

Balancing equations

Specification reference

- 2.1.2 a) (i) b)

Introduction

Writing balanced equations is something that you will be asked to do throughout your chemistry course. A balanced equation is a way of summarising and visualising what happens in a chemical reaction, and it allows chemists to calculate the quantities of substance that react.

Even experienced students can make mistakes in balancing chemical equations. This support sheet provides you with some activities to help avoid making these mistakes when you balance equations.

Learning outcomes

After completing the worksheet you should be able to:

- construct formulae of ionic compounds from ionic charges
- construct balanced chemical equations including state symbols for familiar and unfamiliar reactions.

Background

You can read about balancing equations in Topic 2.3: 'Formulae and equations'. If you are finding it difficult to balance equations, you may find the flow chart in Figure 1 helpful. The flow chart takes you through the process of balancing equations and also reminds you of things to be careful about at each stage. There are also some useful tips for successful balancing.

You may not always need to write an equation from scratch – sometimes you will be given the word equation or the formulae of the substances involved. In these cases, just start at the appropriate point on the flow chart.

Remember that, in exam questions, you may also be asked to add state symbols to your equation. There will always be some useful clues in the question to help you to do this, but students often lose marks by forgetting about this final step in the question.

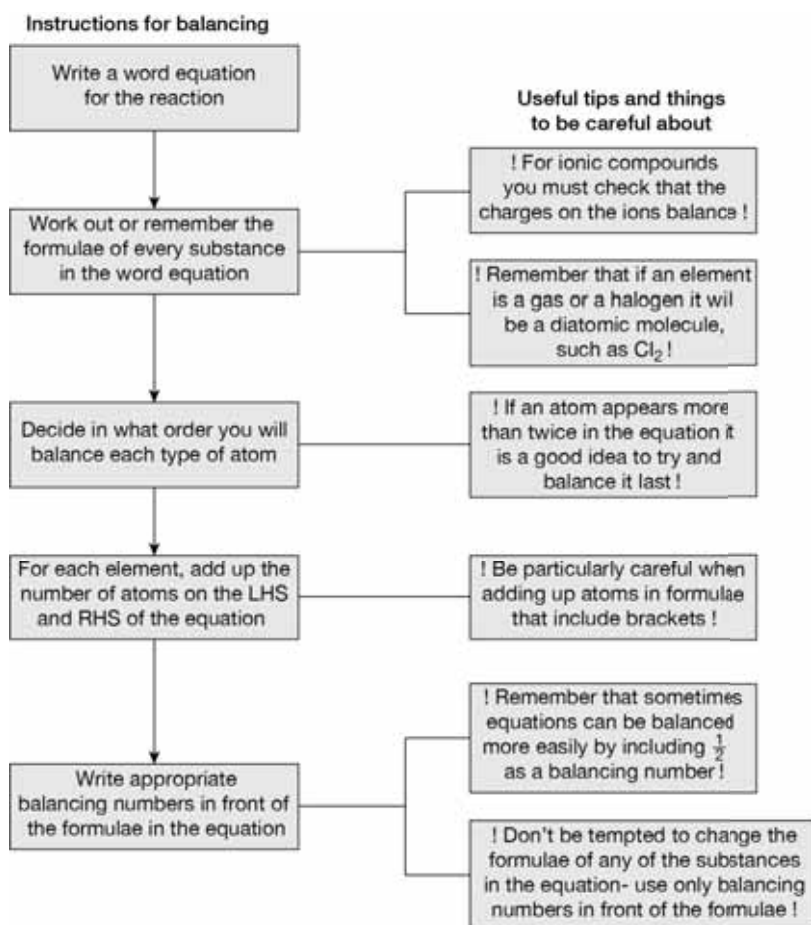


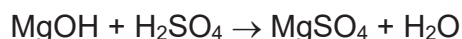
Figure 1 Flow chart of steps for balancing chemical equations

Task

Some students tried to balance equations. Each of them found themselves stuck and unable to write a balanced equation.

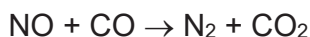
Use the hints and tips in the flow chart in Figure 1 to decide where they are going wrong, and then write a correct balanced equation.

- 1 Adam tried to balance an equation for the reaction between magnesium hydroxide and sulfuric acid. He got as far as writing the formulae of the substances involved, constructing the equation below.

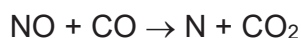


Adam then could not find a way of balancing the equation. Suggest what he has done wrong. Construct the correct balanced equation. (2 marks)

- 2 Becky is given an equation to balance, as below.



She balances it by rewriting it as



Suggest what she has done wrong. Construct the correct balanced equation. (2 marks)

- 3 Claire has got as far as writing the formulae for an equation showing the decomposition of lead(II) nitrate, as below.

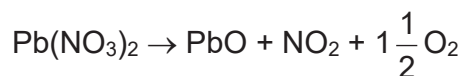


She adds up the number of atoms on each side, using Table 1.

Table 1 Number of atoms in the equation of the decomposition of lead(II) nitrate

Atom	No. on left hand side	No. on right hand side
Pb	1	1
N	1	1
O	6	5

She then balances the equation in this way



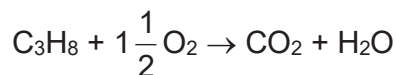
Suggest what she has done wrong. Construct the correct balanced equation.

(2 marks)

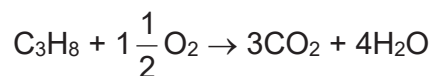
- 4 Dinesh is balancing a combustion reaction:



He decides to balance the oxygen first:



He then balances the hydrogen and carbon:



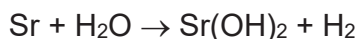
Suggest what he has done wrong. Construct the correct balanced equation.

(2 marks)

Exam-style question

- 1 Strontium is a metal in Group 2 of the periodic table. It reacts fairly rapidly with water to produce an alkaline solution. This solution can then react with acids to produce a range of salts. Other metals may behave in a similar way.

- a i Construct a balanced equation for the reaction of strontium with water, based on the unbalanced equation:



(2 marks)

- ii A student notices that when a piece of lithium, a Group 1 metal, is added to water, it behaves in a similar way to strontium. Name the two substances that will be formed in this reaction.

(2 marks)

- b When solid strontium hydroxide reacts with hydrochloric acid, a neutralisation reaction occurs, forming a salt and water.

- i Construct a word equation for this neutralisation reaction.

(2 marks)

- ii State the formula of the salt that is formed.

(1 mark)

- c Another salt of strontium is strontium nitrate, $\text{Sr}(\text{NO}_3)_2$. If a solid sample of this nitrate is heated it decomposes to form strontium oxide. Nitrogen dioxide and oxygen gases are given off. Construct a balanced equation for this reaction, including state symbols.

(3 marks)

Answers**Tasks**

- 1 Adam has written an incorrect formula for magnesium hydroxide. (1 mark)

Using the charges on the ions (Mg^{2+} and OH^-) the correct formula is $\text{Mg}(\text{OH})_2$

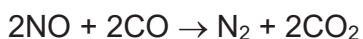
A correct balanced equation is: $\text{Mg}(\text{OH})_2 + \text{H}_2\text{SO}_4 \rightarrow \text{MgSO}_4 + 2\text{H}_2\text{O}$ (1 mark)

- 2 Becky has changed the formula of nitrogen from N_2 to N . (1 mark)

Keeping the formula as N_2 , the equation can easily be balanced by using a $\frac{1}{2}$:

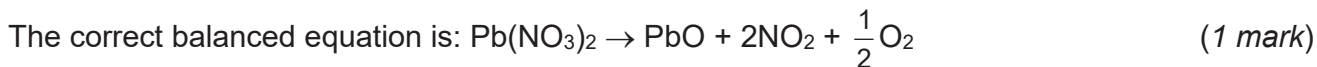


Alternatively, the numbers can be doubled up, to give the same ratios:



- 3 Claire has added up the number of atoms in the brackets incorrectly. The correct figures for the left hand side are nitrogen: 2 and oxygen: 6. She has also put the incorrect number of oxygen atoms on the right hand side. There are 5, not 6 oxygen atoms on the right-hand side. (1 mark)

This means that a 2 must be placed before the N in nitrogen dioxide to balance the nitrogen atoms, and then the oxygen atoms must be added up again.



Alternatively, the numbers can be doubled up, to give the same ratios:



- 4 Dinesh has not successfully balanced the oxygen on both sides of the equation. He should have balanced the oxygen last of all, since it appears more than twice in the equation. (1 mark)

A good order to balance these atoms would be: carbon, hydrogen and then oxygen.

There are three carbon atoms in C_3H_8 so there will be three carbon dioxide molecules on the right hand side.

There are eight hydrogen atoms in C_3H_8 so there will be four water molecules on the right hand side.

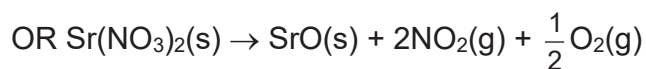
That now makes ten oxygen atoms on the right hand side, so there must be five oxygen molecules on the left hand side. The balanced equation is therefore:

**Exam-style question**

- 1 a i $\text{Sr} + 2\text{H}_2\text{O} \rightarrow \text{Sr}(\text{OH})_2 + \text{H}_2$
Left hand side correct. (1 mark)
Right hand side correct. (1 mark)
ii lithium hydroxide (1 mark)
hydrogen (1 mark)
b i strontium hydroxide + hydrochloric acid \rightarrow strontium chloride + water (1 mark for each product)



(1 mark)

NO₂ balancing correct.

(1 mark)

SrO and O₂ balancing correct.

(1 mark)

State symbols correct.

(1 mark)

Calculating empirical and molecular formulae

Specification reference

- 2.1.3 b) (i) (ii) c)

Learning outcomes

After completing the activity you should be able to:

- calculate the empirical formula of a compound from given data
- use the relative formula mass to deduce the molecular formula of a compound.

Worked example

A 2.84 g sample of phosphorus oxide was analysed and found to contain 1.24 g of phosphorous.

Questions

- Calculate the empirical formula of the compound.
- The compound has a formula mass of 142. State the formula of the compound.

The mass of oxygen = 2.84 g – 1.24 g = 1.60 g

	P	O
Mass of element	1.24	1.60
A_r of element (relative atomic mass)	31	16
Number of moles	$\frac{1.24}{31} = 0.04$	$\frac{1.60}{16} = 0.1$
Ratio of elements	$\frac{0.04}{0.04} = 1$	$\frac{0.1}{0.04} = 2.5$
Simplest whole number ratio of elements	2	5

Answers to questions

- The empirical formula is P_2O_5 .
- The mass of the empirical formula = $(2 \times 31) + (5 \times 16) = 142$. So the mass of the molecular formula is the same as the empirical formula, therefore, the formula of the compound is P_2O_5 .

Questions

- 1 A sample of a nitrogen oxide was analysed and found to contain 0.28 g of nitrogen and 0.64 g of oxygen by mass. (2 marks)
($A_r \text{ N} = 14$, $A_r \text{ O} = 16$)
- a Calculate the empirical formula of the compound and select the correct answer from:
- N_2O
 - NO
 - NO_2
- b The compound has a formula mass of 46. State the molecular formula of the compound.
- 2 A sample of an alcohol was analysed and found to contain 0.300 g of carbon, 0.075 g of hydrogen and 0.200 g of oxygen by mass. (2 marks)
($A_r \text{ C} = 12$, $A_r \text{ H} = 1$, $A_r \text{ O} = 16$)
- a Calculate the empirical formula of the compound and select the correct answer from:
- CH_4O
 - $\text{C}_2\text{H}_6\text{O}$
 - CHO
- b The compound has a formula mass of 46. State the molecular formula of the compound.
- 3 A 0.84 g sample of a hydrocarbon was analysed and found to contain 0.72 g of carbon. (2 marks)
($A_r \text{ C} = 12$, $A_r \text{ H} = 1$)
- a Calculate the mass of hydrogen in this sample and select the correct answer from:
- 1.56 g
 - 0.12 g
 - 0.42 g
- b Calculate the empirical formula of the compound.
- c The compound has a formula mass of 42. State the molecular formula of the compound.
- 4 A 0.28 g sample of a hydrocarbon was analysed and found to contain 0.24 g of carbon. (2 marks)
($A_r \text{ C} = 12$, $A_r \text{ H} = 1$)
- a Calculate the mass of hydrogen in this sample.
- b Calculate the empirical formula of the compound.
- c The compound has a formula mass of 28. State the molecular formula of the compound.

-
- 5** A sample of a hydrocarbon was analysed and found to contain 1.80 g of carbon and 0.35 g of hydrogen. (2 marks)
- ($A_r \text{ C} = 12$, $A_r \text{ H} = 1$)
- a** Calculate the empirical formula of the compound.
- b** The compound has a formula mass of 86. State the molecular formula of the compound.

Answers

- 1**
- a** NO_2 (1 mark)
- b** NO_2 (1 mark)
- 2**
- a** $\text{C}_2\text{H}_6\text{O}$ (1 mark)
- b** $\text{C}_2\text{H}_6\text{O}$ (1 mark)
- 3**
- a** 0.12 g (1 mark)
- b** CH_2 (1 mark)
- c** C_3H_6 (1 mark)
- 4**
- a** 0.04 g (1 mark)
- b** CH_2 (1 mark)
- c** C_2H_4 (1 mark)
- 5**
- a** C_3H_7 (1 mark)
- b** C_6H_{14} (1 mark)

Ionic and covalent bonding

Specification reference

- 2.2.2 a) b) c) d) e) (i)

Learning outcomes

After completing this worksheet you should be able to:

- describe the bonding in ionic and covalent compounds and the properties resulting from these
- compare the bonding in ionic compounds and simple molecular substances.

Questions

1 Ionic bonding involves the transfer of electrons. The electrons are transferred from metal atoms to non-metal atoms. The metal atoms become positively charged ions and the non-metal atoms become negatively charged ions. Upon transfer, both sets of ions have a full outer shell of electrons. Ionic bonding is therefore the electrostatic attraction between the oppositely charged ions.

- a Sodium reacts with chlorine to form the ionic compound sodium chloride. Construct a balanced symbol equation for this reaction. (1 mark)
- b Copy and complete the dot-and-cross diagram in Figure 1 to show the sodium ions and chloride ions in this compound. (4 marks)

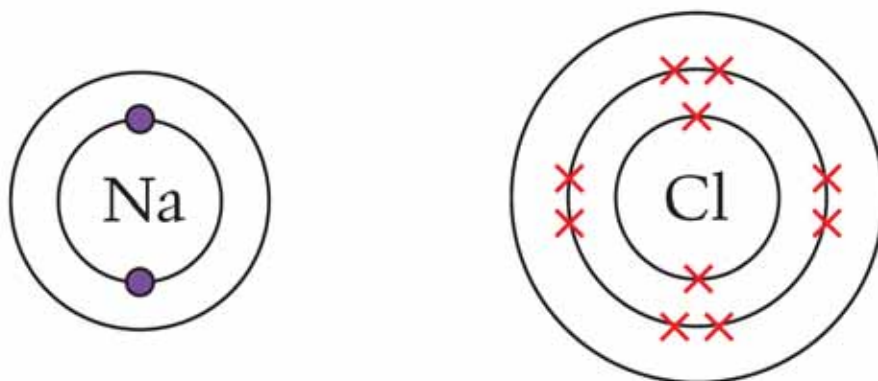


Figure 1 Incomplete dot-and-cross diagram for sodium chloride

- c Explain why sodium chloride has a high melting point. (3 marks)
- d Explain why solid sodium chloride **does not conduct** electricity. (1 mark)
- e Explain why molten sodium chloride **does conduct** electricity. (1 mark)

2 Covalent bonding occurs between non-metal atoms. The atoms share pairs of electrons so that all the atoms have a full outer shell of electrons. Carbon, for example, reacts with hydrogen to form methane, CH_4 . Methane is a simple molecule formed when a small number of non-metal atoms are joined together by covalent bonds.

- a** Construct a balanced symbol equation for the formation of methane from carbon and hydrogen. (1 mark)
- b** Copy and complete the dot-and-cross diagram in Figure 2 to show the bonding in a molecule of methane, CH_4 . (2 marks)

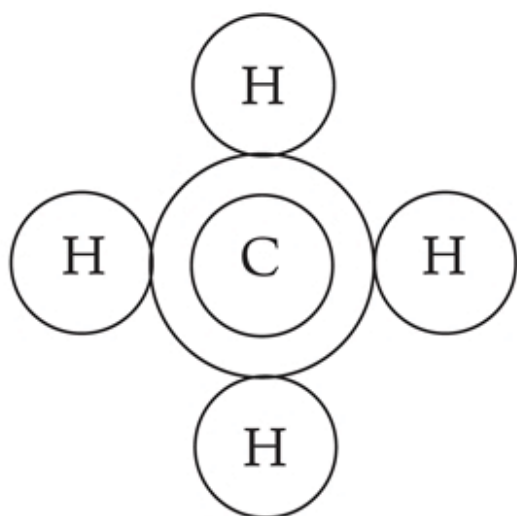


Figure 2 Incomplete dot-and-cross diagram for methane

- c** Explain why methane **does not conduct** electricity. (1 mark)
- d** Compare the bonding in **ionic compounds** and in simple molecular substances. (4 marks)

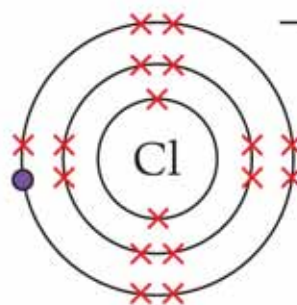
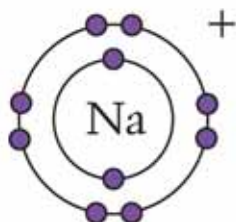
Answers

1



b Students should copy and complete the diagrams from the student sheet, so produce the following. Award a maximum of four marks from the following:

- electrons drawn correctly on sodium (1 mark)
- 'plus' sign indicating positive charge on sodium (1 mark)
- electrons drawn correctly on chlorine (1 mark)
- 'minus' sign indicating negative charge on chloride (1 mark)



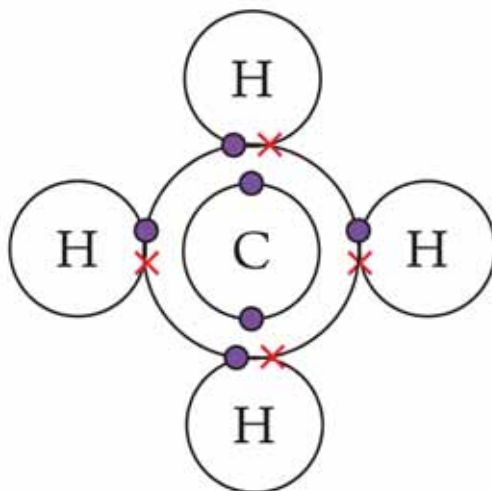
- c Sodium chloride is an ionic compound. (1 mark)
The sodium and chloride ions are held together by strong electrostatic forces. (1 mark)
A large amount of energy is required to break these forces of attraction so sodium chloride will only melt at a high temperature. (1 mark)
- d Solid sodium chloride does not conduct electricity because the ions are held in a lattice and cannot move. (1 mark)
- e In molten sodium chloride, the ions can move. (1 mark)

2



b Students should copy and complete the diagrams from the student sheet, so produce the following. Award one mark for each of the following:

- six electrons from carbon all placed correctly (1 mark)
- one electron from each hydrogen, placed correctly. (1 mark)



- c Methane does not conduct electricity because it has no overall electrical charge.
(1 mark)
- d In ionic compounds, electrons are transferred from metal atoms to non-metal atoms to form positively and negatively charged ions. (1 mark)
These ions are then held together by strong electrostatic charges. In simple molecular substances, non-metal atoms are held together by shared pairs of electrons. (1 mark)
There are strong covalent bonds between the atoms within a simple molecule but only very weak forces of attraction between the molecules. (1 mark)
Little energy is required to break the forces of attraction between the molecules so methane melts and boils at low temperatures and is a gas at room temperature.
(1 mark)

Shapes of molecules

Specification reference

- 2.2.2 g) h)

Introduction

In exam questions you may be asked to predict the shapes of molecules. As you already know, the key idea that you use to do this is electron pair repulsion theory – electron pairs repel each other and will arrange themselves to be as far apart as possible.

In this support sheet you will use a flow chart to help you visualise how to apply electron pair repulsion theory to help you tackle this type of question.

Learning outcome

After completing the worksheet you should be able to:

- use electron pair repulsion theory to predict the shapes of, and bond angles in, molecules and ions with up to six electron pairs surrounding the central atom.

Background

Most of the questions that you are likely to come across in an exam will be about molecules that have a central atom bonded to, and surrounded by, a number of other atoms – for example methane, CH_4 or sulfur hexafluoride, SF_6 .

When you use electron pair repulsion theory, you will need to count up the electron pairs around the central atom – any other electrons do not matter. The best way of doing this is to think about what the dot and cross diagram would look like. You may be asked to draw this out, or you might want to sketch it out to help you make progress with the question.

Topic 6.1: *Shapes of molecules and ions* shows you the different shapes of molecules and ions with different numbers of electron pairs around the central atoms.

One way to become more confident with this technique is to use a flow chart such as that shown in Figure 1.

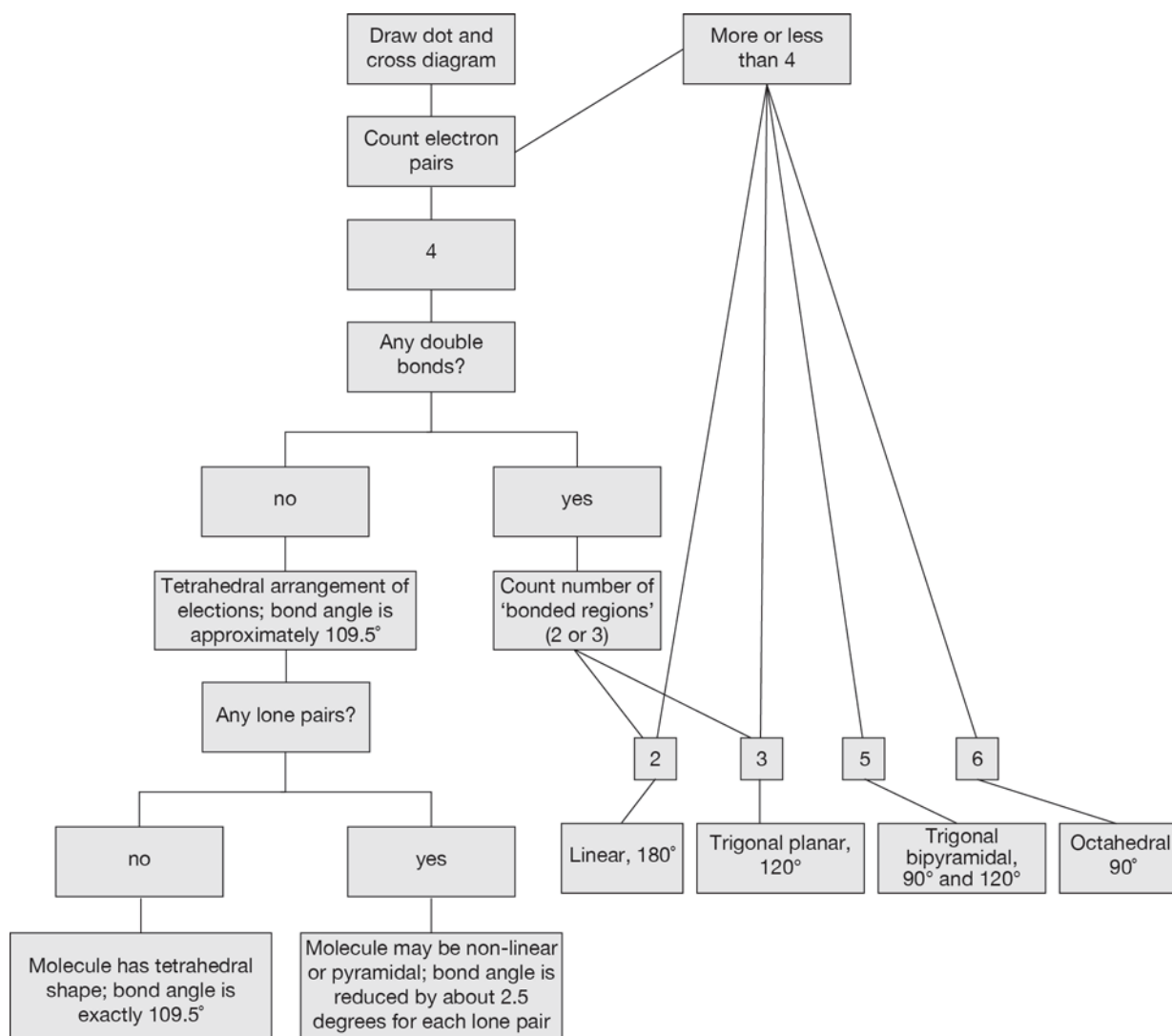


Figure 1 Flow chart for determining the shapes of molecules

Task

To understand how the flow chart can be used, work your way through the structured examples in this task.

Example 1: Chlorine(V) fluoride, ClF_5

- a This molecule has a central chlorine atom surrounded by five fluorine atoms. Sketch a dot and cross diagram of the molecule. (2 marks)

You should find that the chlorine atom has more than four pairs of electrons in its outer shell; atoms of p-block elements from Period 3 of the periodic table sometimes have 10, 12 or even 14 electrons in their outer shells when they form compounds.

- b State the shape of the molecule and suggest a value for the bond angle(s). (3 marks)

Count up the electron pairs in the outer shell of the chlorine atom in your dot and cross diagram. Then use the flow chart to deduce the shape and bond angles.

- c Sketch a diagram to show the three-dimensional (3D) shape of the molecule, marking two different bond angles clearly on your diagram. (3 marks)

Remember to draw the structure with chlorine as the central atom, surrounded by the five fluorine atoms. Make sure that when you draw a bond angle it shows the angle between two adjacent Cl–F bonds.

Example 2: Methanal, CH₂O

- a This molecule has a central carbon atom surrounded by two hydrogen atoms and an oxygen atom. Sketch a dot and cross diagram of the molecule. (3 marks)

You should find that there are four electron pairs around the carbon atom, but some of these electron pairs form a double bond.

- b State the shape of the molecule and suggest a value for the bond angle. (2 marks)

Remember that although there may be four electron pairs around the carbon atom, the electron pairs in the double bond count as one region of bonding electrons. Use the flow chart to deduce the shape and bond angle(s).

- c Sketch a diagram to show the shape of the molecule, marking a bond angle clearly on your diagram. (3 marks)

Remember to draw the structure with carbon as the central atom, surrounded by the two hydrogen and one oxygen atoms. You can either show the bond angle between two C–H bonds or between a C–H and a C=O bond. There should not be any need to use wedges to show the arrangement of the atoms as the molecule is planar.

Example 3: Hydrogen sulphide, H₂S

- a This molecule has a central sulfur atom surrounded by two hydrogen atoms. Sketch a dot and cross diagram of the molecule. (2 marks)

You should find that there are four electron pairs around the sulfur atom, but some of these electron pairs are lone pairs.

- b i Suggest a value for the bond angle in this molecule. (1 mark)

The four electron pairs, including the bonding pairs arrange themselves tetrahedrally, so the bond angle should be approximately 109.5°. The presence of lone pairs will reduce this bond angle slightly; use information on the flow chart to suggest a value for the actual bond angle.

- ii State the shape of the molecule. (1 mark)

Remember that although the arrangement of electron pairs may be tetrahedral, the shape of the molecule will not be, as there are only two atoms around the central atom. Use the flow chart to identify the correct shape.

- c Sketch a diagram to show the shape of the molecule, marking a bond angle clearly on your diagram. (3 marks)

Remember to draw the structure with sulfur as the central atom, surrounded by the two hydrogen atoms. You should draw a bond angle between two S–H bonds and not, for example, between a lone pair and a S–H bond.

Exam-style question

1 Urea, $\text{CO}(\text{NH}_2)_2$ is one of the simplest organic molecules found in living organisms. The 3D shape of a urea molecule can be deduced using electron pair repulsion theory.

- a Copy and complete the diagram in Figure 2 using dots and crosses to show the electron arrangement in a molecule of urea. (4 marks)

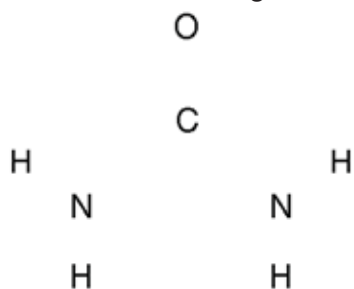


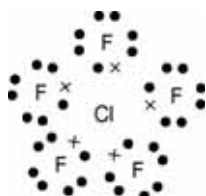
Figure 2 *The bonding in urea*

- b i Predict the bond angle between the $\text{C}=\text{O}$ and $\text{C}-\text{N}$ bonds and label this bond angle on your diagram from part a. (2 marks)
- ii State the name given to the arrangement of atoms around the carbon atom in urea. (1 mark)
- c The bond angle in the $-\text{NH}_2$ group of urea is 107° . Explain why the bond angle has this value. (4 marks)
- d Use information from parts b and c of this question to draw a diagram to show the 3D arrangement of the atoms in a molecule of urea. (3 marks)

Answers

Task examples

1 a



Five electron pairs around chlorine.

(1 mark)

All fluorine atoms correct.

(1 mark)

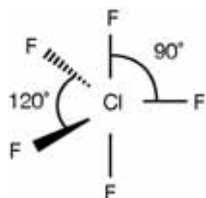
b Trigonal bipyramid.

(1 mark)

120° and 90°

(2 marks)

c



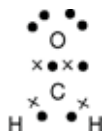
Correct three-dimensional (3D) structure.

(1 mark)

Two bond angles indicated correctly.

(2 marks)

2 a



C=O bond correct.

(1 mark)

C-H bonds correct.

(1 mark)

Lone pairs on oxygen.

(1 mark)

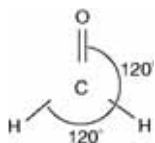
b Trigonal (planar).

(1 mark)

120°

(1 mark)

c



Atoms arranged trigonally around carbon.

(1 mark)

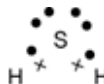
Structure is planar.

(1 mark)

One bond angle marked correctly.

(1 mark)

3 a



Both S-H bonds correct.

(1 mark)

Two lone pairs shown.

(1 mark)

b i 104.5°

(1 mark)

ii Non-linear.

(1 mark)

c



Correct structure.

(1 mark)

Two lone pairs shown.

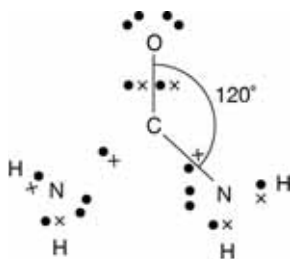
(1 mark)

Bond angle indicated correctly.

(1 mark)

Exam-style question

1 a



Double bond between C=O.

(1 mark)

At least one lone pair on oxygen.

(1 mark)

All N–H and C–H bonding pairs.

(1 mark)

Lone pair on at least one nitrogen atom.

(1 mark)

b i See diagram, 120°.

(1 mark)

Bond angle clearly shown between correct bonds / electron groups.

(1 mark)

ii Trigonal planar.

(1 mark)

c Four electron pairs around nitrogen.

(1 mark)

Electron pairs repel each other AND take up approximately tetrahedral arrangement.

(1 mark)

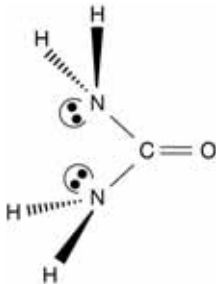
Lone pairs repel more strongly than bonding pairs.

(1 mark)

Each lone pair reduces bond angle by about 2.5°.

(1 mark)

d



Carbon, oxygen and nitrogen planar.

(1 mark)

Use of wedges to show 3D structure around nitrogen.

(1 mark)

Angles around carbon and nitrogen drawn to look approximately 120° and 107°.

(1 mark)