Answer all the questions in the spaces provided.

1 (a) The solubility of the Group 2 sulfates decreases down the group.

Explain this trend.
....................................................................................................................................................
....................................................................................................................................................
....................................................................................................................................................
....................................................................................................................................................
..............................................................................................................................................  [3]

(b) Describe what is observed when magnesium and barium are reacted separately with an excess of dilute sulfuric acid.

magnesium ................................................................................................................................

barium ........................................................................................................................................  [1]

(c) The solubility product, $K_{sp}$, of BaSO$_4$ is $1.08 \times 10^{-10}$ mol$^2$ dm$^{-6}$ at 298 K.

Calculate the solubility of BaSO$_4$ in g per 100 cm$^3$ of solution.

solubility of BaSO$_4$ = .................................. g per 100 cm$^3$ of solution  [2]
(d) (i) The equation for the formation of a gaseous sulfate ion is shown.

\[
\text{S(s) + 2O}_2(\text{g}) + 2e^- \rightarrow \text{SO}_4^{2-}(\text{g}) \quad \Delta H = \Delta H_f^0 \text{ of SO}_4^{2-}(\text{g})
\]

Calculate the standard enthalpy change of formation, \(\Delta H_f^0\), of SO\(_4^{2-}\)(g). It may be helpful to draw a labelled energy cycle. Use relevant data from Table 1.1 in your calculations.

**Table 1.1**

<table>
<thead>
<tr>
<th>energy change</th>
<th>value / kJ mol(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>lattice energy of barium sulfate, BaSO(_4)(s)</td>
<td>–2469</td>
</tr>
<tr>
<td>standard enthalpy change of formation of barium sulfate</td>
<td>–1473</td>
</tr>
<tr>
<td>standard enthalpy change of atomisation of barium</td>
<td>+180</td>
</tr>
<tr>
<td>first ionisation energy of barium</td>
<td>+503</td>
</tr>
<tr>
<td>second ionisation energy of barium</td>
<td>+965</td>
</tr>
<tr>
<td>standard enthalpy change of atomisation of sulfur</td>
<td>+279</td>
</tr>
<tr>
<td>standard enthalpy change for S(g) (\rightarrow) S(^2-)(g)</td>
<td>+440</td>
</tr>
<tr>
<td>standard enthalpy change for O(g) (\rightarrow) O(^2-)(g)</td>
<td>+657</td>
</tr>
<tr>
<td>O=O bond energy</td>
<td>+496</td>
</tr>
</tbody>
</table>

\[\Delta H_f^0 \text{ of SO}_4^{2-}(\text{g}) = \ldots \quad \text{kJ mol}^{-1}\quad [3]\]
(ii) Suggest how the lattice energy of BaSO₄(s) differs from the lattice energy of Cs₂SO₄(s). Explain your answer.

.............................................................................................................................................
.............................................................................................................................................
.............................................................................................................................................
............................................................................................................................................. [2]

(e) The reaction of solid hydrated barium hydroxide, Ba(OH)₂•8H₂O, with ammonium salts is endothermic.

(i) Calculate the minimum temperature at which the reaction of Ba(OH)₂•8H₂O with NH₄NO₃ becomes feasible. Show all your working.

\[
\text{Ba(OH)₂•8H₂O(s) + 2NH₄NO₃(s) → 2NH₃(g) + Ba(NO₃)₂(s) + 10H₂O(l)} \quad \Delta H^\circ = +132 \text{ kJ mol}^{-1} \\
\Delta S^\circ = +616 \text{ J K}^{-1} \text{ mol}^{-1}
\]

\[
\text{temperature} = \text{.............................. °C} \ [2]
\]

(ii) Barium hydroxide reacts readily with ammonium chloride on mixing at room temperature.

\[
\text{Ba(OH)₂•8H₂O(s) + 2NH₄Cl(s) → 2NH₃(g) + BaCl₂•2H₂O(s) + 8H₂O(l)} \quad \Delta H^\circ = +133 \text{ kJ mol}^{-1}
\]

Some relevant standard entropies are given in Table 1.2.

<table>
<thead>
<tr>
<th>substance</th>
<th>Ba(OH)₂•8H₂O(s)</th>
<th>NH₄Cl(s)</th>
<th>NH₃(g)</th>
<th>BaCl₂•2H₂O(s)</th>
<th>H₂O(l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S°/JK⁻¹mol⁻¹</td>
<td>427</td>
<td>95</td>
<td>192</td>
<td>203</td>
<td>70</td>
</tr>
</tbody>
</table>

Calculate the standard Gibbs free energy change, \(\Delta G^\circ\), for this reaction at 25°C.

\[
\Delta G^\circ = \text{.............................. kJ mol}^{-1} \ [3]
\]

[Total: 16]
2 (a) Define transition element.
....................................................................................................................................................
.................................................................................................................................................... [1]

(b) Sketch the shape of a 3d$_2$ orbital.

(c) Manganese(IV) oxide, MnO$_2$, acts as a heterogeneous catalyst in the decomposition of hydrogen peroxide, H$_2$O$_2$.

(i) Explain what is meant by a heterogeneous catalyst.
....................................................................................................................................................
.................................................................................................................................................... [1]

(ii) Describe the mode of action of a heterogeneous catalyst in a reaction.
....................................................................................................................................................
....................................................................................................................................................
....................................................................................................................................................
.................................................................................................................................................... [3]

(d) Manganese(VII) oxide, Mn$_2$O$_7$, can be made by treatment of KMnO$_4$ with concentrated sulfuric acid (reaction 1).

Mn$_2$O$_7$ readily decomposes at room temperature to form manganese(IV) oxide and a colourless diatomic gas (reaction 2).

Construct equations for both the reactions described.

reaction 1 ...........................................................................................................................................
reaction 2 ........................................................................................................................................... [2]
(e) Aqueous manganese(II) ions show similar chemical properties to aqueous copper(II) ions when reacted separately with NaOH(aq) and with concentrated HCl.

(i) Write the ionic equation, and state the type of reaction, for the reaction of \([\text{Mn(H}_2\text{O)}_6\text{]}^{2+}\) with NaOH(aq).

ionic equation ........................................................................................................................................

type of reaction ...................................................................................................................................... [2]

(ii) Write the ionic equation, and state the type of reaction, for the reaction of \([\text{Mn(H}_2\text{O)}_6\text{]}^{2+}\) with concentrated HCl.

ionic equation ........................................................................................................................................

type of reaction ...................................................................................................................................... [2]

(iii) Table 2.1 lists relevant electrode potentials for some electrode reactions.

<table>
<thead>
<tr>
<th>electrode reaction</th>
<th>(E^o/V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{Mn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Mn})</td>
<td>(-1.18)</td>
</tr>
<tr>
<td>(\text{Cl}_2 + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-)</td>
<td>(+1.36)</td>
</tr>
<tr>
<td>(2\text{HOCI} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Cl}_2 + 2\text{H}_2\text{O})</td>
<td>(+1.64)</td>
</tr>
<tr>
<td>(\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{Mn}^{2+} + 2\text{H}_2\text{O})</td>
<td>(+1.23)</td>
</tr>
<tr>
<td>(\text{MnO}_4^{2-} + 4\text{H}^+ + 3\text{e}^- \rightleftharpoons \text{MnO}_2 + 2\text{H}_2\text{O})</td>
<td>(+1.67)</td>
</tr>
</tbody>
</table>

Suggest the formula of the manganese species formed when Mn\(^{2+}\)(aq) reacts with Cl\(_2\).

State the type of reaction.

formula of manganese species formed .........................................................................................

type of reaction ............................................................................................................................... [1]

[Total: 13]
3 (a) The rate of reaction between 2-chloro-2-methylpropane, \((\text{CH}_3)_3\text{CCl}\), and methanol is investigated. When a large excess of methanol is used, the overall reaction is first order.

\[
(\text{CH}_3)_3\text{CCl} + \text{CH}_3\text{OH} \rightarrow (\text{CH}_3)_3\text{COCH}_3 + \text{HCl}
\]

Fig. 3.1 shows the results obtained.

![Graph showing reaction rates](image)

(i) Use the graph to determine the rate of reaction at 40 s. Show all your working.

rate = .................................. mol dm\(^{-3}\) s\(^{-1}\) [1]

(ii) Use the graph to show that the overall reaction is first order. Explain your answer.

..................................................................................................................................... [2]

(b) In a different reaction, which is also a first order reaction, 75% of the reactant is consumed in 320 s.

Calculate the rate constant, \(k\), for this reaction. State the units for \(k\).

\(k = \) ......................... units = ......................... [2]
(c) (i) Define standard electrode potential, $E^\circ$.

.............................................................................................................................................
.............................................................................................................................................
............................................................................................................................................... [1]

(ii) A salt bridge is used in an electrochemical cell.

State the function of the salt bridge. Explain your answer.

.............................................................................................................................................
............................................................................................................................................... [1]

(iii) Complete the diagram of the apparatus that can be used to measure the $E^\circ$ of the \( \text{Cr}_2\text{O}_7^{2-}(aq) \), \( \text{H}^+(aq)/\text{Cr}^{3+}(aq) \) electrode against the standard hydrogen electrode.

Your diagram should be fully labelled to identify all apparatus, substances and conditions.

![Diagram of electrochemical cell]

[3]

(iv) The $E^\circ$ of the \( \text{Cr}_2\text{O}_7^{2-}(aq) \), \( \text{H}^+(aq)/\text{Cr}^{3+}(aq) \) electrode is +1.33 V.

Label the negative electrode and the direction of electron flow in the external circuit when the current flows in your diagram in (c)(iii).

[1]
(d) Table 3.1 lists relevant electrode potentials for some electrode reactions for use in (d)(i) and (d)(ii).

<table>
<thead>
<tr>
<th>electrode reaction</th>
<th>$E^\circ/V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightleftharpoons 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$</td>
<td>+1.33</td>
</tr>
<tr>
<td>$\text{CH}_3\text{CHO} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{CH}_3\text{CH}_2\text{OH}$</td>
<td>-0.61</td>
</tr>
<tr>
<td>$\text{CH}_3\text{COOH} + 2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{CH}_3\text{CHO} + \text{H}_2\text{O}$</td>
<td>-0.94</td>
</tr>
<tr>
<td>$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}$</td>
<td>+1.23</td>
</tr>
</tbody>
</table>

(i) Ethanal is oxidised to ethanoic acid in the presence of $\text{Cr}_2\text{O}_7^{2-}$ ions.

Construct the ionic equation for the oxidation of ethanal to ethanoic acid using dichromate(VI) in acid conditions. Calculate the $E^\circ_{\text{cell}}$ for this reaction.

ionic equation .............................................................................................................................................

$$E^\circ_{\text{cell}} = \text{...............} \text{V}$$ [2]

(ii) In an ethanol-oxygen fuel cell, $\text{CH}_3\text{CH}_2\text{OH}(l)$ and $\text{O}_2(g)$ are in contact with two inert electrodes immersed in an acidic solution.

The cell reaction for the oxidation of ethanol by oxygen is shown.

$$2\text{CH}_3\text{CH}_2\text{OH} + \text{O}_2 \rightarrow 2\text{CH}_3\text{COOH} + 2\text{H}_2\text{O} \quad E^\circ_{\text{cell}} = +2.01 \text{V}$$

Calculate $\Delta G^\circ$, in kJ mol$^{-1}$, for the oxidation of ethanol by oxygen.

$$\Delta G^\circ = \text{...............} \text{kJ mol}^{-1}$$ [2]

[Total: 15]
4  (a)  The 3d orbitals in an isolated Fe$^{2+}$ ion are degenerate.

Complete the diagram to show the splitting of the 3d orbital energy levels in an isolated Fe$^{2+}$ ion and when Fe$^{2+}$ forms an octahedral complex.

\[ \text{energy} \]

\[ \text{isolated Fe}^{2+} \text{ ion} \quad \text{Fe}^{2+} \text{ in an octahedral complex} \]

(b)  (i)  Bipyridine, bipy, is a bidentate ligand.

![Bipyridine structure]

**Fig. 4.1**

Explain what is meant by bidentate ligand.

...............................................................................................................................................
...............................................................................................................................................
...............................................................................................................................................
.............................................................................................................................................  [2]
(ii) The complex \([\text{Fe(bipy)}_3]^2^+\) exists as two stereoisomers.

Complete the three-dimensional diagrams to show the two stereoisomers of \([\text{Fe(bipy)}_3]^2^+\).

State the type of stereoisomerism shown.

Use \(\text{N} \text{N}\) to represent \text{bipy} in your diagrams.

\[\text{Fe} \quad \text{N} \quad \text{N} \quad \text{Fe} \]

Type of stereoisomerism .................................................................

\[3\]

(c) Standard electrode potentials can be used to compare the stability of different complex ions for a given transition element.

Table 4.1 lists electrode potentials for some electrode reactions for Fe\(^{3+}\)/Fe\(^{2+}\) systems.

<table>
<thead>
<tr>
<th>electrode reaction</th>
<th>(E^*/V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>([\text{Fe(H}_2\text{O)}_6]^3^+ + e^- \rightleftharpoons [\text{Fe(H}_2\text{O)}_6]^2^+)</td>
<td>+0.77</td>
</tr>
<tr>
<td>([\text{Fe(CN)}_6]^3^- + e^- \rightleftharpoons [\text{Fe(CN)}_6]^4^-)</td>
<td>+0.36</td>
</tr>
<tr>
<td>([\text{Fe(bipy)}_3]^3^+ + e^- \rightleftharpoons [\text{Fe(bipy)}_3]^2^+)</td>
<td>+0.96</td>
</tr>
</tbody>
</table>

Use relevant data from Table 4.1 to state which iron(III) complex is hardest to reduce. Explain your choice.

Iron(III) complex .........................................................

Explanation ..............................................................................

............................................................................................................

\[1\]
(d) The ligand bipyridine consists of two pyridine rings.

Pyridine, C₅H₅N, and benzene, C₆H₆, have similar planar, cyclic structures.

![Pyridine structure]

**Fig. 4.2**

By reference to the hybridisation of the carbon atoms and the nitrogen atom, and orbital overlap, suggest how the $\sigma$ and $\pi$ bonds are formed in a pyridine molecule.

....................................................................................................................................................
....................................................................................................................................................
....................................................................................................................................................
....................................................................................................................................................
..............................................................................................................................................  [3]

(e) Pyridine reacts with Cl₂ in the presence of AlCl₃ as shown in Fig. 4.3.

![Pyridine and 3-chloropyridine reaction]

**Fig. 4.3**

The mechanism of this reaction is similar to that of the chlorination of benzene. AlCl₃ reacts with chlorine to generate an electrophile, Cl⁺.

Complete the diagram to show the mechanism for the reaction of pyridine with Cl⁺. Include all relevant charges, dipoles, lone pairs of electrons and curly arrows as appropriate.

.................................................................................................................................................... [3]

[Total: 14]
5 (a) Compare the relative acidities of benzoic acid (C₆H₅COOH), phenylmethanol (C₆H₅CH₂OH), and phenol (C₆H₅OH).
Explain your reasoning.

........................................... > ........................................... > ...........................................
most acidic least acidic

...........................................

...........................................

...........................................

...........................................

...........................................

...........................................

...........................................

...........................................

...........................................

...........................................

...........................................

[3]

(b) A series of nine separate experiments is carried out as shown in Table 5.1.

Complete the table by placing a tick (✓) in the relevant box if a reaction occurs. Place a cross (✗) in the box if no reaction occurs.

<table>
<thead>
<tr>
<th></th>
<th>benzoic acid</th>
<th>phenylmethanol</th>
<th>phenol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na(s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaOH(aq)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na₂CO₃(aq)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[3]

(c) (i) Benzoyl chloride, C₆H₅COCl, can be synthesised by the reaction of benzoic acid with either PCl₅ or SOCl₂.

Complete the equations for these reactions.

reaction 1 C₆H₅COOH + PCl₅ → C₆H₅COCl + .................. + ..................

reaction 2 C₆H₅COOH + SOCl₂ → C₆H₅COCl + .................. + .................. [1]

(ii) Use your answer to (c)(i) to suggest why it is easier to isolate, in a pure form, the C₆H₅COCl from reaction 2 compared to reaction 1.

............................................................................................................................................
............................................................................................................................................... [1]
(d) Benzoyl chloride is hydrolysed by water at room temperature to form benzoic acid.

(i) Complete the diagram to show the mechanism for the reaction between C₆H₅COCl and H₂O.

Include charges, dipoles, lone pairs of electrons and curly arrows as appropriate.

(ii) Name the type of mechanism you showed in (d)(i).

....................................................................................................................................... [1]
(e) Acyl chlorides react with sodium carboxylates to form acid anhydrides as shown in Fig. 5.1.

\[
\begin{align*}
\text{acyl chloride} & \quad \text{sodium carboxylate} & \quad \text{acid anhydride} \\
\text{RC} & \quad \text{R'} & \quad \text{RCR'} + \text{NaCl}
\end{align*}
\]

Fig. 5.1

The condensation polymers, polyanhydride and polyester, are formed by similar methods.

The repeat unit for a polyanhydride is shown in Fig. 5.2.

(i) Use Fig. 5.1 and Fig. 5.2 to suggest the structures of the two monomers used to make this polyanhydride.

(ii) Polyanhydrides are biodegradable polymers.

Suggest how this polyanhydride can be degraded.

............................................................................................................................................
............................................................................................................................................ [1]

[Total: 16]
6 (a) Describe what is meant by a racemic mixture.

.................................................................................................................................................... [1]

(b) Asparagine is an amino acid that contains a chiral carbon atom and displays stereoisomerism.

Separate samples of asparagine are dissolved in CDCl₃ and analysed using carbon-13 and proton (¹H) NMR spectroscopy.

![Asparagine structure]

Fig. 6.1

Predict the number of peaks seen in the carbon-13 and proton (¹H) NMR spectra of asparagine.

<table>
<thead>
<tr>
<th></th>
<th>carbon-13 NMR</th>
<th>proton (¹H) NMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of peaks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[1]

(c) The isoelectric point of asparagine, asn, is at pH 5.4.

(i) Describe the meaning of the term isoelectric point.

.................................................................................................................................................... [1]

(ii) Draw the structure of asparagine at pH 1.0.

[1]
(d) Asparagine can polymerise to form poly(asparagine).

Draw the structure of poly(asparagine), showing two repeat units. The peptide linkage should be shown displayed.

(e) The isoelectric point of lysine, lys, is at pH 9.8.

Fig. 6.2

A mixture of the dipeptide lys-asn and its two constituent amino acids, asparagine and lysine, is analysed by electrophoresis using a buffer at pH 5.0. The results obtained are shown in Fig. 6.3.

Fig. 6.3

Suggest identities for the species responsible for spots E, F and G. Explain your answers.
(f) Thin-layer and gas-liquid chromatography can be used to analyse mixtures of substances. Each type of chromatography makes use of a stationary phase and a mobile phase.

(i) Complete Table 6.1 with an example of each of these.

<table>
<thead>
<tr>
<th></th>
<th>stationary phase</th>
<th>mobile phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>thin-layer chromatography</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gas-liquid chromatography</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(ii) An unknown amino acid is analysed using thin-layer chromatography. Two chromatographs of the unknown amino acid and four reference amino acids, P, Q, R and S, are obtained using two different solvents.

![Figure 6.4](image)

Identify the unknown amino acid. Justify your answer.

............................................................................................................................................
............................................................................................................................................
............................................................................................................................................ [1]
(g) A mixture containing three organic compounds is analysed by gas chromatography and mass spectrometry. The gas chromatogram is shown.

Fig. 6.5

The area underneath each peak is proportional to the mass of the respective compound in the mixture.

The concentration of K in the mixture is $5.52 \times 10^{-2}$ g dm$^{-3}$.

Calculate the concentration, in mol dm$^{-3}$, of compound L in the mixture.

$[M_r: L, 116]$

Concentration of L = ........................................ mol dm$^{-3}$ [1]

[Total: 12]
Procaine is used as an anaesthetic in medicine. It can be synthesised from methylbenzene in five steps as shown in Fig. 7.1.

(a) (i) Name all the functional groups present in procaine. 
..................................................................................................................................................................................... [1]

(ii) A molecule of procaine has 13 carbon atoms. 
State the number of carbon atoms that are sp, sp² and sp³ hybridised in procaine. 
sp carbons = .................. sp² carbons = .................. sp³ carbons = .................. [1]

(b) The proton (¹H) NMR spectrum of procaine dissolved in D₂O is recorded. 
Predict the number of peaks observed. 
..................................................................................................................................................................................... [1]

(c) State why procaine can act as a base. 
..................................................................................................................................................................................... [1]
(d) Compound X can be synthesised in two steps from methylbenzene.

![Diagram of synthesis](image)

Fig. 7.2

(i) Draw the structure of compound W in the box provided. [1]

(ii) State the reagents and conditions for step 1 and step 2.

   step 1 ..................................................................................................................................

   step 2 .................................................................................................................................. [2]

(e) Procaine is synthesised in three steps from X.

Suggest the reagents and conditions for step 4 and for step 5 in Fig. 7.1.

step 4 .........................................................................................................................................

step 5 ....................................................................................................................................... [3]

(f) (i) Explain what is meant by partition coefficient, $K_{pc}$.

.............................................................................................................................................

............................................................................................................................................. [2]

(ii) The partition coefficient of procaine between octan-1-ol and water is 1.77.

Octan-1-ol and water are immiscible. A solution containing 0.500 g of procaine in 75.0 cm$^3$ of water is shaken with 50.0 cm$^3$ of octan-1-ol.

Calculate the mass of procaine that is extracted into the octan-1-ol.

mass of procaine extracted = ......................... g [2]

[Total: 14]
### Important values, constants and standards

<table>
<thead>
<tr>
<th></th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>molar gas constant</td>
<td>$R = 8.31 \text{ J K}^{-1} \text{mol}^{-1}$</td>
</tr>
<tr>
<td>Faraday constant</td>
<td>$F = 9.65 \times 10^4 \text{ C mol}^{-1}$</td>
</tr>
<tr>
<td>Avogadro constant</td>
<td>$L = 6.022 \times 10^{23} \text{ mol}^{-1}$</td>
</tr>
<tr>
<td>electronic charge</td>
<td>$e = -1.60 \times 10^{-19} \text{ C}$</td>
</tr>
<tr>
<td>molar volume of gas</td>
<td>$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273K)</td>
</tr>
<tr>
<td></td>
<td>$V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions</td>
</tr>
<tr>
<td>ionic product of water</td>
<td>$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298K (25°C))</td>
</tr>
<tr>
<td>specific heat capacity of water</td>
<td>$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g$^{-1}$K$^{-1}$)</td>
</tr>
</tbody>
</table>
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The Periodic Table of Elements

<table>
<thead>
<tr>
<th>Group</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td>C</td>
<td>N</td>
<td>O</td>
<td>F</td>
<td>He</td>
<td>Ne</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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The key to the table:

- **1** Hydrogen (H)
- **2** Helium (He)
- **3** Lithium (Li)
- **4** Beryllium (Be)
- **5** Carbon (C)
- **6** Nitrogen (N)
- **7** Oxygen (O)
- **8** Fluorine (F)
- **9** Neon (Ne)
- **10** Sodium (Na)
- **11** Magnesium (Mg)
- **12** Aluminum (Al)
- **13** Silicon (Si)
- **14** Phosphorus (P)
- **15** Sulfur (S)
- **16** Chlorine (Cl)
- **17** Argon (Ar)
- **18** Potassium (K)
- **19** Calcium (Ca)
- **20** Scandium (Sc)
- **21** Titanium (Ti)
- **22** Vanadium (V)
- **23** Chromium (Cr)
- **24** Manganese (Mn)
- **25** Iron (Fe)
- **26** Cobalt (Co)
- **27**Nickel (Ni)
- **28** Copper (Cu)
- **29** Zinc (Zn)
- **30** Gallium (Ga)
- **31** Germanium (Ge)
- **32** Arsenic (As)
- **33** Selenium (Se)
- **34** Bromine (Br)
- **35** Krypton (Kr)
- **36** Rubidium (Rb)
- **37** Strontium (Sr)
- **38** Yttrium (Y)
- **39** Zirconium (Zr)
- **40** Nb (Niobium)
- **41** Mo (Molybdenum)
- **42** Technetium (Tc)
- **43** Ruthenium (Ru)
- **44** Rhodium (Rh)
- **45** Pd (Palladium)
- **46** Ag (Silver)
- **47** Cd (Cadmium)
- **48** In (Indium)
- **49** Sn (Tin)
- **50** Sb (Antimony)
- **51** Te (Tellurium)
- **52** I (Iodine)
- **53** Xe (Xenon)
- **54** Cs (Cesium)
- **55** Ba (Barium)
- **56** Ra (Radium)
- **57** Ac (Actinium)
- **58** Th (Thorium)
- **59** Pa (Protactinium)
- **60** U (Uranium)
- **61** Np (Neptunium)
- **62** Pu (Plutonium)
- **63** Am (Americium)
- **64** Cm (Curium)
- **65** Bk (Bernstein)
- **66** Cf (Californium)
- **67** Es (Einsteinium)
- **68** Fm (Fermium)
- **69** Md (Mendelevium)
- **70** No (Nobelium)
- **71** Lr (Lawrencium)

**Lanthanoids**

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