RECENT BOOKS FOR
TEACHERS AND STUDENTS

WATER
Revised
1st Edition

by Felix Franks
Softcover 102 pp
ISBN 0 85186 473 2
Price £2.50 ($6.00)

This book considers the present state of our knowledge of liquid water, its remarkable physical properties and how these give rise to a unique structure, its influence on the interactions between solutes, its role in maintaining biologically active structures, its involvement in chemical reactions and the problems posed by its management and in providing sufficient amounts of water of adequate quality.

An understanding of the behaviour of water is fundamental to gaining an appreciation of many scientific processes and principles. Science students and teachers will, therefore, find Water not only interesting reading but also of considerable relevance to their studies.

Contents:
Occurrence, Importance and Physical Properties of Water
The Structure of the Water Molecule
The Nature of the Hydrogen Bond in Water
Ionisation and Dynamic Properties of Liquid Water
Toward a Molecular Description of Water
Aqueous Solutions of Simple Molecules
Aqueous Solutions of Electrolytes
The Role of Water in the Stabilisation of Biologically Significant Structures
Reactions in Aqueous Solutions
Water in the Environment: Quality, Availability and Exploitation
Summary and Future Prospects
RSC Paperback (1984)

FOOD
The Chemistry of its Components

by T. P. Caultate
Softcover 202 pp
ISBN 0 85186 483 X
Price £5.95 ($11.00)

This book gives a detailed account of the chemistry of the principal substances of which our food is composed. Both the macro-components, the carbohydrates, lipids and proteins, which can be classified by their structural chemical properties; and the micro-components, the colours, flavours, vitamins and preservatives, which are considered in terms of function are considered. Throughout the book, Dr. Caultate's theme is the relationship between the chemical structure of a substance and its contribution to the properties and behaviour of foods - whether observed in the laboratory, the factory, the kitchen or the dining room.

Contents:
Introduction, Carbohydrates, Lipids, Proteins, Colours, Flavours, Vitamins, Preservatives, EEC Numbers of Food Additives, Subject Index. This book will be of particular benefit to students and teachers of food science and related courses in universities, colleges of further education and schools.

RSC Paperback (1984)

THE ARCHITECTURE OF MATTER

Graham Hill
John Holman

Educational Techniques Group Trust
Royal Society of Chemistry
CHEMISTRY CASSETTES
A-level series

Published 1986 by the Educational Techniques Group Trust, Royal Society of Chemistry, London.

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ISBN 0 85186 957 2

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ROYAL SOCIETY OF CHEMISTRY

Class No........

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

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USING CHEMISTRY CASSETTES

Please read this before you start.

This Chemistry Cassette learning programme has two components — an audio-cassette and a workbook. They are designed to be used together so make sure that you have both of them before you start.

The cassette will fit any standard audio-cassette player. You will have to turn it over to Side B when you are about half-way through the programme.

So that you can easily find material in the workbook it has been divided into numbered sections called ‘frames’. These frames contain diagrams, tables, problems (questions), etc. Graham and John will give you the appropriate frame number whenever they want you to look at something in the workbook.

The programme has been designed so that you can use it either in class or on your own. If you are working on your own you will be able to go through at your own pace. Switch off the tape player whenever you want time to think, to write notes, or to answer questions. Use the rewind control if there is something that you don’t understand on a first hearing and that you want to go over again.

Every now and then you will be presented with a problem. You can either attempt this straight away or wait until you get to the end of the tape. Each problem is printed in a relevant frame of the workbook. All the answers are at the end.
ACKNOWLEDGMENTS

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Frame 7 - Nuffield Chelsea Curriculum Trust
Frame 8 - Dr Brian Johnson
Frame 29 - Luton College of Higher Education.

SUMMARY

As with other programmes in this series, the authors' intention is to explore major themes that link several areas of chemistry. In this programme they consider the structure of matter and the ways in which the properties of substances depend on their structures.

CONTENTS

The diversity of materials
The factors affecting the properties of materials
The major types of structures - metallic
   - giant ionic
   - simple molecular
   - giant molecular

One, two and three dimensional giant molecules
Volatile - ionic solids, lattice energy, coordination number
   - simple molecular substances, intermolecular forces, hydrogen bonding
Solubility - ionic solids, energy cycle
   - metals, amalgams
Density - metals, packing types
Conductivity
1. Two ways of arranging bricks in a wall.

Which arrangement will give the stronger wall?

2. Factors affecting the properties of a substance.

The properties of a substance are dictated by:
1) the particles in the structure,
2) the bonding between the particles,
3) the packing of the particles.
The four types of solid structure and their constituent particles.

<table>
<thead>
<tr>
<th>Constituent particles</th>
<th>Solid structure</th>
<th>Type of substance</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atoms</td>
<td>Giant metallic</td>
<td>Metal element</td>
<td>Na, Fe, Cu</td>
</tr>
<tr>
<td>Ions</td>
<td>Giant ionic</td>
<td>Metal/non-metal compound</td>
<td>Na(^{+})Cl(^{-}), Ca(^{+})O(^{-})</td>
</tr>
<tr>
<td>Atoms in large molecules</td>
<td>Giant molecular</td>
<td>Non-metal element or Non-metal/non-metal compound</td>
<td>C(graphite), C(diamond), poly(ethylene), sand</td>
</tr>
<tr>
<td>Atoms in small molecules</td>
<td>Simple molecular</td>
<td>Non-metal element or Non-metal/non-metal compound</td>
<td>I(_2), S(_2), H(_2)O, CO(_2)</td>
</tr>
</tbody>
</table>

A simple model of metallic structure

A model of the structure of salt (Na\(^{+}\)Cl\(^{-}\))
The crystal structures of iodine and ice.

(a) The tetrahedral arrangement of carbon atoms in diamond.

(b) A worm's eye view of the giant structure in diamond.

- oxygen atom
- hydrogen atom
- hydrogen bond

indicates the centre of an I₂ molecule
A natural uncut diamond weighing 120g.

PROBLEM 1  How many atoms does this molecule contain?

A summary of the four main types of structure.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Examples</th>
<th>Hardness and/ or malleability</th>
<th>Volatility</th>
<th>Conductivity (solid)</th>
<th>Conductivity (molten)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giant metallic</td>
<td>Lattice of positive ions in a delocalised electron cloud.</td>
<td>copper, iron.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giant ionic</td>
<td>Regular lattice of positive and negative ions held by electrostatic attraction.</td>
<td>salt (NaCl), lime (CaO), limestone (CaCO₃), chalk (CaCO₃).</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple molecular</td>
<td>Small molecules, Atoms held within molecules by strong covalent bonds, but weak forces between molecules.</td>
<td>iodine, ice, sugar.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giant molecular</td>
<td>Large molecules containing thousands of atoms held together by strong covalent bonds.</td>
<td>diamond, sand.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PROBLEM 2  Complete this table.

The molecular structure of nylon.

The 'nylon rope trick'.

nylon 'rope' being wound onto glass rod

solution of 1,6-diaminohexane in water

interface - nylon is formed here

solution of hexanediol chloride in tetrachloromethane
The structure of graphite.

Playing cards slip over each other in the same way as graphite sheets slip.

The structure of sand—silica, SiO.

Si atom
O atom

PROBLEM 3 Classify these giant molecular structures as one-dimensional, two-dimensional or three-dimensional:

polyester
mica
keratin (hair protein)
carborundum (silicon carbide)
quartz
### Important physical properties of materials.

- **Volatile** (melting, boiling, vaporization)
- **Solubility** (in water and other solvents)
- **Conductivity** (thermal and electrical)
- **Hardness** (including malleability)
- **Density**

### Why does lime have a higher melting point than salt?

<table>
<thead>
<tr>
<th></th>
<th>Salt (NaCl)</th>
<th>Lime (CaO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>Na⁺Cl⁻</td>
<td>Ca²⁺O²⁻</td>
</tr>
<tr>
<td>Melting point /°C</td>
<td>808</td>
<td>2600</td>
</tr>
<tr>
<td>Structure</td>
<td>Simple cubic</td>
<td>Simple cubic</td>
</tr>
<tr>
<td>Ionic radius /nm</td>
<td>0.095 0.181</td>
<td>0.099 0.140</td>
</tr>
<tr>
<td>Interionic distance /nm</td>
<td>0.267</td>
<td>0.239</td>
</tr>
<tr>
<td>Lattice energy /kJ mol⁻¹</td>
<td>-776</td>
<td>-3523</td>
</tr>
</tbody>
</table>

\[
X^+(g) + Y^-(g) \rightarrow XY(s)
\]

\[
\Delta H_{latt} = \text{lattice energy}
\]
**PROBLEM 4** What other factors will affect the lattice energy besides the charge on an ion?

**PROBLEM 5** Would you expect calcium oxide to have a higher or lower melting point than magnesium oxide? Explain your answer.

---

**19** The arrangement of Na$^{+}$ and Cl$^{-}$ ions in sodium chloride.

---

**20** The arrangement of Cs$^{+}$ and Cl$^{-}$ ions in caesium chloride.
**21** The relationship of co-ordination numbers in ionic crystals to radius ratio \( r_+ / r_- \)

<table>
<thead>
<tr>
<th>Radius ratio ( r_+ / r_- )</th>
<th>Co-ordination number predicted</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;0.73</td>
<td>8:8</td>
<td>caesium chloride, CsCl</td>
</tr>
<tr>
<td>between 0.73 and 0.41</td>
<td>6:6</td>
<td>sodium chloride, NaCl</td>
</tr>
<tr>
<td>&lt;0.41</td>
<td>4:4</td>
<td>Zinc sulphide, ZnS</td>
</tr>
</tbody>
</table>

**PROBLEM 6** Use the table above to predict the co-ordination numbers for:
(a) caesium iodide  (b) rubidium iodide  (c) beryllium oxide.

Ionic radii/nm  \( \text{Be}^{2+} \) 0.030  \( \text{I}^- \) 0.219  \( \text{Cs}^+ \) 0.167  \( \text{O}^{2-} \) 0.146  \( \text{Rb}^+ \) 0.148

**22** Inter- and intramolecular bonding in oxygen, \( \text{O}_2 \).

- **nuclei of oxygen atoms**
- **weak intermolecular bond**
- **electron cloud**
- **strong covalent intramolecular bond**

**23** The origin of intermolecular forces in oxygen.

This molecule is temporarily polarized...

\[ \delta^+ \rightarrow \delta^- \]

... inducing a dipole in this molecule.

\[ \delta^+ \delta^- \delta^+ \delta^- \]
The permanent dipole in hydrogen chloride, HCl.

'Dot-cross' representation

\[
\begin{array}{cccc}
H & \text{X} & \text{Cl} & \text{X} \\
\text{X} & \text{X} & \text{X} & \text{X}
\end{array}
\]

Shared electrons nearer chlorine than hydrogen

'Electron cloud' representation

\[\delta^+ \quad \delta^-
\]

The boiling points of hydrides in Groups IV and VI of the periodic table.
The methane molecule, \( \text{CH}_4 \).

Although there may be small dipoles in individual C-H bonds the symmetry of the molecule means that they cancel out, giving an overall non-polar molecule.

Hydrogen bonds between water molecules.

ProBLEM 7 Use the data given below to plot a graph, similar to the one on frame 25, for the hydrides of the elements in Group 5. Comment on the shape of your graph.

Boiling points/°C:
- \( \text{NH}_3 \), -33
- \( \text{PH}_3 \), -88
- \( \text{AsH}_3 \), -55
- \( \text{SbH}_3 \), -17.
A water beetle skating on the surface of a pond.

A simplified structure of DNA. S represents a sugar molecule; B represents an organic base.

`backbone` of one chain  `backbone` of second chain
Hydrogen-bonded base pairs in DNA

[Chemical structure images showing bonding to deoxyribose sugar/phosphate chain for Adenine, Thymine, Cytosine, and Guanine]

Splitting a log along the grain of the wood.

An energy cycle for the solubility of sodium chloride in water.

\[ \text{Na}^+(g) + \text{Cl}^-(g) + (aq) \]

\[ \Delta H_{\text{latt}}(\text{NaCl}(s)) = +776 \text{ kJ} \]

\[ \Delta H_{\text{hyd}}(\text{Na}^+(g)) + \Delta H_{\text{hyd}}(\text{Cl}^-(g)) = -390 - 381 = -771 \text{ kJ} \]

\[ \text{Na}^+(aq) + \text{Cl}^-(aq) \]

\[ \Delta H_{\text{soln}}(\text{NaCl}(s)) = +5 \text{ kJ} \]

PROBLEM 8 Use the data below to calculate the heat of solution of potassium iodide.

- Lattice energy of KI = -643 kJ mol\(^{-1}\)
- Heat of hydration of K\(^+\) = -305 kJ mol\(^{-1}\)
- Heat of hydration of I\(^-\) = -307 kJ mol\(^{-1}\)
A layer of close-packed atoms.

First and second layers of close-packed atoms.

First, second and third layers of close-packed atoms - ababab arrangement.

First, second and third layers of close-packed atoms - abcabc arrangement.
The electron structures and conductivities of sodium, magnesium, aluminium and silicon.

<table>
<thead>
<tr>
<th></th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron structure</td>
<td>2, 8, 1</td>
<td>2, 8, 2</td>
<td>2, 8, 3</td>
<td>2, 8, 4</td>
</tr>
<tr>
<td>Thermal conductivity J cm$^{-2}$ s$^{-1}$ K$^{-T}$</td>
<td>1.34</td>
<td>1.6</td>
<td>2.1</td>
<td>0.84</td>
</tr>
<tr>
<td>Atomic electrical conductivity x 1000 Ωm$^{-1}$ cm$^{-4}$</td>
<td>10</td>
<td>16</td>
<td>38</td>
<td>4</td>
</tr>
</tbody>
</table>

PROBLEM 9: Why does the electrical conductivity rise from sodium to magnesium to aluminium?

PROBLEM 10: Why is the electrical conductivity of silicon much lower than that of the three metals?

PROBLEM 11: Why does the thermal conductivity rise from sodium to magnesium and from magnesium to aluminium?
ANSWERS TO PROBLEMS

PROBLEM 1

Mass of diamond = 120 g
Number of atoms = \( \frac{120 \times 6 \times 10^2}{12} \)
\[ = 6 \times 10^2 \]

PROBLEM 2

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Examples</th>
<th>Hardness and/or malleability</th>
<th>Volatility</th>
<th>Conductivity (solid)</th>
<th>Conductivity (molten)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Giant metallic</td>
<td>Lattice of positive ions in a delocalised electron cloud.</td>
<td>copper, iron.</td>
<td>hard, malleable</td>
<td>volatile</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Giant ionic</td>
<td>Regular lattice of positive and negative ions held by electrostatic attraction.</td>
<td>salt (NaCl), limestone (CaCO₃), chalk (CaCO₃).</td>
<td>hard, brittle</td>
<td>volatile</td>
<td>very poor</td>
<td>good</td>
</tr>
<tr>
<td>Simple molecular</td>
<td>Small molecules. Atoms held within molecules by strong covalent bonds, but weak forces between molecules.</td>
<td>iodine, ice, sugar.</td>
<td>soft.</td>
<td>volatile</td>
<td>very poor</td>
<td>very poor</td>
</tr>
<tr>
<td>Giant molecular</td>
<td>Large molecules containing thousands of atoms held together by strong covalent bonds.</td>
<td>diamond, sand.</td>
<td>very hard.</td>
<td>very volatile</td>
<td>very poor</td>
<td>very poor</td>
</tr>
</tbody>
</table>

PROBLEM 3

polyester 1-dimensional
mica 2-dimensional
keratin 1-dimensional
carbonrundum 3-dimensional
quartz 3-dimensional

PROBLEM 4

The size of the ion and the way the ions are packed.

PROBLEM 5

Calcium oxide has a lower melting point (2600°C) than magnesium oxide (2900°C). Although both Mg²⁺ and Ca²⁺ have the same charge, the smaller Mg²⁺ ion can get closer to the O²⁻ ion, leading to a stronger bond.

PROBLEM 6

<table>
<thead>
<tr>
<th>Compound</th>
<th>Radius ratio ( \frac{r_+}{r_-} )</th>
<th>Predicted co-ordination</th>
</tr>
</thead>
<tbody>
<tr>
<td>CsI</td>
<td>0.76</td>
<td>8:8</td>
</tr>
<tr>
<td>RbI</td>
<td>0.68</td>
<td>6:6</td>
</tr>
<tr>
<td>BeO</td>
<td>0.21</td>
<td>4:4</td>
</tr>
</tbody>
</table>

PROBLEM 7

The graph shows that ammonia has a higher boiling point than expected on the basis of the trend shown by the other three compounds. This reflects the hydrogen bonding in ammonia.
PROBLEM 8

\[ \Delta H_{\text{soln}} = (\Delta H_{\text{latt}}) + \Delta H_{\text{hyd}}(K^+) + \Delta H_{\text{hyd}}(I^-) \]

\[ = +643 \quad -305 \quad -307 \]

\[ = +31 \text{ kJ mol}^{-1} \]

PROBLEM 9

Electrical conductivity in metals is related to mobile electrons. Since the outermost electrons are the most mobile, electrical conductivity rises from Na to Mg to Al because they have 1, 2 and 3 outermost electrons respectively.

PROBLEM 10

The outermost electrons of silicon are localized in covalent bonds and therefore are not free to move. (However, under certain conditions silicon can behave as a semi-conductor.)

PROBLEM 11

Heat is transferred through metals by the thermal motion of mobile electrons. The thermal conductivity therefore rises in this way for the same reason as the electrical conductivity (Problem 9).