## UNIT 2

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### AREA OF STUDY 2

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YOU WILL EXAMINE:

- the difference between chemical and physical changes
- how chemical equations can be written to summarise chemical reactions
- how chemical equations are balanced to reflect the law of conservation of mass
- how patterns in chemical reactions can be used to predict the products of a chemical reaction.

Measure what is measurable, and make measurable what is not so.

Galileo Galilei

Sparkling wines have a characteristic 'pop and froth' effect due to the release of carbon dioxide gas that was bottled under pressure. Is this a physical change or a chemical change?
In a chemical change, one or more new substances are formed. A physical change does not produce any new substances. It simply involves a change of state in the substances already present.

A chemical equation is a way of summarising a chemical change. It shows the formulas of the original reactants on the left and the formulas of the new substances (products) on the right. It also shows the physical state of each substance involved, and it may indicate conditions necessary for the reaction to occur.
For example, when sodium is heated and plunged into green chlorine gas, the white ionic solid sodium chloride is formed. This can be represented in a chemical equation using the symbol for each element and formula of the compound.

\[
\text{Na} + \text{Cl}_2 \rightarrow \text{NaCl}
\]

\[
\text{sodium} + \text{chlorine gas} \rightarrow \text{sodium chloride}
\]

\[
\text{reactants} \rightarrow \text{products}
\]

Such equations, which show just the formulas of the reactants and products, are called ‘skeleton’ equations.

The physical states of the substances should be added to the equation. These are shown in brackets after each symbol or formula: (s) for a solid, (l) for a liquid, (g) for a gas, and (aq) for a solution in water.

\[
2\text{Na}(s) + \text{Cl}_2(g) \rightarrow 2\text{NaCl}(s)
\]

In some chemical reactions, a substance called a **catalyst** is used. A catalyst speeds up a reaction without being used up. Because a catalyst is not used up, it is neither a reactant nor a product and is written above the arrow in the equation. For example, manganese dioxide is a catalyst that speeds up the decomposition of a solution of hydrogen peroxide, H\(_2\)O\(_2\), to water and oxygen.

\[
2\text{H}_2\text{O}_2(aq) \xrightarrow{\text{MnO}_2} 2\text{H}_2\text{O}(l) + \text{O}_2(g)
\]

A similar notation is used to denote dissolving and heating. When a substance such as copper sulfate, CuSO\(_4\), is dissolved, water merely causes the ions in the lattice to come apart. Since the water is not being changed, it is written above the arrow as shown below.

\[
\text{CuSO}_4(s) \xrightarrow{\text{H}_2\text{O}} \text{Cu}^{2+}(aq) + \text{SO}_4^{2-}(aq)
\]

Also, when a reaction requires heat, the word ‘heat’ is written above the arrow to denote that heat has been applied. For example, the melting of ice to form water requires heat and may be described by the following chemical equation:

\[
\text{H}_2\text{O}(s) \xrightarrow{\text{heat}} \text{H}_2\text{O}(l)
\]

Table 11.1 shows many of the symbols that are used in writing chemical equations.

**Table 11.1 Symbols used in equations**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>(s)</td>
<td>a reactant or product in the solid state</td>
</tr>
<tr>
<td>(l)</td>
<td>a reactant or product in the liquid state</td>
</tr>
<tr>
<td>(aq)</td>
<td>an aqueous solution (the substance is dissolved in water)</td>
</tr>
<tr>
<td>(g)</td>
<td>a reactant or product in the gaseous state</td>
</tr>
<tr>
<td>heat</td>
<td>indicates that heat is supplied to the reaction</td>
</tr>
<tr>
<td>Pt</td>
<td>a formula written above the arrow indicates its use as a catalyst (in this case, platinum)</td>
</tr>
</tbody>
</table>

**Sample problem 11.1**

When solid mercury(II) sulfide is heated in air, molten mercury and gaseous sulfur dioxide are produced. Write an equation for this chemical change.

**Solution:**

The reactants are mercury(II) sulfide and oxygen, so they are written on the left-hand side of the reaction arrow. The products, mercury and sulfur dioxide, are written on the right-hand side of the reaction arrow. The states of all reactants and products are included.

\[
\text{HgS}(s) + \text{O}_2(g) \rightarrow \text{Hg}(l) + \text{SO}_2(g)
\]
Sample problem 11.2

Write a sentence that completely describes the following reaction:

\[ \text{N}_2\text{O}_3(g) + \text{H}_2\text{O}(l) \rightarrow 2\text{HNO}_2(\text{aq}) \]

**Solution:** Gaseous dinitrogen trioxide reacts with water to produce a solution of nitrous acid.

**Revision questions**

1. Write a skeleton equation for each of these chemical changes.
   (a) Aluminium reacts with oxygen in the air to form aluminium oxide powder.
   (b) Oxygen gas can be made by heating potassium chlorate in the presence of the catalyst manganese dioxide. Solid potassium chloride is produced.

2. Write sentences that completely describe the following chemical changes.
   (a) \( \text{Pb(NO}_3)_2(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{PbSO}_4(\text{s}) + 2\text{HNO}_3(\text{aq}) \)
   (b) \( 4\text{NH}_3(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow \text{Pt} \rightarrow 4\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\text{g}) \)

**Balancing chemical equations**

To represent chemical reactions correctly, equations must be balanced. This means the number of atoms of each element must be the same on both sides of the equation. According to the law of conservation of mass, the total mass of the reactants in a chemical reaction is equal to the total mass of the products. Atoms are not created or destroyed, but are rearranged to form new substances. In order to balance an equation, numbers called coefficients are placed in front of the whole formulas. Remember that we cannot change the formula of any substance in the equation, as these are found by experiment. In the example on the previous page, where two formula units of NaCl are produced, 2NaCl is used, rather than Na\(_2\)Cl\(_2\).

A balanced chemical equation has the same number of each type of atom on each side of the equation. Balancing is achieved by placing numbers (called coefficients) in front of each formula.

A balanced chemical equation applies to the whole formula. (a) CH\(_4\) means one molecule of methane consisting of one C atom and four H atoms. (b) Here, the coefficient ‘2’ is used to indicate the presence of two molecules: 2CH\(_4\) means two molecules of methane, each consisting of one C atom and four H atoms.
The vast range of possible chemical reactions (and associated chemical equations) makes it difficult to produce a list of hard and fast rules for balancing equations. However, the following rules should be considered a starting point.

**Rules for balancing equations**

1. Write the reactants and products using the correct formula and state for each substance.
2. Count the number of atoms of each element on the left-hand side of the equation. Do the same for the right-hand side and compare for each element. If any of these numbers do not match, the equation is not balanced and you need to proceed to the following steps.
3. Balance by placing coefficients in front of the formulas. *Do not change the actual formula.* If any substance is present as an element, leave the balancing of it to last.
4. Check all atoms or ions to ensure that they are balanced.
5. Make sure that the coefficients are in their lowest possible ratio.

**Sample problem 11.3**

At 1000 °C, ammonia gas, NH₃, reacts with oxygen gas to form gaseous nitric oxide, NO, and water vapour. Write a chemical equation for this reaction.

**Solution:**

**STEP 1**

Write the reactants and products including states.

\[ \text{NH}_3(g) + \text{O}_2(g) \rightarrow \text{NO}(g) + \text{H}_2\text{O}(g) \]

**STEP 2**

This is an unbalanced equation because there are three atoms of hydrogen on the left-hand side of the equation and only two atoms of hydrogen on the right-hand side.

**STEP 3**

Begin to balance the equation by correcting for hydrogen atoms. A coefficient of 2 for NH₃ and a coefficient of 3 for H₂O gives six atoms of hydrogen on both sides:

\[ 2\text{NH}_3(g) + \text{O}_2(g) \rightarrow \text{NO}(g) + 3\text{H}_2\text{O}(g) \]

Now, an imbalance in nitrogen atoms has occurred.

Balance the nitrogen atoms by introducing a coefficient of 2 for NO.

\[ 2\text{NH}_3(g) + \text{O}_2(g) \rightarrow 2\text{NO}(g) + 3\text{H}_2\text{O}(g) \]

**STEP 4**

Now there are two atoms of oxygen on the left and five on the right. Balance the oxygen atoms. This can be done by introducing a coefficient of \( \frac{5}{2} \) for O₂.

\[ 2\text{NH}_3(g) + \frac{5}{2} \text{O}_2(g) \rightarrow 2\text{NO}(g) + 3\text{H}_2\text{O}(g) \]

**STEP 5**

Check the equation. The same numbers of N, H and O atoms are on both sides of the equation, and states have been included. The equation is balanced. But the ratios are not yet in the simplest ratio.

**STEP 6**

Since the usual practice is to have whole-number coefficients, multiply the entire equation by 2.

\[ 4\text{NH}_3(g) + 5\text{O}_2(g) \rightarrow 4\text{NO}(g) + 6\text{H}_2\text{O}(g) \]
Revision questions

3. Balance the following equations.
   (a) $N_2(g) + H_2(g) \rightarrow NH_3(g)$
   (b) $SiO_2(s) + C(s) \rightarrow Si(s) + CO(g)$
   (c) $FeO(s) + O_2(g) \rightarrow Fe_2O_3(s)$
   (d) $Cr(s) + S_8(s) \rightarrow Cr_2S_3(s)$
   (e) $NaHCO_3(s) \rightarrow Na_2CO_3(s) + CO_2(g) + H_2O(g)$

4. When silicon tetrachloride, a liquid, reacts with solid magnesium, two solid products are formed: silicon and magnesium chloride. Write a balanced equation for this reaction.

5. Although each of the equations listed below is ‘balanced’, the equations are all incorrect. Identify the errors in each equation, then write a correct equation for each reaction.
   (a) $CH_4 + O_2 \rightarrow CO_2 + H_4$
   (b) $I_2 + Cl_2 \rightarrow I_2Cl_2$
   (c) $K + O_2 \rightarrow KO_2$
   (d) $Cl_2 + NaBr \rightarrow NaCl_2 + Br$

Types of chemical reaction

Patterns can be found in the vast number of chemical reactions taking place around us. Chemists have determined several main groups of chemical reactions that help us predict the products of these reactions. We should keep in mind, however, that when we write equations they should be based on experimental data for complete certainty.

The main types of chemical reaction discussed in this chapter are:
- precipitation
- acid–base
- combustion.

Precipitation reactions

Precipitation occurs when ions in solution combine to form a new compound of low solubility in water. This low-solubility compound forms as solid particles that eventually settle. It is called a precipitate. In order to predict whether a precipitate will form, we must know which substances are soluble in water and which substances are insoluble.

From table 11.2 we can predict that, when a solution of sodium chloride is mixed with a solution of silver nitrate, a precipitate of silver chloride will form:

$$NaCl(aq) + AgNO_3(aq) \rightarrow NaNO_3(aq) + AgCl(s)$$
In a precipitation reaction, ions from the first reactant swap with ions from the second reactant to form new combinations, one of which is insoluble.

That is, the Ag\(^+\) ions combine with the Cl\(^-\) ions to form solid AgCl while the Na\(^+\) and NO\(_3\)^\(-\) ions remain in solution.

**TABLE 11.2** Solubility in water of compounds of common ions

<table>
<thead>
<tr>
<th>Name of ion</th>
<th>Symbol</th>
<th>Soluble compounds of ion</th>
<th>Insoluble compounds of ion</th>
</tr>
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<tbody>
<tr>
<td>group I ions</td>
<td>Li(^+), Na(^+), K(^+), Rb(^+), Cs(^+), Fr(^+)</td>
<td>all</td>
<td>none</td>
</tr>
<tr>
<td>ammonium</td>
<td>NH(_4)^(+)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>hydrogen</td>
<td>H(^+)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nitrate</td>
<td>NO(_3)^(-)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nitrite</td>
<td>NO(_2)^(-)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>chlorides</td>
<td>Cl(^-)</td>
<td></td>
<td>Ag(^+), Pb(^{2+}), Hg(^{2+}) (PbCl(_2) is moderately soluble in hot water.)</td>
</tr>
<tr>
<td>bromides</td>
<td>Br(^-)</td>
<td>most</td>
<td></td>
</tr>
<tr>
<td>iodides</td>
<td>I(^-)</td>
<td>most</td>
<td></td>
</tr>
<tr>
<td>sulfates</td>
<td>SO(_4^{2-})</td>
<td></td>
<td>Ba(^{2+}), Pb(^{2+}) (Ag(_2)SO(_4) and CaSO(_4) are slightly soluble.)</td>
</tr>
<tr>
<td>carbonates</td>
<td>CO(_3^{2-})</td>
<td>Na(^+), K(^+), NH(_4)^(+)</td>
<td>most</td>
</tr>
<tr>
<td>phosphates</td>
<td>PO(_4^{3-})</td>
<td>Na(^+), K(^+)</td>
<td>most (Mg(_2), Ca(_2), Ba(_2), Al(_2)S(_3) and Fe(_2)S(_3) decompose in water.)</td>
</tr>
<tr>
<td>sulfides</td>
<td>S(^2-)</td>
<td>Na(^+), K(^+)</td>
<td>most (Ca(OH)(_2) is slightly soluble.)</td>
</tr>
<tr>
<td>hydroxides</td>
<td>OH(^-)</td>
<td>Na(^+), K(^+), Ba(^{2+}) (NH(_4))OH and (NH(_4))(_2)O do not exist as solids.</td>
<td>most</td>
</tr>
<tr>
<td>oxides</td>
<td>O(^2-)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: Most of the ionic compounds not listed here may be assumed to be insoluble in water.*
Precipitation reactions are dealt with further in chapter 15.

Sample problem 11.4

Predict the products and write a balanced equation for the reaction occurring between sodium carbonate and copper(II) sulfate.

Solution:  
**STEP 1**
Write the reactants.
\[ \text{Na}_2\text{CO}_3 + \text{CuSO}_4 \rightarrow \]

**STEP 2**
Look at the solubility table to determine which of the ions are soluble. Sodium carbonate is aqueous (since all group I ions are soluble) and copper(II) sulfate is aqueous (since most sulfates are soluble). The products are sodium sulfate and copper(II) carbonate. Sodium sulfate is aqueous (since all group I compounds are soluble), but copper(II) carbonate is an insoluble compound.

**STEP 3**
Write the balanced equation for the reaction.
\[ \text{Na}_2\text{CO}_3(aq) + \text{CuSO}_4(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + \text{CuCO}_3(s) \]

Revision questions

6. Determine whether each of the following ionic compounds is soluble:
   (a) BaSO_4
   (b) Pb(NO_3)_2
   (c) PbI_2
   (d) sodium sulfide.

7. Use table 11.2 to determine:
   (a) which sodium compounds are soluble
   (b) which potassium compounds are insoluble
   (c) which silver compounds are soluble.

8. Predict products and write balanced equations for:
   (a) KOH(aq) + Ca(NO_3)_2(aq) →
   (b) Na_2S(aq) + (CH_3COO)Pb(aq) →
   (c) (NH_4)_2PO_4(aq) + CaCl_2(aq) →

Acid–base and neutralisation reactions

When an acid reacts with a base to form a salt and water, a **neutralisation reaction** occurs:

acid + base → salt + water

For example, hydrochloric acid reacts with the base sodium hydroxide to form sodium chloride (common table salt) and water:

\[ \text{HCl}(aq) + \text{NaOH}(aq) \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l) \]

Other common reactions involving acids are:

1. acid + metal → salt + hydrogen
   This reaction does not occur with Cu, Hg, or Ag.
2. acid + metal carbonate → salt + water + carbon dioxide
   \[ 2\text{HCl}(aq) + \text{Na}_2\text{CO}_3(aq) \rightarrow 2\text{NaCl}(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]
3. acid + metal oxide → salt + water
   \[ 2\text{HCl}(aq) + \text{CuO}(s) \rightarrow \text{CuCl}_2(aq) + \text{H}_2\text{O}(l) \]
4. acid + metal hydroxide → salt + water
   \[ \text{H}_2\text{SO}_4(aq) + 2\text{NaOH}(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l) \]
Since a neutralisation reaction is often difficult to detect, a chemical indicator can be used. Indicators are compounds that change colour when an acid or a base has completely reacted.
Acid–base reactions are dealt with further in chapter 17.

### Sample problem 11.5

Write a balanced chemical equation for the reaction between sulfuric acid and magnesium carbonate.

**Solution:**
The reaction of an acid (sulfuric acid) and a metal carbonate (magnesium carbonate) produces a salt (magnesium sulfate), water and carbon dioxide. Magnesium sulfate dissolves in water. The equation for the reaction is:

\[
\text{H}_2\text{SO}_4(\text{aq}) + \text{MgCO}_3(\text{s}) \rightarrow \text{MgSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})
\]

### Revision questions

9. Predict the products and write balanced equations for:
   (a) \(\text{LiOH}(\text{aq}) + \text{HCl}(\text{aq}) \rightarrow\)
   (b) \(\text{NaOH}(\text{aq}) + \text{HNO}_3(\text{aq}) \rightarrow\)
   (c) \(\text{KOH}(\text{aq}) + \text{HCl}(\text{aq}) \rightarrow\)

10. Write balanced equations for:
    (a) nitric acid reacting with lithium hydroxide
    (b) sulfuric acid reacting with sodium carbonate
    (c) sulfuric acid reacting with copper(II) oxide
    (d) hydrochloric acid reacting with magnesium metal.

### Combustion reactions

When hydrocarbons burn in a plentiful supply of oxygen, they give off heat to their surroundings and produce carbon dioxide and water.

When a limited air supply is available for a combustion reaction, carbon monoxide may be formed in preference to carbon dioxide. For example, when octane, \(\text{C}_8\text{H}_{18}\), is burned in air, the combustion reaction may be represented as:

\[
2\text{C}_8\text{H}_{18}(\text{l}) + 25\text{O}_2(\text{g}) \rightarrow 16\text{CO}_2(\text{g}) + 18\text{H}_2\text{O}(\text{g})
\]

However, when octane is burned in an engine, where the supply of oxygen is limited, carbon monoxide gas is one of the products:

\[
2\text{C}_8\text{H}_{18}(\text{l}) + 17\text{O}_2(\text{g}) \rightarrow 16\text{CO}(\text{g}) + 18\text{H}_2\text{O}(\text{g})
\]

The products of hydrocarbon combustion are in the gaseous state.
Sample problem 11.6

Candle wax, C_{25}H_{52}, burns in air. Write a chemical equation for the reaction.

Solution:  

**STEP 1**  
Carbon dioxide and water are the products of combustion in air:  
\[ \text{C}_{25}\text{H}_{52}(s) + \text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(g) \]

**STEP 2**  
Balance the equation, first for carbon, then hydrogen, and then oxygen.  
\[ \text{C}_{25}\text{H}_{52}(s) + 38\text{O}_2(g) \rightarrow 25\text{CO}_2(g) + 26\text{H}_2\text{O}(g) \]

For hydrocarbon combustion, an algebraic chemical equation can be written. By knowing the values of just \( x \) and \( y \), the combustion equation can be written quickly. This equation is:  
\[ \text{C}_x\text{H}_y + \left(\frac{x+\frac{y}{4}}{2}\right)\text{O}_2 \rightarrow x\text{CO}_2 + \frac{y}{2}\text{H}_2\text{O} \]

Revision questions

11. Write balanced equations for the following reactions:  
(a) propane gas burning in oxygen \( \rightarrow \)  
(b) ethene gas burning in oxygen \( \rightarrow \)  
(c) ethane gas burning in a limited supply of oxygen \( \rightarrow \)

12. Butane, C_4H_{10}, in cigarette lighters burns with a sooty flame. The soot that forms is actually carbon. Water vapour is also produced in this reaction.  
(a) Explain why carbon, rather than carbon dioxide, forms when a cigarette lighter is lit.  
(b) Write a balanced molecular equation for the cigarette lighter reaction, showing the physical states of all reactants and products.  
(c) Write a balanced molecular equation for the complete combustion of butane in air, showing the physical states of all reactants and products.

13. Predict whether a reaction will take place between the following substances and, if so, write a balanced equation for it.  
(a) Cu + Pb(NO_3)_2  
(b) Mg + ZnCl_2  
(c) Fe + AgNO_3

Chemical reactions — by patterns

Many people find it useful to predict chemical reactions by using certain patterns — many of which have been alluded to in the previous section under their particular reaction type. However, it still must be remembered that it is only predictions that are being made. Exceptions can always occur and all such predictions should really be checked by experiment. Shown below is a list of some of the more common patterns.

- acid + metal hydroxide (base) \( \rightarrow \) salt + water
- acid + basic oxide \( \rightarrow \) salt + water
- acidic oxide + base \( \rightarrow \) salt + water
- acid + metal \( \rightarrow \) salt + hydrogen  
  (no reaction for Ag, Cu, Pt or Au)
- acid + metal carbonate \( \rightarrow \) salt + carbon dioxide + water
- acid + metal hydrogen carbonate \( \rightarrow \)  
  salt + carbon dioxide + water
- metal carbonate \( \xrightarrow{\text{heat}} \) metal oxide + carbon dioxide
- hydrocarbon + (plentiful) oxygen \( \rightarrow \)  
  carbon dioxide + water
Summary

- A chemical reaction involves a chemical change in which one or more kinds of matter (reactants) are transformed into one or more new kinds of matter (products). In this way it differs from a physical change, in which no new substances are produced.
- A chemical change may be indicated by:
  - disappearance of a substance
  - evolution of a gas
  - formation of a precipitate (solid)
  - colour change
  - temperature change
  - odour change.
- A chemical reaction may be expressed symbolically by a chemical equation. Principles for writing chemical equations include:
  - Indicate the physical states of the reactants and products in parentheses after each chemical formula.
  - Above the reaction arrow, show the presence of any catalysts (substances that are used to alter the rate of a chemical reaction but are not themselves used up in the reaction).
  - According to the law of conservation of mass, atoms are neither created nor destroyed in chemical reactions but rearranged to form new substances. Therefore all atoms in the equation must be balanced. This is done by placing numbers, called coefficients, in front of the whole formulas.
- Three main types of chemical reaction are:
  - A precipitation reaction produces a compound (precipitate) of low solubility in water. A solubility table may be used to predict the formation of a precipitate when solutions are mixed.
  - A neutralisation reaction occurs when an acid reacts with a base to produce a salt and water. These reactions can be detected using a chemical indicator. Common reactions of acids include:
    - acid + metal hydroxide → salt + water
    - acid + metal carbonate → salt + water + carbon dioxide
    - acid + metal oxide → salt + water
    - acid + metal → salt + hydrogen (not Cu, Hg or Ag).
  - A combustion reaction involves the burning of an organic compound in oxygen to produce carbon dioxide or carbon monoxide as well as water, generating heat.
    - hydrocarbon + oxygen (plentiful supply) → carbon dioxide + water
    - hydrocarbon + oxygen (limited supply) → carbon monoxide + water

Multiple choice questions

1. Which one of the following processes is not an example of a chemical change?
   A. Ice melts.
   B. Iron rusts.
   C. Wood burns.
   D. Leaves turn brown in autumn.

2. During any chemical reaction, there is never a change to the:
   A. total number of molecules in the system
   B. heat produced by the system
   C. heat absorbed by the system
   D. total mass of the system.

3. Consider the following equation:
   \[ a\text{NH}_3(g) + b\text{O}_2(g) \rightarrow c\text{N}_2(g) + d\text{H}_2\text{O}(g) \]
   The coefficients that balance the equation are represented by \(a, b, c\) and \(d\). These are, respectively:
   A. 2, 1, 1, 3
   B. 2, 2, 1, 3
   C. 4, 3, 2, 6
   D. 4, 3, 2, 4.

4. Consider the following equation:
   \[ a\text{C}_6\text{H}_{14}(g) + b\text{O}_2(g) \rightarrow c\text{H}_2\text{O}(g) + d\text{CO}(g) \]
   The coefficients that balance the equation are represented by \(a, b, c\) and \(d\). These are, respectively:
   A. 1, 13, 7, 6
   B. 1, 19, 7, 6
   C. 2, 13, 14, 12
   D. 2, 19, 14, 12.

5. Hydrogen gas burns readily in oxygen to produce water. Which of the following is the correctly balanced equation for this process?
   A. \( \text{H}_2(g) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) \)
   B. \( 2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(l) \)
   C. \( \text{H}_2(g) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) \)
   D. \( \text{H}_2(g) + \text{O}(g) \rightarrow \text{H}_2\text{O}(l) \)

6. Which of the following is a correctly balanced equation?
   A. \( 2\text{CuO}(s) + 2\text{C}(s) \rightarrow \text{Cu}(s) + 4\text{CO}_2(g) \)
   B. \( \text{SO}_2(g) + \text{O}_2(g) \rightarrow \text{SO}_3(g) \)
   C. \( \text{H}_2\text{S}(g) + \text{O}_2(g) \rightarrow \text{H}_2\text{O}(l) + \text{SO}_2(g) \)
   D. \( \text{P}_4\text{O}_{10}(g) + 10\text{C}(s) \rightarrow \text{P}_4(g) + 10\text{CO}(g) \)
7. In which of the following cases would you expect a chemical reaction to not occur?
   A Magnesium is added to dilute sulfuric acid.
   B Copper is added to dilute hydrochloric acid.
   C Magnesium is added to dilute nitric acid.
   D Zinc is added to ethanoic acid.

8. Carbon dioxide gas is identified using the ‘limewater test’. When the gas is bubbled through a solution of limewater (calcium hydroxide), the solution turns milky due to the formation of insoluble calcium carbonate. The equation for this reaction is:
   \[ \text{Ca(OH)}_2(aq) + \text{CO}_2(g) \rightarrow \text{CaCO}_3(s) + \text{H}_2\text{O}(l) \]
   Which of the following hydroxide solutions would produce a similar observation?
   A NH\textsubscript{4}OH
   B NaOH
   C KOH
   D Ba(OH\textsubscript{2})

**Review questions**

**Identifying chemical reactions**

1. Explain how physical changes:
   (a) are similar to chemical changes
   (b) differ from chemical changes.

2. Describe four observations that provide evidence for a chemical reaction having taken place, illustrating your answer with examples from everyday life.

3. What is a chemical equation? Why does it have to be balanced?

4. Explain how the law of conservation of mass is related to the balancing of a chemical equation.

5. Consider the following balanced equation:
   \[ 2\text{SO}_2(g) + \text{O}_2(g) \rightarrow 2\text{SO}_3(g) \]
   (a) What information does this give about the reaction?
   (b) What information is not given?

**Balancing and completing chemical equations**

6. Balance the following equations.
   (a) \( N_2(g) + H_2(g) \rightarrow NH_3(g) \)
   (b) \( \text{HCl}(aq) + \text{Al}(s) \rightarrow \text{AlCl}_3(aq) + H_2(g) \)
   (c) \( \text{NH}_3(g) + \text{O}_2(g) \rightarrow \text{NO}(g) + \text{H}_2\text{O}(g) \)
   (d) \( \text{NO}(g) + \text{O}_2(g) \rightarrow \text{NO}_2(g) \)
   (e) \( \text{Na}(s) + \text{P}_4(s) \rightarrow \text{Na}_3\text{P}(s) \)

7. Write fully balanced equations, including the physical states of all reactants and products, for each of the following word equations.
   (a) When solid sodium is added to water, aqueous sodium hydroxide and hydrogen gas are formed.
   (b) Hydrogen chloride gas and ammonia gas react to form ammonium chloride.
   (c) Nitrogen monoxide gas reacts with oxygen gas to form nitrogen dioxide.
   (d) Solid zinc sulfide reacts with oxygen gas to form solid zinc oxide and sulfur dioxide gas.

8. Balance the following equations.
   (a) \( \text{Cu} + \text{O}_2 \rightarrow \text{CuO} \)
   (b) \( \text{HgO} \rightarrow \text{Hg} + \text{O}_2 \)
   (c) \( \text{AsCl}_3 + \text{H}_2\text{S} \rightarrow \text{As}_2\text{S}_3 + \text{HCl} \)
   (d) \( \text{Fe}_2\text{O}_3 + \text{H}_2 \rightarrow \text{Fe} + \text{H}_2\text{O} \)
   (e) \( \text{NaCl} \rightarrow \text{Na} + \text{Cl}_2 \)
   (f) \( \text{Al} + \text{H}_2\text{SO}_4 \rightarrow \text{H}_2 + \text{Al}_2(\text{SO}_4)_3 \)
   (g) \( \text{C}_8\text{H}_8 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \)

9. Complete and balance the following equations.
   (a) \( \text{HNO}_3(aq) + \text{Zn}(s) \rightarrow \)
   (b) \( \text{HCl}(aq) + \text{MgO}(s) \rightarrow \)
   (c) \( \text{HCl}(aq) + \text{Ca(OH)}_2(s) \rightarrow \)
   (d) \( \text{H}_2\text{SO}_4(aq) + \text{Na}_2\text{CO}_3(s) \rightarrow \)
   (e) \( \text{Ca}(s) + \text{O}_2(g) \rightarrow \)

10. Write balanced formula equations for the following word equations.
    (a) granulated zinc + sulfuric acid →
    (b) metallic barium + oxygen gas →
    (c) hydrochloric acid + magnesium hydroxide →
    (d) calcium oxide + water →

11. Bubbling chlorine gas through a solution of potassium iodide produces elemental iodine and a solution of potassium chloride. Write a balanced chemical equation, showing the physical states of all reactants and products, for this reaction.

12. Write sentences to describe each of the reactions below.
    (a) \( 2\text{K}(s) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{KOH}(aq) + \text{H}_2(g) \)
    (b) \( \text{FeO}(s) + \text{C}(s) \xrightarrow{\text{heat}} \text{Fe}(s) + \text{CO}(g) \)

13. Complete the following equations.
    (a) \( \text{Ca(OH)}_2(s) + \text{H}_2\text{PO}_4(aq) \rightarrow \)
    (b) \( \text{H}_2\text{SO}_4(aq) + \text{Al(OH)}_3(s) \rightarrow \)
    (c) \( \text{Fe(OH)}_3(s) + \text{HCl}(aq) \rightarrow \)
    (d) \( \text{BaCl}_2(aq) + (\text{NH}_4)_2\text{CO}_3(aq) \rightarrow \)
    (e) \( \text{AgNO}_3(aq) + \text{H}_2\text{S}(g) \rightarrow \)
    (f) \( \text{K}_2\text{CrO}_4(aq) + \text{Pb(NO}_3)_2(aq) \rightarrow \)

**Combustion reactions**

14. Write hydrocarbon combustion equations for ethene, propene and 1-butene:
    (a) in a plentiful air supply
    (b) in a limited air supply.

15. Write hydrocarbon combustion reactions for pentane, 2-pentene and 2-pentyne:
    (a) in a plentiful air supply
    (b) in a limited air supply.

16. Octane, \( \text{C}_8\text{H}_{18} \), is the major hydrocarbon present in petrol. Write a balanced molecular equation, including physical states, for the combustion of octane:
    (a) in a plentiful air supply
    (b) in a limited air supply.

17. Write an equation for the complete combustion of:
    (a) glycerol, \( \text{C}_3\text{H}_8\text{O}_3 \)
    (b) sucrose, \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \)
    (c) ethanoic acid, \( \text{CH}_3\text{COOH} \).
Exam practice questions

In a chemistry examination you will be required to answer a number
of short and extended response questions.

Extended response questions

1. (a) From the following list of substances, choose a precipitate that would form in an
aqueous solution: CuSO₄, Ba(OH)₂, KOH, BaSO₄.
   
   (b) Write a chemical equation for the reaction between two reactants of your choice
that would produce the precipitate you chose in part (a). (Remember that the reactants
must be soluble in water.)

2. Two common fuels for outdoor barbecues are natural gas and propane gas.
   (a) Write the equation for the combustion of natural gas (assuming it to be methane)
in a plentiful supply of oxygen.
   
   (b) Write the equation for the combustion of propane in a plentiful supply of oxygen.

   These barbecues often display a warning for them not to be operated in confined
spaces due to the possibility that the oxygen supply might start to become limited.
   (c) Write the equation for the combustion of propane in a limited supply of oxygen.
   (d) Using your answer to part (c), suggest why it would be dangerous to operate an outdoor
   barbecue in a confined space.
   (e) If the same number of molecules of methane and propane are burned, which fuel
would produce more molecules of carbon dioxide? Explain.

Another commonly available fuel for barbecues is butane. The equation for the combustion
of butane is:

\[ 2\text{C}_4\text{H}_{10}(g) + 13\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 10\text{H}_2\text{O}(g) \]

4. If the same number of molecules of propane and butane are burned, which fuel would
produce more molecules of water?