium oxide is obtained from the thermal decomposition of sodium carbonate.

Write equations for the following reactions:

(i) sodium oxide with silicon(IV) oxide

[1]

(ii) the thermal decomposition of sodium carbonate, forming sodium oxide and carbon dioxide.

[1]

8. PCl_5 , PCl_3 and NCl_3 are halides of Group 15 elements.
 PCl_5 can be formed from the reaction of phosphorus with chlorine. PCl_5 has a melting point of 161°C .
 (i) Write an equation for the formation of PCl_5 from the reaction of phosphorus and chlorine. [1]
9. Solid magnesium nitride, Mg_3N_2 , is a crystalline solid.
 Magnesium nitride reacts with an excess of water to produce ammonia and magnesium hydroxide only. Construct an equation to describe this reaction. [1]
6. Aluminium carbide, Al_4C_3 , reacts readily with aqueous sodium hydroxide. The two products of the reaction are NaAlO_2 and a hydrocarbon. Water molecules are also involved as reactants.
 What is the formula of the hydrocarbon?
- A CH_4 B C_2H_6 C C_3H_8 D C_6H_{12}
7. If ammonium cyanate is heated in the absence of air, the only product of the reaction is urea, $\text{CO}(\text{NH}_2)_2$. No other products are formed in the reaction.
 What is the formula of the cyanate ion present in ammonium cyanate?
- A CON_2^- B CON_2^{2-} C OCN^- D OCN^{2-}
8. A student reacts 1 mol of copper with concentrated nitric acid to produce 1 mol of copper(II)nitrate, 2 mol of water and substance X. No other product is formed.
 Substance X does not contain copper or hydrogen.
 What could be substance X?
- A N_2 B N_2O C NO D NO_2
9. Chlorine dioxide, ClO_2 , reacts with aqueous sodium hydroxide to produce water and a mixture of two sodium salts, NaClO_2 and NaClO_3 .
 What is the mole ratio of NaClO_2 to NaClO_3 in the product mixture?
- A 1 : 2 B 3 : 5 C 1 : 1 D 5 : 3
10. Zinc atoms can be oxidised to Zn^{2+} ions by dichromate(VI) ions in acid solution. Chromium is reduced to Cr^{3+} in this reaction.
 Which equation is correct?
- A $\text{Cr}_2\text{O}_7^{2-} + \text{Zn} + 14\text{H}^+ \rightarrow 2\text{Cr}^{3+} + \text{Zn}^{2+} + 7\text{H}_2\text{O}$
 B $\text{Cr}_2\text{O}_7^{2-} + \text{Zn} + 14\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{Zn}^{2+} + 7\text{H}_2\text{O}$
 C $\text{Cr}_2\text{O}_7^{2-} + 3\text{Zn} + 14\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{Zn}^{2+} + 7\text{H}_2\text{O}$
 D $2\text{Cr}_2\text{O}_7^{2-} + 3\text{Zn} + 14\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{Zn}^{2+} + 7\text{H}_2\text{O}$

11. Which equation correctly describes the complete combustion of an alkene, C_nH_{2n} ?

- A $C_nH_{2n} + \frac{2}{3} nO_2 \rightarrow nCO_2 + 2nH_2O$
- B $C_nH_{2n} + \frac{3}{2} nO_2 \rightarrow nCO_2 + nH_2O$
- C $C_nH_{2n} + 2nO_2 \rightarrow nCO_2 + nH_2O$
- D $C_nH_{2n} + 2nO_2 \rightarrow nCO_2 + 2nH_2O$

12. Originally, chemists thought indium oxide had the formula InO . By experiment, they showed that 4.8 g of indium combined with 1.0 g of oxygen to produce 5.8 g of indium oxide. The A_r of oxygen was known to be 16. Which value for the A_r of indium is calculated using these data?

A 38

B 77

C 115

D 154

13. A sample of solid ammonium chloride decomposes on heating.
solid ammonium chloride $\rightarrow$ ammonia gas + hydrogen chloride gas
A total of 2.4×10^{21} molecules of gas is formed.
How many hydrogen atoms are present in the gaseous products?

A 1.2×10^{21}

B 2.4×10^{21}

C 4.8×10^{21}

D 9.6×10^{21}

[What are ionic equations and ionic half-equations? \(chemistrytutor.me\)](http://chemistrytutor.me)

Use this link to learn in more depth about writing ionic equations.

Empirical formula

The simplest whole number ratio of the elements present in one molecule or formula unit of the compound.

10. Deduce the empirical formula of the following compounds.

a. Hexane (C_6H_{12})

b. Glucose ($C_6H_{12}O_6$)

c. Ethanoic acid (CH_3COOH)

d. Water (H_2O)

e. Hydrazine (NH_2NH_2)

11. Ethanedioic acid, $\text{HO}_2\text{CCO}_2\text{H}$, has a relative molecular mass of 90.0.
State the empirical formula of ethanedioic acid. [1]
12. The composition by mass of a hydrocarbon is 10% hydrogen and 90% carbon. Deduce the empirical formula of this hydrocarbon.
13. Tungsten oxide, W_xO_y , is used to give colour to ceramic materials.
A sample of W_xO_y contains 79.29% tungsten by mass.
Calculate the empirical formula of W_xO_y .
Show your working. [3]
14. 100 g of pure boron carbide contains 78.26 g of boron.
Calculate the empirical formula of boron carbide.
Show your working. [2]

14. Compound X consists of 40.0% carbon, 6.7% hydrogen and 53.3% oxygen by mass.
What is the empirical formula of compound X?

A CH₂O

B C₂H₂O

C C₂H₄O

D CHO

15. Compound X is an organic compound that contains 30.6% carbon, 3.8% hydrogen, 20.4% oxygen and 45.2% chlorine by mass.
What is the empirical formula of X?

A C₂H₃OC/

B C₂H₄OC/

C C₃H₄OC/

D C₄H₃O₂Cl₂

Anhydrous, hydrated and water of crystallisation

Water of crystallization: a specific number of moles of water associated with a crystal structure.

Hydrated compound: a compound which contains a definite number of moles of water in their structure

Anhydrous: containing no water of crystallization

15. Calculate the relative formula mass of CuSO₄·5H₂O. [1]

16. Calculate the relative formula mass of FeSO₄·xH₂O. [1]

17. Calculate the relative formula mass of (NH₄)₂Fe(SO₄)₂·xH₂O. [1]

18. Struvite is a soft hydrated mineral with $M_r = 245.3$. The anhydrous form of the mineral has the formula NH_4MgPO_4 .

Calculate the number of molecules of water of crystallisation in struvite.

Give your answer to the nearest integer. Show your working.

[2]

16. A sample of 35.6 g of hydrated sodium carbonate contains 25.84% sodium ions by mass.

When this sample is heated, anhydrous sodium carbonate and water are formed.

Which mass of water is given off?

A 7.2 g

B 10.6 g

C 14.4 g

D 21.2 g

17. Hydrated cobalt(II) sulfate loses water when heated to give anhydrous cobalt(II) sulfate. All the water of crystallisation is lost to the atmosphere as steam.

When 3.10 g of hydrated cobalt(II) sulfate, $\text{CoSO}_4 \cdot x\text{H}_2\text{O}$, is heated to constant mass the loss in mass is 1.39 g.

What is the value of x , to the nearest whole number?

A 4

B 6

C 7

D 11

18. Glauber's salt consists of crystals of hydrated sodium sulfate, $\text{Na}_2\text{SO}_4 \cdot x\text{H}_2\text{O}$, which can be used for the manufacture of detergents.

When a sample of Glauber's salt was heated, 1.91 g of water was removed leaving 1.51 g of anhydrous Na_2SO_4 .

What is the value of x in $\text{Na}_2\text{SO}_4 \cdot x\text{H}_2\text{O}$?

A 1

B 8.85

C 10

D 11.25

19. The equation shown in (a)(i) describes the reaction which occurs when aqueous potassium iodide is added to aqueous copper(II) sulfate. A white precipitate of copper(I) iodide forms in a brown solution of iodine and potassium sulfate.

(i) Balance the equation.



(ii) In the reaction above, a student uses 17.43 g of $\text{CuSO}_4 \cdot y\text{H}_2\text{O}$. By further titration of the reaction products the student concludes that the total amount of CuSO_4 in the sample is 0.0982 mol.

Use the *Data Booklet* to complete the table to calculate the value of y , where y is an integer.

Show your working.

mass of 0.0982 mol CuSO_4	 g
amount of H_2O in 17.43 g of $\text{CuSO}_4 \cdot y\text{H}_2\text{O}$	 mol H_2O
value of y	$y = \text{.....}$

20. Hydrated rhodium(III) chloride, $\text{RhCl}_3 \cdot x\text{H}_2\text{O}$, catalyses the conversion of ethene to but-2-ene.

Both stereoisomers of but-2-ene are formed in the reaction.

(i) Hydrated rhodium(III) chloride contains 20.5% by mass of water of crystallisation.

Deduce the integer value of x in $\text{RhCl}_3 \cdot x\text{H}_2\text{O}$.

Show your working.

$x = \text{.....}$

[2]

21. An experiment is carried out to determine the value of x in hydrated lithium hydroxide, $\text{LiOH} \cdot x\text{H}_2\text{O}$. A sample of the solid is heated in a crucible over a Bunsen flame.

Complete dehydration takes place; decomposition does not occur.

mass of empty crucible / g = Q

mass of crucible with $\text{LiOH} \cdot x\text{H}_2\text{O}$ / g = R

mass of crucible and residue after heating / g = S

Which equation gives the correct value of x ?

- A $\frac{S-R}{18}$ B $\frac{R-S}{18}$ C $\frac{23.9(R-S)}{18(S-Q)}$ D $\frac{23.9(S-R)}{18(S-Q)}$

This is not a complete note. It is to guide you. It is recommended to study the prescribed textbooks along with this material.

