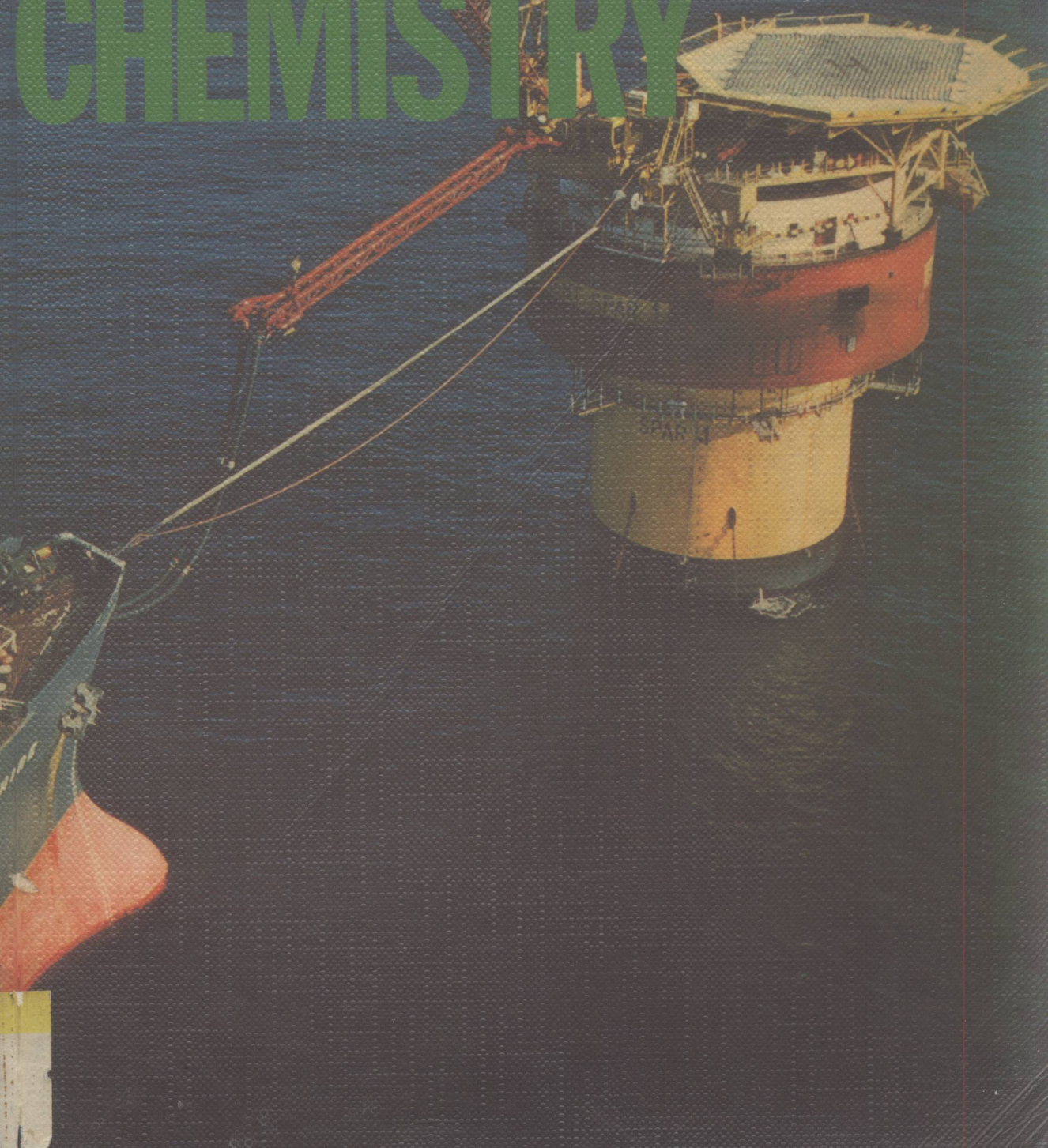


REVISED

NUFFIELD CHEMISTRY

Handbook
for pupils



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REVISED

NUFFIELD CHEMISTRY HANDBOOK FOR PUPILS



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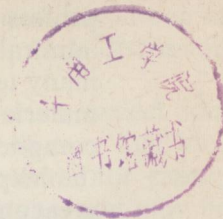
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Foreword

All successful developments in the curriculum depend upon the teaching profession not only for their initiation but for their renewal. This book admirably illustrates this point because it results from the request of the many teachers consulted in the course of revising the Nuffield Chemistry materials that more support should be provided for the pupil. Written and compiled by teachers with long experience of the Nuffield scheme, with the help of advisers in industry and universities, it demonstrates how the great and abiding aim of the devisers of the first edition – education through chemistry – can be reinterpreted to provide for the needs of the pupils and teachers of the coming decade. It reflects, to give one instance, the increasing concern of scientists with the effect of technology on the environment and with the social aspects of science. It also provides in Part I the grounding in the theory and a clear exposition of the ideas employed by chemists that are essential both to the discussion of the social aspects of science and to the future development of the young scientist.

In the prefaces to the Teachers' Guides of the revised materials I have acknowledged more fully the debt we owe to the Examination Boards, to the Association for Science Education, and to the organizer and editors of the first edition. Here I would like to express our thanks to the editors of this volume Professor E. H. Coulson and Dr Richard Ingle, to the authors and contributors, to our friends in industry for their help and advice, to William Anderson, our publications manager and his colleagues, to Ivan Dodd our designer and the artists who have worked under his direction, and to our publishers, Longman Group Limited, for their various parts in the production of a book of which we can well be proud.

K. W. Keohane

Coordinator of the Nuffield Foundation Science Teaching Project

Introduction

This book has been planned to support the joint efforts of you and your teacher in understanding the work that you have done in the laboratory, and the ideas that have been developed in class discussion.

Because there are several authors, you must expect some differences in both treatment and style. Sometimes you may find ideas are expressed in a way you have not come across before; for example, if you have already studied electricity in physics lessons, you may find the approach to electricity in Chapter 7 rather different from what you are accustomed to. You may also find some of the subjects discussed in Part 2, 'Chemistry and our lives', ones that you are more familiar with in other subjects such as history. This is because we want you to be able to approach chemistry from different angles, and to grasp the many implications of it as a subject.

Although all the contents of the book can assist in one way or another when you have to take external examinations, it is important to remember that chemistry is an experimental subject, and the practical work that you do in the laboratory contributes a great deal to your knowledge of it. You will find it helpful also to read other books; some suggestions are given on pages 212–3.

Most of the chapters contain questions among the reading matter. These are intended to help you to grasp the ideas which are discussed, so it is an advantage to try to answer them as you read each chapter. Answers to the majority of these questions are given at the end of the book. Questions at the ends of chapters are intended for set homework and the answers to these are not provided.

The editors hope that you will find the book both enjoyable and profitable. It often takes a little time to appreciate worthwhile information, so do not be discouraged if some parts of the book need to be read more than once.

Acknowledgements

Many people have helped in the production of this book. The editors wish to tender grateful thanks to the large number of teachers and pupils who have read and commented on trial versions of two of the chapters; to Mr W. Blyberg, Professor H. F. Halliwell, Professor F. R. Jevons, Mr. J. G. Raitt, Professor Harold Silver, and Miss Erica Wheeler, who read parts of the original manuscript and made valuable contributions to its final form; and to the University of London School Examinations Council who kindly allowed the use of structured questions from the O-Level Nuffield Examinations. (These form question 1 at the ends of Chapters 1, 4, 5, 6, and 7; slight changes have been made in one of the questions to bring it into line with the S.I. units used in the book.) They would also like to express their gratitude to the project's many friends in industry who have contributed illustrations and advice, especially to Mr R. A. Finch, Schools Liaison Officer of Imperial Chemical Industries Ltd, for his help and that of his colleagues over the illustration of Olefines 5 at Wilton on pp 152–3.

Note on contributors

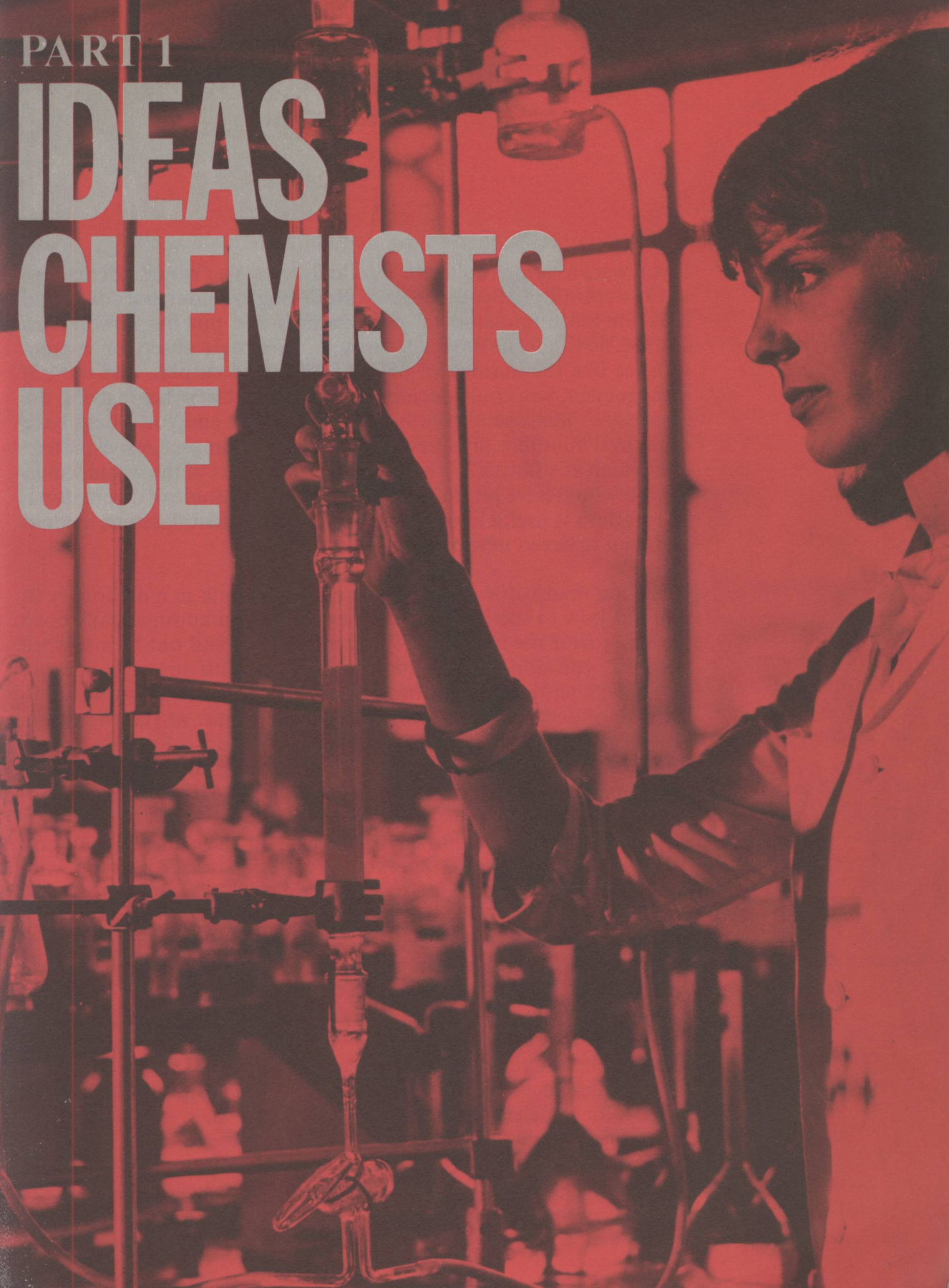
In addition to their contributions which are acknowledged elsewhere in this book, the following acted as editors of the three parts of the book: Professor E. H. Coulson, editor of Part 1, 'Ideas chemists use'; Dr A. L. Mansell, editor of Part 2, 'Chemistry and our lives'; and Dr A. D. Gazard, editor of Part 3, 'Reference section'. J. A. Hunt produced and supplied the questions at the end of the chapters.

Opposite

Studying the separation of various glass constituents in an ion exchange column in the chemistry section of the British Glass Industry Research Association.
Glass Manufacturers' Federation.

PART 1

IDEAS CHEMISTS USE



Chapter 1
PERIODICITY
by Constance Groves

Bringing order to the elements

If you were a serious collector of wild flowers, you would not arrange the flowers in alphabetical order or according to colour, but you would look for more fundamental relationships and put the flowers into families as Linnaeus did 250 years ago. By closely observing characteristics like the number of petals, sepals, and carpels, and the leaf arrangement, you could decide whether your flowers belonged to the rosaceae or liliaceae or to other families. In the end you would have organized hundreds of different flowers into a comprehensive pattern into which any flower, big or small, from any part of the world would fit; you would have produced order out of a multitude of diverse facts. The pattern is useful in other ways than mere identification; it could help you to breed new plants.

There are many other useful patterns. If you look in a dictionary to find out how to spell 'biennial' for example, you automatically open the book near the beginning. Wanting next to find out how to spell 'parallel', you skip a great chunk of the book with one turn. Because you have a pattern in your head, you save time. You know where to look among all the thousands of words. And just as the twenty-six letters of the alphabet can form these thousands of words, so the ninety or so chemical elements can be arranged to form millions of compounds, each element and compound having its own set of properties. To remember all this information would be a colossal task. It would obviously help to have a pattern for the elements and their compounds. This chapter tells you how that pattern was found, and how useful it has been since its discovery.

Nearly two hundred years ago chemists began to feel that a pattern might exist among the elements, which would bring them into some sort of order. When studying the elements they noticed that some had similar properties, as you found when you studied chlorine, bromine, and iodine as a family of elements. Also, they knew that magnesium and calcium are similar in that both are hard metals which burn with a bright flame, and have alkaline oxides. The search for an overall pattern for the elements took a long time and was very difficult. Let us examine some of the pioneer work.

Note: If you have not read the introduction on page vii, you will find it helpful to do so as it contains suggestions on how to use this book.

In 1817 Döbereiner, a German chemist, found similar properties in two groups of three elements which he called triads:

Element	Relative atomic mass (approx.)	Element	Relative atomic mass (approx.)
Ca	40	Cl	35.5
Sr	88	Br	80
Ba	137	I	127

What do you notice about their relative atomic masses?⁽¹⁾

Further progress was made in 1864 when Newlands, an English scientist, arranged *all* the known elements in order of relative atomic mass. He noticed that the eighth element starting from a given one is similar to the first.

As Newlands wrote, 'the eighth element starting from a given one, is a kind of repetition of the first, like the eighth note in an octave of music.' To show up the pattern clearly, Newlands arranged elements, which were alike, in seven vertical groups as follows:

H	Li	Be	B	C	N	O
F	Na	Mg	Al	Si	P	S
Cl	K	Ca	(etc.)			

He called the rule he had discovered the *law of octaves*. This kind of repetition, with similar properties recurring at intervals, is called periodic, and is the origin of the name 'Periodic Table'. Unfortunately, although the periodic relationship Newlands had found held good for the first seventeen elements, it did not work after the seventeenth.

In 1870, Lothar Meyer, in Germany, published values for *atomic volumes* of elements, that is, the volume (in cm³) of 1 mole (gram-atom, often written as g-atom) of a *solid* element. Look at the atomic volume curve in figure 1.2 overleaf. How many examples of periodicity can you find? Assuming that a period starts with an alkali metal and finishes with a halogen (the inert gases were not discovered until more than thirty years later), how would you describe the change in atomic volumes as you cross a period?⁽²⁾ Are there the same number of elements in all the periods?⁽³⁾

Lothar Meyer, with his atomic volume curve, had made a brilliant discovery—that periods could differ in length. However, it was the Russian chemist, Mendeleev, who made the really big breakthrough, in 1869. He arranged the known elements in order of relative atomic mass, as Newlands had done, but with two important differences: he left gaps for elements which he said had not yet been discovered. He recognized that periods could differ in length, by listing separately elements which did not fit in the main vertical columns (*groups*).

lithium
13 cm³

sodium
23.7 cm³

potassium
44.9 cm³

rubidium
55.7 cm³

caesium
71 cm³

magnesium
14 cm³

aluminium
10 cm³

silicon
11.6 cm³

phosphorus (red)
14.1 cm³

sulphur
15.5 cm³

chlorine
18.7 cm³

Figure 1.1
Atomic volumes (cm³ per mole) of a selection of elements. Notice the pattern of volumes and look at the places these

elements occupy in the Lothar Meyer curve (figure 1.2). (The volumes are one-fifth actual size.)

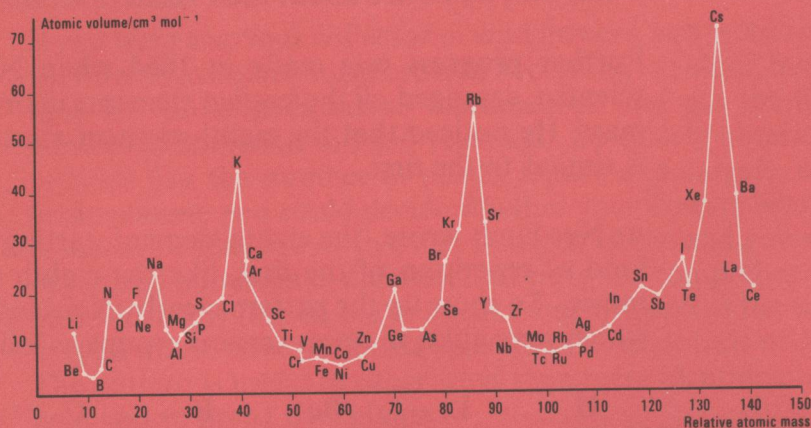


Figure 1.2 above right
A modern version of Lothar Meyer's atomic volume curve, showing a periodic relationship of the elements based on relative atomic mass.

Figure 1.3 right
Dmitri Ivanovich Mendeleev. He made an important contribution to chemistry when he arranged the elements in the form of his Periodic Table.
Novosti Press Agency.

Table 1
Mendeleev's second Periodic Table (1872). It contains many gaps for elements which Mendeleev predicted but which had not then been discovered.

The second version of the Periodic Table devised by Mendeleev is shown in table 1. This provided him with a way of showing periodicity over a large range of elements. It was a bold move and its success depended on the missing elements being found. He stated the periodic law as follows: 'When the elements are arranged in order of relative atomic mass, similar properties recur at intervals.'

Series	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
1 2	H = 1 Li = 7	Be = 9.4	B = 11	C = 12	N = 14	O = 16	F = 19	
3 4	Na = 23 K = 39	Mg = 24 Ca = 40	Al = 27.3 — = 44	Si = 28 Ti = 48	P = 31 V = 51	S = 32 Cr = 52	Cl = 35.5 Mn = 55	Fe = 56, Co = 59 Ni = 59, Cu = 63
5 6	(Cu = 63) Rb = 85	Zn = 65 Sr = 87	— = 68 ?Yt = 88	— = 72 Zr = 90	As = 75 Nb = 94	Se = 78 Mo = 96	Br = 80 — = 100	Ru = 104, Rh = 104 Pd = 106, Ag = 108
7 8	(Ag = 108) Cs = 133	Cd = 112 Ba = 137	In = 113 ?Di = 138	Sn = 118 ?Ce = 140	Sb = 122 —	Te = 125? —	I = 127 —	— — — —
9 10	(—) —	— —	— ?Er = 178	— ?La = 180	— Ta = 182	— W = 184	— —	Os = 195, Ir = 197 Pt = 198, Au = 199
11 12	(Au = 199) —	Hg = 200 —	Tl = 204 —	Pb = 207 Th = 231	Bi = 208 —	— U = 240	— —	— — —

Using the known properties of elements surrounding the gaps in his table, Mendeleev was able to predict the properties of some of the missing elements. To take one example, there was a gap between silicon and tin in group 4 of his table. He predicted the properties of this missing element, which he called ekasilicon. In 1886 the element was discovered (by a German) and named germanium; table 2 tells the story.

Table 2 Mendeleev's predictions about ekasilicon

Will be a light grey metal
Will form a white oxide (EsO_2) with a high melting point
The chloride will have a boiling point less than 100°C and density of about 1.9 g cm^{-3}

Observed properties of germanium

Is a dark grey metal
Forms a white oxide (GeO_2) which melts at 1116°C
The chloride boils at 86.5°C and its density is 1.887 g cm^{-3}

Other predictions about missing elements—ekaluminium (gallium, discovered in 1875) and ekaboron (scandium, discovered in 1879)—were similarly successful. Not only did Mendeleev's table account for known facts, but it predicted the existence and the properties of undiscovered elements.

A modern version of the Periodic Table is printed on pages 8 and 9. You will see that in three pairs of elements the relative atomic mass order has not been followed. One of these is potassium (relative atomic mass 39.1) and argon (relative atomic mass 39.9), argon being put before potassium. Can you find the other two pairs?⁽⁴⁾ These 'anomalies', as they are called, have led modern scientists to give numbers to the elements, starting with hydrogen as 1 and ending with kurchatovium as 104. For us, at the moment, the number of the element in the table merely gives its position. It is called the *atomic number* and, as you will find later, it has great significance. (See Chapter 3, page 29.) We can use these atomic numbers to explain what is meant by periodicity. From the Periodic Table you will see that Li (atomic number 3), Na (11), K (19), Rb (37), Cs (55), and Fr (87) are placed in the same vertical column. Some of their properties are similar, other properties show gradations. Repetitions occur after intervals of 8, 8, 18, 18, and 32 elements, so the period is not constant.

The modern Periodic Table and its uses

One of the early uses of the Periodic Table was to start a search for missing elements and to check relative atomic masses. Its main use today is what it has always been: to order a confused collection of factual information into a simple pattern of related facts which the human mind can comprehend.

Let us examine what we mean by 'order' among the elements. The elements in the table are related to each other in two ways: vertically in columns called 'groups', and horizontally in rows called 'periods'. We will now consider *some* of the groups and periods in detail.

Groups in the Periodic Table

These groups consist of elements which have (a) similar properties, or (b) properties in which there is a definite trend with increasing atomic number. (It must be admitted, however, that irregularities occur which stimulate a search for reasons for them.)

In looking at similarities and trends in the groups, we are using tables of properties for groups 1, 7, 4, and 0. In addition we have given you some of the modern uses of these elements.

Group 1: the alkali metals

These are the metals lithium, sodium, potassium, rubidium, caesium, and francium. Table 3 gives information on the first three of these. They are stored under oil to exclude air and water with which they react. When freshly cut they have lustre, like silver and platinum, but the surface dulls almost instantaneously because a coating of oxide and then of carbonate is formed.

7	0	1
	He	Li
F	Ne	Na
Cl	Ar	K
Br	Kr	Rb
I	Xe	Cs
At	Rn	Fr

Like other metals they are good conductors of heat and electricity and are malleable and ductile, but they have little tensile strength, so they are useless for structural purposes.

The alkali metals are too reactive to be found uncombined in the Earth's crust. They are found as salts, usually chlorides, which can be mined, purified, melted, and electrolysed to obtain the pure metal at the cathode.

	*m.p. /°C	*b.p. /°C	How easily the metal can be cut with a knife	What happens when the element is melted and plunged into chlorine	Colour imparted to the flame by the metal or its salts	Action with cold water	Formula of simplest oxide	Formula of hydride	*At. no.
Li	181	1331	moderately easily	fairly energetic reaction producing white LiCl	crimson	fairly fast reaction to produce an alkali (LiOH) and hydrogen	Li ₂ O	LiH	3
Na	98	890	easily	energetic reaction producing white NaCl	yellow	fast reaction to produce an alkali (NaOH) and hydrogen	Na ₂ O	NaH	11
K	64	766	very easily	very energetic reaction producing white KCl	lilac	very fast reaction to produce an alkali (KOH) and hydrogen	K ₂ O	KH	19

Table 3
Similarities and trends in
group 1: the alkali metal family.

*m.p. is an abbreviation for normal melting temperature, b.p. for normal boiling temperature, and at. no. for atomic number.

Uses *Sodium* This has more uses than the other alkali metals because its ores are more abundant.

Sodium vapour is responsible for the intense yellow glow in some street lamps, and the metal itself is used as a coolant in nuclear reactors (for example, at Dounreay) and also in the manufacture of tetraethyl lead, a petrol additive which prevents car engines from 'pinking'.

A Periodic Table

Period	Group 1		Group 2							atomic number	
	ALKALI METALS		ALKALINE EARTH METALS							1	
1										H Hydrogen 1.0 relative atomic mass	
2	3 Li Lithium 6.9		4 Be Beryllium 9.0								
3	11 Na Sodium 23.0		12 Mg Magnesium 24.3								
4	19 K Potassium 39.1		20 Ca Calcium 40.1		21 Sc Scandium 45.0	22 Ti Titanium 47.9	23 V Vanadium 50.9	24 Cr Chromium 52.0	25 Mn Manganese 54.9	26 Fe Iron 55.9	← TRANSITION ELEMENTS SERIES
5	37 Rb Rubidium 85.5		38 Sr Strontium 87.6		39 Y Yttrium 88.9	40 Zr Zirconium 91.2	41 Nb Niobium 92.9	42 Mo Molybdenum 95.9	43 Tc Technetium (99)	44 Ru Ruthenium 101.1	
6	55 Cs Caesium 132.9		56 Ba Barium 137.3		57-71 see below Lanthanum	72 Hf Hafnium 178.5	73 Ta Tantalum 181.0	74 W Tungsten 183.9	75 Re Rhenium 186.2	76 Os Osmium 190.2	
7	87 Fr Francium (223)		88 Ra Radium (226)		89- 103 see below Actinium	104 Ku Kurchatovium					

LANTHANIDE SERIES

57 La Lanthanum 138.9	58 Ce Cerium 140.1	59 Pr Praseodymium 140.9	60 Nd Neodymium 144.2	61 Pm Promethium (147)	62 Sm Samarium 150.4	63 Eu Europium 152.0
--------------------------------	-----------------------------	-----------------------------------	--------------------------------	---------------------------------	-------------------------------	-------------------------------

ACTINIDE SERIES

89 Ac Actinium (227)	90 Th Thorium 232.0	91 Pa Protactinium (231)	92 U Uranium 238.1	93 Np Neptunium (237)	94 Pu Plutonium (242)	95 Am Americium (243)
-------------------------------	------------------------------	-----------------------------------	-----------------------------	--------------------------------	--------------------------------	--------------------------------

of the Elements

Group 3	Group 4	Group 5	Group 6	Group 7 HALOGENS	Group 8 INERT GASES
---------	---------	---------	---------	---------------------	---------------------------

					2 He Helium 4.0
--	--	--	--	--	--

5 B Boron 10.8	6 C Carbon 12.0	7 N Nitrogen 14.0	8 O Oxygen 16.0	9 F Fluorine 19.0	10 Ne Neon 20.2
---------------------------------------	--	--	--	--	--

13 Al Aluminium 27.0	14 Si Silicon 28.1	15 P Phosphorus 31.0	16 S Sulphur 32.1	17 Cl Chlorine 35.5	18 Ar Argon 39.9
---	---	---	--	--	---

27 Co Cobalt 58.9	28 Ni Nickel 58.7	29 Cu Copper 63.5	30 Zn Zinc 65.4	31 Ga Gallium 69.7	32 Ge Germanium 72.6	33 As Arsenic 74.9	34 Se Selenium 79.0	35 Br Bromine 79.9	36 Kr Krypton 83.8
--	--	--	--	---	---	---	--	---	---

45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3
--	--	---	--	---	--	---	--	--	--

77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (210)	85 At Astatine (210)	86 Rn Radon (222)
--	---	---	--	---	---	--	---	---	--

Key

57	Atomic Number
La	Symbol
Lanthanum	Name
138.9	Relative atomic mass

64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0
---	--	---	--	---	--	--	---

96 Cm Curium (247)	97 Bk Berkelium (245)	98 Cf Californium (251)	99 Es Einsteinium (254)	100 Fm Fermium (253)	101 Md Mendelevium (256)	102 No Nobelium (254)	103 Lr Lawrencium (257)
---	--	--	--	---	---	--	--

Group 7: the halogens

6	7	0
O	F	Ne
S	Cl	Ar
Se	Br	Kr
Te	I	Xe
Po	At	Rn

These are the non-metallic elements fluorine, chlorine, bromine, and iodine (and astatine, which is not dealt with here). The name 'halogen' was coined by the early experimenters from the Greek for 'salt-producer', because the elements form salts very readily with metals.

The halogens are too reactive to occur in the free state, but their compounds are widely distributed. Sodium chloride is one of the most important; it occurs dissolved in sea water and as deposits of rock salt, the remains of dried-up seas. Chlorine is obtained by electrolysis of sodium chloride, bromine is obtained from sea water, and iodine from caliche, a mineral found in South America.

	m.p. /°C	b.p. /°C	Appearance at 25°C	Formula of hydride	Action with cold alkali solutions	Action on vegetable dyes in solution	Action of halogen gases on hot iron	Action on solutions of halogen salts	At. no.
F	-220	-188	pale yellow gas	HF(g)	*fluorine reacts with water		very energetic reaction to make iron(III) fluoride crystals	fluorine reacts with water	9
Cl	-101	-34	yellowish green gas	HCl(g)	All three halogens react to form colourless solutions	chlorine water bleaches them very quickly	energetic reaction to make iron(III) chloride crystals	displaces bromine from bromides and iodine from iodides	17
Br	-7	58	brown liquid	HBr(g)		bromine water bleaches them much more slowly	less energetic reaction to make iron(III) bromide crystals	displaces iodine from iodides but not chlorine from chlorides	35
I	114	183	black solid	HI(g)		iodine is hardly soluble in water; nevertheless the solution will bleach on warming	reaction is even less energetic and the product is iron(II) iodide crystals	will not displace other halogens from their salts	53

Table 4
Similarities and trends in
group 7: the halogen family.

*Fluorine is extremely poisonous; its properties cannot be investigated in a school laboratory.

Uses *Fluorine* It is the most reactive of all the elements. A highly important compound of fluorine is dichlorodifluoromethane (fluon for short) which is the working liquid in household refrigerators, air-conditioning equipment, and aerosol propellents. It is an excellent liquid for these purposes, being entirely non-corrosive, non-toxic, and non-inflammable.

Polytetrafluoroethylene (PTFE) is a polymer containing fluorine, used for 'non-stick' cooking utensils.