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 3 The mass spectrometer.


Figure 3 The mass spectrometer.

Figure 7 Variation of first ionisation enthalpy with atomic number for elements with atomic numbers 1 to 56.



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 $4 s$.




|  |
| :---: |

$\square$

|  |  |
| :---: | :---: |



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.

| G Period | roup 1 | 14 <br> 2.2 |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 2 | Li | $\mathrm{Be}$ | $\begin{gathered} \text { B } \\ 2.0 \\ \hline \end{gathered}$ | $\begin{gathered} \text { C } \\ 2.6 \end{gathered}$ | $\begin{array}{r} \mathbf{N} \\ 3.0 \\ \hline \end{array}$ | O 3.4 | F <br> 4.0 |
|  | 3 | $\begin{gathered} \mathrm{Na} \\ 0.9 \end{gathered}$ | $\mathrm{Mg}$ | $\begin{aligned} & \hline \mathbf{A l} \\ & 1.6 \end{aligned}$ | $\begin{aligned} & \mathrm{Si} \\ & 1.9 \end{aligned}$ | $\begin{gathered} \hline \mathbf{P} \\ 2.2 \end{gathered}$ | $\begin{gathered} \mathbf{S} \\ 2.6 \\ \hline \end{gathered}$ | CI 3.2 |
|  | 4 | $\begin{aligned} & \mathrm{K} \\ & 0.8 \\ & \hline \end{aligned}$ | Ca |  |  |  |  | Br 3.0 |
|  | 5 | $\begin{gathered} \text { Rb } \\ 0.8 \\ \hline \end{gathered}$ | $\mathrm{Sr}$ |  |  |  |  | I <br> 2.7 |

KEY



Figure 15 A model of metallic bonding.


Figure 17 The relative sizes of atoms and ions.

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

$\mathrm{Na}^{+}$ion
(charge $1+$, radius 0.098 nm )
On average, each
$\mathrm{Na}^{+}$ion is surrounded by
5 water molecules

$\mathrm{Mg}^{2+}$ ion (charge $2+$, radius 0.078 nm )

On average, each
$\mathrm{Mg}^{2+}$ ion has 15 water molecules around it

Figure 18 Ions with higher charge densities attract more water molecules (ions are only shown in two dimensions).

isolated $\mathrm{Li}^{+}$ion
(radius $=0.078 \mathrm{~nm}$ )


Figure 19 Hydrated ions are much bigger than isolated ions.



imaginary mirror

Figure 36 Two isomers of alanine.




Progress of reaction
reactants $\longrightarrow$ products

Figure 2 Enthalpy level diagram for an endothermic reaction, eg decomposing calcium carbonate:
$\mathrm{CaCO}_{3} \rightarrow \mathrm{CaO}+\mathrm{CO}_{2}$

Figure 3 A bomb calorimeter for making accurate measurements of energy changes. The fuel is ignited electrically and burns in the oxygen inside the pressurised vessel. Energy is transferred to the surrounding water, whose temperature rise is measured.
Note that the experiment is done at constant volume in a closed container. Enthalpy changes are for reactions carried out at constant pressure, so the result needs to be modified accordingly.

$$
\mathrm{CO}_{2}(\mathrm{~g})+2 \mathrm{H}_{2} \mathrm{O}(\mathrm{I})
$$

Figure 4 An enthalpy cycle for finding the enthalpy change of formation of methane, $\mathrm{CH}_{4}$.


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 21 An enthalpy cycle to show the

dissolving of an ionic solid.


Figure 26 Born-Haber cycle for sodium chloride.


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


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


Solid sodium chloride a retular ionic lattice


Figure 2 What happens when an ionic substance such as sodium chloride dissolves in water.


Sodium chloride dissolved in water
$\mathrm{Cl}^{-}(\mathrm{aq}) \quad \mathrm{Na}^{+}(\mathrm{aq}) \quad$ water molecule
${ }^{\mathrm{Cl}^{-}(\mathrm{aq})}{ }^{-\mathrm{Na}^{+}(\mathrm{aq})}$


Figure 5 Polar water molecules attract the ions in a solid lattice.


Figure 11 (a) The structure of diamond and (b) the structure of graphite.


Figure 12 Imagine you are inside a diamond. The regular network structure would repeat in all directions - as far as the edge of the diamond.


Figure 13 The fullerenes are a recently discovered molecular form of carbon.
(a) shows $C_{60}$, named buckminsterfullerene.

It is made up of a mixture of 5-membered and 6membered rings and looks like a football
(b) is another way of presenting $C_{60}$, showing the positions of the carbon atoms
(c) shows $C_{70}$, which is shaped like a rugby ball.

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


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.

Figure 18 How an induced dipole is formed in a


This atom is instantaneously polarised


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


Xe atom.



Figure 15 How a dipole forms in a chlorine molecule.

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.




Hydrogen bond


Figure 25 The positively charged $H$ atoms line $u p$ 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.

ili!ili! hydrogen bond

Figure 28 The arrangement of water molecules in ice.

(a) Thermoplastic: no cross-linking

(b) Thermoset: extensive cross-linking

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


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

Figure 29 Thermoplastics and thermosets.


Figure 32 Crystalline and amorphous regions of a polymer.


Figure 36 A summary of the structures of substances.

line absorption spectrum (black lines on a bright coloured background)

Figure 4 Obtaining a line absorption spectrum.

Figure 6 How the Lyman series in the emission spectrum is related to energy levels in the H atom.


sample cell for solution of sample


Figure 16 The basic parts of a double beam infrared spectrometer.

$$
\mathrm{CH}_{3}-\mathrm{CH}_{2}-\mathrm{CH}_{2}-\mathrm{CH}_{3}
$$

Absorption/cm ${ }^{-1}$ 2970

## Bond

C—H (alkane)

Figure 21 Infrared spectrum of butane.





| Absorption $/ \mathbf{c m}^{-1}$ | Bond |
| :--- | :--- |
| 3050 | C-H (arene) |
| 2940 | C-H (alkane) |

Figure 22 Infrared spectrum of methylbenzene.


Absorption/cm ${ }^{-1}$ Bond
3580
3080 1760 Bond
$\mathrm{O}-\mathrm{H}$
$\mathrm{C}=\mathrm{H}$ (arene)
$\mathrm{C}=\mathrm{O}$

Figure 23 Infrared spectrum of benzoic acid.
aligned with magnetic field


Figure 36 The principle of n.m.r.: a small magnet in a strong magnetic field can have two different energies.

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



| $\mathrm{CH}_{3}-\mathrm{CH}_{2}-\mathrm{CH}_{2}-\mathrm{CH}_{2}-\mathrm{CH}_{2}-\mathrm{CH}_{3}$ |  |  |
| :---: | :---: | :---: |
| Chemical | Relative | Type of |
| shift | no. protons | proton |
| 0.9 | 3 | $\mathrm{CH}_{3}$ |
| 1.3 | 4 | $\mathrm{CH}_{2}$ |

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



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


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

$$
\mathrm{CH}_{3}-\mathrm{CH}_{2}-\mathrm{CH}_{2}-\mathrm{OH}
$$

| $\begin{gathered} \text { Chemical } \\ \text { shift } \\ 0.9 \end{gathered}$ | Relative no. protons 3 | Type of proton $\mathrm{CH}_{3}$ |
| :---: | :---: | :---: |
| 1.6 | 2 |  |
| 2.3 | 1 | OH |
| 3.6 | 2 | $\xrightarrow[\mathrm{l}]{\mathrm{C}} \mathrm{l}^{\mathrm{C}} \mathrm{CH}_{2}-\mathrm{O}-$ |

Figure 52 How light behaves with transparent and opaque objects.


transmits wavelengths corresponding to other colours: appears green

reflects wavelengths corresponding to other colours: appears orange


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

Figure 59 Absorption and reflectance spectra of Monastral Blue.


excitation

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


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.


Figure 11 Thin-layer chromatography.


Figure 11 Thin-layer chromatography.

$\mathrm{pH}[\mathrm{H}+(\mathrm{aq})] / \mathrm{mol} \mathrm{dm}^{-3}$


Figure 5 The pH scale.


Figure 2 The reaction of chlorine with potassium iodide solution.

$\mathrm{Cl}^{-}$



$\oplus$


$+-\mathrm{Cu}^{2+}$ ion
Cu atom





Figure 4 The reaction of zinc with
copper (II) sulphate solution:
$\mathrm{Zn}(\mathrm{s})+\mathrm{Cu}^{2+}(a q) \rightarrow \mathrm{Cu}(\mathrm{s})+\mathrm{Zn}^{2+}(a q)$


Figure 5 The general arrangement for an electrochemical cell.

Figure 6 An ordinary dry cell - the kind you use in a torch.



Figure 9 A copper-zinc cell.


Figure 9 A copper-zinc cell.


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


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


Figure 12 A standard half-cell for the $F e^{3+}(a q) / F e^{2+}(a q)$ half-reaction.

Figure 2 Enthalpy profile for an exothermic reaction.

Figure 4 Distribution curves for molecular kinetic energies in a gas at 300 K and 310 K .



Kinetic energy ( $E$ )



Kinetic energy ( $E$ )

Figure 5 Distribution curve showing collisions with energy $50 \mathrm{~kJ} \mathrm{~mol}^{-1}$ and above.

Figure 6 Distribution curves showing the effect on the proportion of collisions with energy $50 \mathrm{~kJ} \mathrm{~mol}^{-1}$ and above of changing the temperature from 300 K to 310 K .


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

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




Progress of reaction

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.

catalyst surface
 Bonds are weakened.
 $\sqrt{2}$ Bonds break.


New bond forms. 3


Second bond
forms, and product diffuses away from catalyst surface,
leaving it free to
adsorb fresh
reactants.


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.


Progress of reaction

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


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

Figure 3 Densities of elements in Periods 2 and 3.



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


Figure 5 Variation in atomic size across Period 3.

Figure 6 First ionisation enthalpies of elements $1-20$.



octahedral complex of FE (III) coordination number 6


shape

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

tetrahedral complex of $\mathrm{Ni}(\mathrm{II})$ coordination number 5

shape

Figure 28 A tetrahedral complex of $N i(I I)$. Coordination number 4.

square planar complex of $\mathrm{Ni}(I I)$ coordination number 4

shape

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



Figure 30 A linear complex of $\operatorname{Ag}(I)$. Coordination number 2.

Figure 32
(a) Edta ${ }^{4}$, a hexadentate ligand.
(b) The nickel-edta complex ion $[\mathrm{Ni}(\mathrm{edta})]^{2-}$.


Figure 36 The cis and trans isomers of $\left[\mathrm{Co}\left(\mathrm{NH}_{3}\right)_{4} \mathrm{Cl}_{2}\right]^{+}$have different colours.


|  | Name | Molecular formula | Full structural formula | Shortened structural formula | Further shortened to |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | methane | $\mathrm{CH}_{4}$ |  | $\mathrm{CH}_{4}$ |  |
| $?$ | ethane | $\mathrm{C}_{2} \mathrm{H}_{6}$ |  | $\mathrm{CH}_{3}-\mathrm{CH}_{3}$ | $\mathrm{CH}_{3} \mathrm{CH}_{3}$ |
|  | propane | $\mathrm{C}_{3} \mathrm{H}_{8}$ |  | $\mathrm{CH}_{3}-\mathrm{CH}_{2}-\mathrm{CH}_{3}$ | $\mathrm{CH}_{3} \mathrm{CH}_{2} \mathrm{CH}_{3}$ |

Table 2 Structural formulae of alkanes.

Figure 5 The three-dimensional shape of methane.


Figure 6 The three-dimensional shape of ethane.



skeletal formula of butane

|  | ALKANES |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | Isomerisation | Reforming | Cracking |  |
|  |  |  | Steam cracking | Catalytic cracking |
| Feedstock | $\mathrm{C}_{4}-\mathrm{C}_{6}$ 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 $\mathrm{C}_{2} \mathrm{H}_{4}, \mathrm{C}_{2} \mathrm{H}_{6}, \mathrm{C}_{3} \mathrm{H}_{6}, \mathrm{C}_{3} \mathrm{H}_{8}$, $\mathrm{C}_{4}$ and $\mathrm{C}_{5}$ alkenes and alkanes | more molecules; fewer C atoms than reactants; some unsaturated; some branched; some cyclic |
| Conditions | $\begin{aligned} & {\mathrm{Pt} / \mathrm{Al}_{2} \mathrm{O}_{3} ;}^{150{ }^{\circ} \mathrm{C}} \end{aligned}$ | ```Pt/Al}\mp@subsup{2}{2}{O 500 '}\mp@subsup{}{}{\circ}\textrm{C} hydrogen is recycled through mixture to reduce 'coking'``` | ```no catalyst; 900 ' C; short residence time; steam is a dilutent to prevent 'coking'``` | zeolite; <br> $500^{\circ} \mathrm{C}$ |
| Example |  |  |  |  |
| 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 <br> Chemical Ideas 15.2 | The Polymer Revolution storyline, Sections PR3 and PR4 <br> Chemical Ideas 15.2 | Developing Fuells storyline, Section DF4 <br> Chemical Ideas 15.2 |

[^0]

Figure 11 The structure of the benzene ring.

Figure 14 An electron density map for benzene at $-3^{\circ} \mathrm{C}$. 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.


Progress of reaction

regions of higher electron density above and below the benzene ring

Figure 16 The regions of higher electron density above and below the benzene ring.
Scale $\qquad$ 0. 1nm

Table 1 Naming halogenoalkanes.

| Full structural formula | Skeletal formula | Name |
| :---: | :---: | :---: |
|  |  | 1-chloropropane |
|  |  | 1,2-dichloropropane |
|  |  | 3-bromo-1-chlorobutane |


| Name and formula | Structure, showing Ione pairs |
| :---: | :---: |
| hydroxide ion, $\mathrm{OH}^{-}$ | H-Ö:- |
| cyanide ion, $\mathrm{CN}^{-}$ | $: N \equiv C:^{-}$ |
| ethanoate ion, $\mathrm{CH}_{3} \mathrm{COO}^{-}$ |  |
| ethoxide ion, $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{O}^{-}$ | $\mathrm{CH}_{3} \mathrm{CH}_{2}-\ddot{\mathrm{O}} \mathrm{O}^{-}$ |
| water molecule, $\mathrm{H}_{2} \mathrm{O}$ |  |
| ammonia molecule, $\mathrm{NH}_{3}$ |  |

Table 3 Some common nucleophiles.

| Full structural formula | Skeletal formula | Name |
| :---: | :---: | :---: |
|  |  | propan-1-ol |
|  |  | propan-2-ol |
|  |  | pentan-3-ol |

Table 4 Naming alcohols.

| Acid derivative | Dealt with in Section(s) | Example |  |
| :---: | :---: | :---: | :---: |
|  | 13.5 and 14.2 |  | ethyl ethanoate |
|  acyl chloride | 13.5 and 14.2 |  | ethanoyl chloride |
|  amide | 13.8 |  | ethanamide |
|  | 13.5 and 14.2 |  | ethanoic anhydride |

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: | propan-1-ol |
| secondary | in middle of chain: | propan-2-ol |
| tertiary | attached to a carbon atom which carries no H atoms: | 2-methylpropan-2-ol |



| This part comes from | This part comes <br> the alcohol and is <br> from the acid and <br> named after it |
| :---: | :---: |
| is named after it |  |

Figure 6 How to name an ester.

glycerol part -
fatty acid parts - $\mathrm{R}^{1}, \mathrm{R}^{2}$ and $\mathrm{R}^{3}$
always the same
may be different or the same
Figure 7 The general structure of the triesters
found in fats and oils.

Figure 9 Representations of triglycerides.


Saturated triglyceride



Figure 18 Making a secondary amide.
$\alpha$-carbon: the first carbon atom attached to the -COOH group
amino group

acid group

Figure 20 The generalised structure of an $\alpha$-amino acid.

Figure 21 How an amino acid forms a zwitterion.



Figure 22 A generalised coupling reaction.


finely divided Ni at $150^{\circ} \mathrm{C}$ and 5 atm (or Pt at room temp and 1 atm.)


Figure 3 Reactions of halogenoalkanes.




$$
\operatorname{HBr}(\mathrm{aq})
$$



Figure 4 Reactions of primary alcohols.

primary alcohol

a cyanohydrin

Figure 5 Reactions of aldehydes.



Figure 6 Reactions of ketones.

carboxylate ion

acid anhydride



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


Figure 8 Reactions of arenes.


Figure 1 Sequence of unit operations in a chemical plant.

(b) Continuous (stirred tank) reactor

Reactants added continuously


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

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



Figure 4 Feedstocks from natural gas.


Figure 5 Feedstocks from oil.


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


[^0]:    Table 5 The action of heat on alkanes. Skeletal formulae are used in the examples.
    $\bigcirc$ is the skeletal formula for a benzene ring.

