

Figure 3 If the  $6.02 \times 10^{23}$  atoms in 12 g of carbon were turned into marbles, the marbles could cover Great Britain to a depth of 1500 km!





*Figure 9 Successive ionisation enthalpies for phosphorus.* 

Figure 10 Energies of electron sub-shells from n = 1 to n = 4 in a typical many-electron atom. The energy of a sub-shell is not fixed, but falls as the charge on the nucleus increases as you go from one element to the next in the Periodic Table. The order shown in the diagram is correct for the elements in Period 3 and up to nickel in Period 4. After nickel the 3d sub-shell has lower energy than 4s.





Figure 13 Arrangement of electrons in atomic orbitals in a ground state sodium atom.





Figure 15 Dividing up the Periodic Table.



Figure 2 The sodium chloride lattice, built up from oppositely charged sodium ions and chloride ions.





Figure 13 Pauling electronegativity values for some main group elements in the Periodic Table.



Figure 15 A model of metallic bonding.



Figure 36 Two isomers of alanine.



Figure 38 The CORN rule. Look down the H—C bond from hydrogen towards the central carbon atom.





Figure 9 Breaking and making bonds in the reaction between methane and oxygen.



Figure 14 A comparison of solids, liquids and gases.



Figure 15 Each electronic energy level has within it several vibrational, rotational and translational energy levels. Note that the levels are not to scale.





Figure 27 Born–Haber cycles for sodium chloride and potassium chloride.

![](_page_11_Figure_0.jpeg)

Figure 27 Born–Haber cycles for sodium chloride and potassium chloride.

![](_page_12_Figure_0.jpeg)

![](_page_13_Figure_0.jpeg)

Figure 14 On heating, the molecular substance (represented by  $\bigcirc$ ) changes from a solid to a liquid and then to a gas. Energy must be supplied to overcome the intermolecular forces. Note that the covalent bonds within the molecules remain intact.

![](_page_13_Picture_2.jpeg)

![](_page_13_Picture_3.jpeg)

Electron cloud evenly distributed; no dipole.

At some instant, more of the electron cloud happens to be at one end of the molecule than the other; molecule has an instantaneous dipole.

![](_page_13_Figure_6.jpeg)

![](_page_13_Picture_7.jpeg)

This atom is not yet polarised, but its electrons are repelled by the dipole next to it ...

![](_page_13_Figure_9.jpeg)

δ+ Xe δ -

![](_page_13_Picture_11.jpeg)

*Figure 18 How an induced dipole is formed in a Xe atom.* 

![](_page_13_Figure_13.jpeg)

*Figure 20 Variation in the boiling points of the hydrides of some Group 4, 5, 6 and 7 elements.* 

Figure 21 Variation in the enthalpy changes of vaporisation of some Group 4, 5, 6 and 7 elements.

![](_page_14_Figure_0.jpeg)

*Figure 25* The positively charged H atoms line up with the lone pairs on the O atoms.

Figure 23 The positively charged H atom lines up with the lone pair on an F atom.

![](_page_14_Figure_3.jpeg)

*Figure 28 The arrangement of water molecules in ice.* 

![](_page_15_Figure_0.jpeg)

![](_page_15_Figure_1.jpeg)

(a) Thermoplastic: no cross-linking

![](_page_15_Figure_3.jpeg)

(b) Thermoset: extensive cross-linking

Weak forces between polymer chains easily broken by heating; polymer can be moulded into new shape.

![](_page_15_Picture_6.jpeg)

Strong covalent bonds between polymer chains cannot be easily broken; polymer keeps shape on heating.

Figure 29 Thermoplastics and thermosets.

![](_page_15_Figure_9.jpeg)

*Figure 32 Crystalline and amorphous regions of a polymer.* 

![](_page_15_Figure_11.jpeg)

![](_page_16_Figure_0.jpeg)

![](_page_17_Figure_0.jpeg)

Figure 21 Infrared spectrum of butane.

![](_page_18_Figure_0.jpeg)

![](_page_18_Figure_1.jpeg)

Figure 22 Infrared spectrum of methylbenzene.

![](_page_18_Figure_3.jpeg)

Figure 23 Infrared spectrum of benzoic acid.

![](_page_18_Figure_5.jpeg)

different energies.

![](_page_18_Figure_6.jpeg)

*Figure 37* A simplified diagram of an n.m.r. spectrometer.

![](_page_19_Figure_0.jpeg)

Figure 43 N.m.r. spectrum of hexane.

![](_page_19_Figure_2.jpeg)

Figure 44 N.m.r. spectrum of trans-but-2-ene.

![](_page_19_Figure_4.jpeg)

Figure 45 N.m.r. spectrum of propan-1-ol.

![](_page_19_Figure_6.jpeg)

![](_page_19_Figure_7.jpeg)

 $\begin{array}{c|c} \mathsf{CH}_3-\mathsf{CH}_2-\mathsf{CH}_2-\mathsf{CH}_2-\mathsf{CH}_2-\mathsf{CH}_2-\mathsf{CH}_3\\ \hline \textbf{Chemical} & \textbf{Relative} & \textbf{Type of}\\ \textbf{shift} & \textbf{no. protons} & \textbf{proton}\\ 0.9 & 3 & \mathsf{CH}_3\\ 1.3 & 4 & \mathsf{CH}_2\\ \end{array}$ 

![](_page_19_Figure_9.jpeg)

CH <sub>3</sub> -	$-CH_2 - CH_2 -$	ОН
ical	Polativo	Type of

Chemical	Relative	Type of
shift	no. protons	proton
0.9	3	CH <sub>3</sub>
1.6	2 -	-C-CH <sub>2</sub> -C-

*Figure 53 How colours arise from absorption of light.* 

![](_page_20_Figure_1.jpeg)

*Figure 57* The absorption spectrum of carotene (in solution in hexane).

Figure 59 Absorption and reflectance spectra of Monastral Blue.

![](_page_20_Figure_4.jpeg)

excitation energy excited electronic state energy absorbed corresponds to ultraviolet light excited electronic state energy absorbed to visible radiation energy absorbed corresponds to visible light ground electronic states

> COLOURED COMPOUND

COLOURLESS COMPOUND Figure 63 The energy needed to excite an electron in a coloured compound and in a colourless compound.

![](_page_22_Figure_0.jpeg)

Figure 10 Ion-exchange columns are used to soften water. The ion-exchange resin removes calcium ions from the 'hard' water, and replaces them with sodium ions to form 'soft' water.

![](_page_22_Figure_2.jpeg)

![](_page_22_Figure_3.jpeg)

![](_page_22_Figure_4.jpeg)

Figure 11 Thin-layer chromatography.

![](_page_22_Figure_6.jpeg)

Figure 15 A gas-liquid chromatograph.

Figure 15 A gas-liquid chromatograph.

![](_page_23_Figure_0.jpeg)

Figure 5 The pH scale.

![](_page_23_Figure_2.jpeg)

*Figure 6 How a buffer solution keeps the pH constant.* 

![](_page_24_Figure_0.jpeg)

![](_page_24_Figure_1.jpeg)

Figure 5 The general arrangement for an electrochemical cell.

in a torch.

![](_page_24_Figure_3.jpeg)

![](_page_25_Figure_0.jpeg)

Figure 9 A copper-zinc cell.

![](_page_25_Figure_2.jpeg)

Figure 9 A copper-zinc cell.

![](_page_25_Figure_4.jpeg)

Figure 11 The standard hydrogen half-cell (sometimes called a standard hydrogen electrode).

![](_page_25_Figure_6.jpeg)

Figure 11 The standard hydrogen half-cell (sometimes called a standard hydrogen electrode).

![](_page_26_Figure_0.jpeg)

Figure 12 A standard half-cell for the  $Fe^{3+}(aq)/Fe^{2+}(aq)$  half-reaction.

![](_page_27_Figure_0.jpeg)

![](_page_28_Figure_0.jpeg)

Figure 8 Apparatus for investigating the rate of decomposition of hydrogen peroxide. The yeast provides the enzyme catalase.

![](_page_28_Figure_2.jpeg)

Figure 11 The initial rate of decomposition of hydrogen peroxide plotted against concentration of hydrogen peroxide.

Figure 10 The decomposition of hydrogen peroxide solutions of differing concentrations.

![](_page_29_Figure_0.jpeg)

Figure 13 Finding half-lives,  $t_{1/2}$ , for the decomposition of hydrogen peroxide.

![](_page_29_Figure_2.jpeg)

Figure 14 Using a progress curve to find the rate of a reaction at different concentrations, by drawing tangents.

Figure 17 For a reaction involving two steps, there are two activation enthalpies.

![](_page_30_Figure_0.jpeg)

catalyst surface

![](_page_30_Figure_2.jpeg)

![](_page_30_Figure_3.jpeg)

Figure 18 An example of heterogeneous catalysis. The diagrams show a possible mechanism for nickel catalysing the reaction between ethene and hydrogen to form ethane.

![](_page_30_Figure_5.jpeg)

Progress of reaction

*Figure 19* The effect of a catalyst on the enthalpy profile for a reaction.

![](_page_30_Figure_8.jpeg)

Progress of reaction

*Figure 19* The effect of a catalyst on the enthalpy profile for a reaction.

![](_page_31_Figure_0.jpeg)

*Figure 3 Densities of elements in Periods 2 and 3.* 

![](_page_31_Figure_2.jpeg)

![](_page_31_Figure_3.jpeg)

*Figure 4 Melting and boiling points of elements in Period 3.* 

Figure 5 Variation in atomic size across Period 3.

![](_page_31_Figure_6.jpeg)

*Figure 6 First ionisation enthalpies of elements 1–20.* 

![](_page_32_Figure_0.jpeg)

Figure 20 Arrangement of electrons in the ground state of elements of the first row of the d block. [Ar] represents the electronic configuration of argon.

Figure 22 The arrangement of metal atoms in a crystal (a) before and (b) after slip has taken place. The shaded circles represent the end row of atoms.

![](_page_32_Figure_3.jpeg)

![](_page_32_Figure_4.jpeg)

The open circles represent atoms of iron. The black circles are the larger atoms of a metal added to make an alloy.

![](_page_32_Figure_6.jpeg)

![](_page_33_Figure_0.jpeg)

CI

Ni

CI

CI

shape

Figure 27 An octahedral complex of Fe(III). Coordination number 6.

![](_page_33_Figure_2.jpeg)

![](_page_33_Figure_3.jpeg)

(a)

Figure 28 A tetrahedral complex of Ni(II). Coordination number 4.

![](_page_33_Figure_5.jpeg)

0:

0:

CI

Figure 29 A square planar complex of Ni(II). Coordination number 4.

 $CH_2$ 

- CH

![](_page_33_Figure_7.jpeg)

CI

Ni

CI

CI

CI

*Figure 30* A linear complex of Ag(I). Coordination number 2.

![](_page_33_Figure_9.jpeg)

*Figure 32*(a) Edta<sup>4-</sup>, a hexadentate ligand.
(b) The nickel–edta complex ion [Ni(edta)]<sup>2-</sup>.

Figure 33 Relative energy levels for the five 3d  $\dot{}$  itals of the hydrated  $Ti^{3+}$  ion.

![](_page_34_Figure_1.jpeg)

cis isomer: violet

trans isomer: green

Name	Molecular formula	Full structural formula	Shortened structural formula	Further shortened to
methane	$CH_4$	Н Н—С—Н Н	CH <sub>4</sub>	
ethane	C <sub>2</sub> H <sub>6</sub>	Н Н     H—С—С—Н     Н Н	$CH_3 - CH_3$	CH <sub>3</sub> CH <sub>3</sub>
propane	C <sub>3</sub> H <sub>8</sub>	Н Н Н       H—С—С—С—Н       Н Н Н	$CH_3 - CH_2 - CH_3$	CH <sub>3</sub> CH <sub>2</sub> CH <sub>3</sub>

Table 2 Structural formulae of alkanes.

![](_page_35_Figure_2.jpeg)

![](_page_35_Figure_3.jpeg)

*Figure 5 The three-dimensional shape of methane.* 

Figure 6 The three-dimensional shape of ethane.

![](_page_35_Figure_5.jpeg)

![](_page_35_Figure_6.jpeg)

a simpler way of drawing ethane which shows the shape less accurately

![](_page_35_Figure_8.jpeg)

skeletal formula

of butane

Figure 7 The three-dimensional shape of butane.

		ALKANES		
	Isomerisation	Reforming	Crac	king
			Steam cracking	Catalytic cracking
Feedstock	C <sub>4</sub> – C <sub>6</sub> alkanes	naphtha	naphtha/kerosene	gas oil
Product molecules	same molecular formula as reactants; branched	same number of C atoms as reactants; cyclic	more molecules; fewer C atoms than reactants; small molecules, such as C <sub>2</sub> H <sub>4</sub> , C <sub>2</sub> H <sub>6</sub> , C <sub>3</sub> H <sub>8</sub> , C <sub>4</sub> and C <sub>5</sub> alkenes and alkanes	more molecules; fewer C atoms than reactants; some unsaturated; some branched; some cyclic
Conditions	PVAI <sub>2</sub> O3; 150 °C	PVAI <sub>2</sub> O <sub>3</sub> ; 500 °C; hydrogen is recycled through mixture to reduce 'coking'	no catalyst; 900 °C; short residence time; steam is a dilutent to prevent 'coking'	zeolite; 500 °C
Example	$  \xrightarrow{\uparrow} \\ \stackrel{\uparrow}{\searrow}  $	+ +		
		+	✓ + ✓	→ + →
Uses of products	to improve octane rating of petrol	to improve octane rating of petrol	to manufacture polymers	to improve octane rating of petrol
Further details	Developing Fuells storyline, Section DF4	Developing Fuels storyline, Section DF4 Chemical Ideas 15.2	The Polymer Revolution storyline, Sections PR3 and PR4 Chemical Ideas 15.2	Developing Fuells storyline, Section DF4 Chemical Ideas 15.2
The i The i th	action of heat on alkanes. Skeletal formult is skeletal formula for a benzene ring.	e are used in the examples.		

![](_page_37_Figure_0.jpeg)

Figure 11 The structure of the benzene ring.

![](_page_37_Figure_2.jpeg)

Figure 14 An electron density map for benzene at -3 °C. The lines are like contour lines on a map: they show parts of the molecule with equal electron density.

Figure 15 Enthalpy changes for the hydrogenation of benzene and the hypothetical Kekulé structure.

![](_page_37_Figure_5.jpeg)

Progress of reaction

![](_page_37_Figure_7.jpeg)

Figure 16 The regions of higher electron density above and below the benzene ring.

Table 1 Naming halogenoalkanes.

![](_page_38_Figure_1.jpeg)

Name and formula	Structure, showing lone pairs
hydroxide ion, OH <sup>—</sup>	н-о:-
cyanide ion, CN <sup>—</sup>	:N≡C:
ethanoate ion, CH <sub>3</sub> COO <sup>−</sup>	сн₃—с–ё: <sup>–</sup> ∥
ethoxide ion, C <sub>2</sub> H <sub>5</sub> O <sup>-</sup>	СН <sub>3</sub> СН <sub>2</sub> —о:-
water molecule, H <sub>2</sub> O	нн
ammonia molecule, NH <sub>3</sub>	H <sup>N</sup> H H

Table 3 Some common nucleophiles.

![](_page_38_Figure_4.jpeg)

Table 4 Naming alcohols.

![](_page_39_Figure_0.jpeg)

Table 6 Some examples of acid derivatives.

Table 7 Primary, secondary and tertiary alcohols.

Type of alcohol	Position of —OH group	Example
primary	at end of chain: H R—C—OH I H	$\begin{array}{c} \text{propan-1-ol} \\ \text{H} \\ \text{CH}_{3}\text{CH}_{2} \overset{\text{I}}{-} \overset{\text{I}}{\text{C}} \overset{\text{OH}}{-} \text{OH} \\ \overset{\text{I}}{\text{H}} \end{array}$
secondary	in middle of chain: H R—C—R' I OH	propan-2-ol H $CH_3 - C - CH_3$ OH
tertiary	attached to a carbon atom which carries no H atoms: R' R — C — R" J OH	2-methylpropan-2-ol CH <sub>3</sub> CH <sub>3</sub> $-$ CH <sub>3</sub> I CH <sub>3</sub> $-$ C-CH <sub>3</sub> I OH

![](_page_39_Figure_4.jpeg)

Figure 6 How to name an ester.

![](_page_40_Figure_0.jpeg)

always the same

fatty acid parts  $- R^1$ ,  $R^2$  and  $R^3$  may be different or the same

Figure 7 The general structure of the triesters found in fats and oils.

Figure 9 Representations of triglycerides.

![](_page_40_Figure_5.jpeg)

![](_page_41_Figure_0.jpeg)

Figure 18 Making a secondary amide.

![](_page_41_Figure_2.jpeg)

Figure 20 The generalised structure of an O-amino acid.

![](_page_41_Figure_4.jpeg)

![](_page_42_Figure_0.jpeg)

Figure 4 Reactions of primary alcohols.

![](_page_43_Figure_0.jpeg)

Figure 7 The reactions of carboxylic acids and some related compounds.

![](_page_44_Figure_0.jpeg)

Figure 8 Reactions of arenes.

![](_page_45_Figure_0.jpeg)

*Figure 1 Sequence of unit operations in a chemical plant.* 

![](_page_45_Figure_2.jpeg)

(b) Continuous (stirred tank) reactor

![](_page_45_Figure_4.jpeg)

*Figure 2* Comparison of (a) batch and (b) continuous tank reactors.

Figure 3 Pipelines from BP, Grangemouth, and Exxon, Mossmorran, for the distribution of ethene.

![](_page_45_Figure_7.jpeg)

![](_page_46_Figure_0.jpeg)

*Figure 6* (a) An example of how energy can be used in a chemical process. (b) A diagram to illustrate a heat exchanger.