# INORGANIC CHEMISTRY

## A GUIDE TO ADVANCED STUDY

### R.B. HESLOP and R. JONES

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（内部交流）

*by*

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A Completely Revised Successor to Heslop/Robinson, Inorganic Chemistry

# Preface

In April 1960, one of us published, in collaboration with the late Professor P.L. Robinson, a text-book of inorganic chemistry with the same title as this present volume. A second edition appeared in 1963 and a third edition in 1967. These facts and much encouraging comment suggest that the choice of material and its manner of presentation have met with wide approval.

In writing this book we have tried to maintain the original aim of providing a text-book of moderate size which does not presume to be a substitute for oral teaching or seek to deal with specialised topics which may be features of courses in some colleges and universities. We have therefore concentrated our attention on presenting the chemistry of the elements by treatment of the groups in the Periodic Table, and have omitted, after due consideration, the separate treatment of topics such as biochemical or environmental aspects of inorganic chemistry.

We have, however, given greater attention to the physical methods used for the determination of structure and the understanding of chemical bonding. We have introduced ideas of molecular and orbital symmetry, and made use of them throughout the text. Another important change is the exclusive use of SI units with the appropriate alterations in physical formulae when the international system makes them necessary.

We have also added, on the suggestion of many helpful critics, a number of problems based on the material in the book, together with answers, and we hope this innovation will prove useful to the students for whom the book is primarily intended.

We should like to thank Mrs. H.M. Shaw, Mrs. J.I. Jones, and particularly Mrs. M.M. Latta for typing the manuscript and helping to prepare it for publication.

# Contents

# Modern Inorganic Chemistry
<span style="float:right">1</span>

The <u>ambit</u> of inorganic chemistry is well established; it comprises the natural occurrence and artificial preparation of the elements, their properties and reactions, and those of their compounds, together with a rational correlation and theoretical interpretation of the phenomena.

Although the oldest discipline in chemistry, inorganic chemistry continues to excite increasing interest as a subject of pure and applied research and is finding manifold applications in industry. It is the foundation of vast endeavour in fine and heavy chemicals, in ceramics, in the production of glass and building materials, and in extraction metallurgy. There is hardly an element which is not being investigated from some aspect at the present time. It is concerned in the preparation of catalysts and has made, and is making, contributions which facilitate the production and exploitation of atomic energy. Inorganic chemists have continued to call attention to much in this vast field which awaits exploration, and this book will have failed in its purpose if something of the enthusiasm and confidence which inspires them is not reflected in its pages. A few of the exciting themes dealt with are: current interpretation of chemical bonding and structure with the modern physico-chemical evidence, non-stoichiometry, electron-deficient compounds, complex compounds, organometallic compounds, materials with exceptional properties (such as great hardness, high melting points, corrosion resistance), noble gas compounds. Most of the compounds of carbon with non-metallic elements lie outside inorganic chemistry, but organometallic compounds (Chapter 18) form one of its most important current topics.

The advances of the last three decades have taken inorganic chemistry right out of the stage of being a mass of arbitrarily chosen facts brought into some relationship by the Periodic Table. Although modern inorganic chemistry remains in a measure descriptive and pictorial (as do the other branches of the subject) the pictures have grown in precision and the descriptions have become more quantitative. Hence an historical approach is now inappropriate because the subject has developed to a point which makes entry from the level of present theoretical and physico-chemical knowledge desirable; such an entry has the advantage of being both easier and more lively. For this reason earlier work on the structure of the atom, culminating in 1913 with Bohr's atomic model, and other classical material has not been included.

## 1.1. Approach to the Subject

Quantum theory has provided a picture of the atom that allows an immediate approach to valency and molecular structure while furnishing a far more secure basis for the periodic arrangement of the elements than selected physical and chemical properties. This is not to overlook the achievements of Thomson, Rutherford and Bohr in atomic structure, or of Newlands, Lothar Meyer, Mendeleev, Bohr and others in evolving the Periodic Law, but rather to seize upon developments which their prescient work made possible. Readers will find it easier to assimilate and remember the facts embodied in the Periodic Classification when these are seen to emerge from the systematic development of electronic structure with increasing atomic number.

The description of atoms and molecules which is used — that of one or more positive nuclei surrounded by a cloud of electrons which, for many purposes, is equivalent to a smeared-out negative charge — presents in pictorial form the results of thirty years of quantum mechanics. All available evidence suggests that this general picture is unlikely to suffer substantial modification. Theoretical chemistry accepts the Schrödinger equation and is largely concerned with finding the most direct mathematical path to a unified explanation of the physico-chemical properties of the molecules. This description has been adopted and used in the interpretation of valency theory, including metal—ligand bonding, and in discussing structure generally. A brief account of the nucleus is included because not only does it determine the extra-nuclear structure of the atom, but is also the seat of radioactivity and the source of nuclear energy. Some knowledge of it is necessary in order to follow present ideas on the synthesis of elements taking place in the stars.

The kinetic and thermodynamic aspects of reactions are stressed wherever the data are available, and examples are worked out which should enable the reader to understand and acquire facility in these essential calculations.

So much of inorganic matter is crystalline that once a means of investigating the structure of solids became available it was eagerly applied. The result has made it necessary to include a short account of the solid state. With this goes a little about the growth of crystals and the way atoms in their lattices suffer dislocation.

## 1.2. Suggestions on the Use of this Book

This book is a brief epitome of modern inorganic chemistry and the reader may usefully begin anywhere, since liberal cross-references provide a constant link with definitions and the underlying theory. These appear mainly in the earlier chapters which need not be mastered before the rest of the book can be understood, and their assimilation by repeated reference will be repaid by a fuller appreciation of what follows. It is idle to suppose that a real appreciation of any branch of chemistry can be had without two things — adequate theory and sufficient facts. The best way to grasp theory is to apply it con-

stantly, and the easiest way to remember facts is to seek their relation to theory.

Appended to every chapter is a short list of references which will be found useful in extending the reader's knowledge of particular aspects of the subjects treated. Because a student's time is limited and his requirement is a wide, balanced view of the subject, books, monographs and review articles, rather than original papers, have mainly been cited.

### 1.3. Symbols and Abbreviations

Chemical symbols and formulae have been used extensively in place of names to save space and often to secure clarity. Symbols which appear frequently are:

| | | | |
|---|---|---|---|
| Atomic number | $Z$ | Magnetic flux density | $B$ |
| Mass number | $A$ | Entropy | $S$ |
| Isotopic mass | $m$ | Frequency | $\nu$ |
| Relative atomic mass | | Wavelength | $\lambda$ |
| (atomic weight) | $A_r$ | Concentration of X | $[X]$ |
| Relative molar mass | | Activity of X | $a_X$ |
| (molecular weight) | $M_r$ | Specific reaction rate | $k$ |
| Enthalpy | $H$ | Equilibrium constant | $K$ |
| Gibbs function | $G$ | Magnetic moment | $\mu$ |

**Some of the abbreviations** which often appear are:

| | | | |
|---|---|---|---|
| $I(1)$ | ionisation energy (first) | u.v. | ultraviolet |
| $r_M$ | single-bond covalent radius of M atom | i.r. | infrared |
| | | n.m.r. | nuclear magnetic resonance |
| $r_{M^+}$ | ionic radius of $M^+$ | | |
| emf | electromotive force | e.s.r. | electron spin resonance |
| $E^0$, $M^+/M$ | standard redox potential for $M^+/M$ couple | n.q.r. | nuclear quadrupole resonance |
| AO | atomic orbital | ln $x$ | logarithm of $x$ to base e |
| MO | molecular orbital | h.c.p. | hexagonal close-packed |
| b.p. | boiling point | c.c.p. | cubic close-packed |
| m.p. | melting point | b.c.c. | body-centred cubic |

Other abbreviations in the text are explained where they occur.

### 1.4. Units

The Système Internationale (SI), which was adopted in 1960, is based on the metre (m) as the unit of length, the kilogram (kg) as the unit of mass, the second (s) as the unit of time, the ampere (A) as the unit of electric current, the kelvin (K) as the unit of temperature and the mole (mol) as the unit of

amount of substance. There is a further basic unit, that of luminous intensity, the candela, which is not required in this book, but the first six units, and other units derived from them, will be used when appropriate.

The principal changes introduced with the SI are:

(1) The metre and kilogram replace the centimetre and the gram as the coherent units, although the latter remain as submultiples.

(2) The unit of energy is the joule $(J = kg\ m^2\ s^{-2})$; thus the variously defined calories and non-metric units of energy are superseded.

(3) 'Electrostatic' and 'electromagnetic' units are replaced by SI electrical units.

For definitions of the basic units and for further information on SI the student should consult one of the first two references given at the end of Section 1.5. The word *mole* however is worthy of a little further treatment here. A mole is defined as that amount of substance which contains the same number of molecules, ions, atoms, electrons, as the case may be, as there are atoms of carbon in exactly 0.012 kg of carbon-12. The word is not a synonym for 'gram-molecule' which can be applied only to substances which exist as discrete molecules at a specified temperature. A gram-molecule of oxygen refers to 32.00 g of oxygen in the form of $O_2$ molecules. The expression 'a mole of oxygen' is ambiguous, because 'mole' can be applied to an amount of $O_2$ molecules or an amount of O atoms, and the former obviously has twice the mass of the latter. Similarly a mole of $Al_2Br_6$ has twice the mass of a mole of $AlBr_3$. It is always safest, therefore, to use a formula to specify exactly what species are being considered. The Avogadro constant, $N_A = 6.0220 \times 10^{23}\ mol^{-1}$, expresses the number of specified particles in one mole, for example the number of $O_2$ molecules per mole of $O_2$. Some other important constants are given in Table 1.1. The unified atomic mass constant, $m_u$, is defined as one-twelfth of the mass of an atom of carbon-12, and is used in the calculation of atomic weights (2.2).

The use of an internationally recommended system of electric and magnetic equations founded on four dimensionally independent quantities, length, mass, time and electric current, requires the introduction of two

**TABLE 1.1**

**VALUES OF SOME PHYSICAL CONSTANTS (5 SIGNIFICANT FIGURES)**

| Physical constant | Symbol | Value |
|---|---|---|
| Speed of light in a vacuum | $c_0$ | $2.9979 \times 10^8\ m\ s^{-1}$ |
| Permeability of a vacuum | $\mu_0$ | $4\pi \times 10^{-7}\ kg\ m\ s^{-2}\ A^{-2}$ exactly |
| Permittivity of a vacuum | $\epsilon_0$ | $8.8542 \times 10^{-12}\ kg^{-1}\ m^{-3}\ s^4\ A^2$ |
| Unified atomic mass constant | $m_u$ | $1.6605 \times 10^{-27}\ kg$ |
| Planck's constant | $h$ | $6.6262 \times 10^{-34}\ J\ s$ |
| Gas constant | $R$ | $8.3143\ J\ K^{-1}\ mol^{-1}$ |
| Faraday's constant | $F$ | $9.6487 \times 10^4\ C\ mol^{-1}$ |

physical constants, the permittivity of a vacuum, $\epsilon_0$, and the permeability of a vacuum, $\mu_0$. In defining these quantities in the SI the opportunity was also taken to *rationalise* the equations, that is to ensure that the factors $2\pi$ or $4\pi$ occur only where the equation relates to a field of cylindrical or spherical symmetry. Thus, in order to be able to express Ampere's law in a rationalised form in which the quantities can all be expressed in SI units, it becomes necessary to give $\mu_0$ the value $4\pi \times 10^{-7}$ kg m s$^{-2}$ A$^{-2}$ exactly. The law is then written

$$F = \frac{\mu_0 I_1 I_2 l}{2\pi d}$$

where $F$ is the force between two parallel conductors of negligible cross-section and length $l$, carrying currents of $I_1$ and $I_2$, respectively, and separated by a distance $d$ in a vacuum.

Similarly Coulomb's law in its four-quantity rationalised form is expressed as

$$F = \frac{Q_1 Q_2}{4\pi \epsilon_0 r^2}$$

in which $F$ is the force exerted by two point charges $Q_1$ and $Q_2$ separated by a distance $r$ in a vacuum. The value of $\epsilon_0$ is defined by the equation

$$\epsilon_0 = \mu_0^{-1} c_0^{-2} ,$$

where $c_0$ is the velocity of light in a vacuum, and is given by $(8.854\,185 \pm 0.000\,006) \times 10^{-12}$ kg$^{-1}$ m$^{-3}$ s$^4$ A$^2$.

TABLE 1.2

DERIVED SI UNITS WITH SPECIAL NAMES

| Physical quantity | Name of SI unit | Symbol | Definition |
|---|---|---|---|
| Frequency | hertz | Hz | s$^{-1}$ |
| Force | newton | N | kg m s$^{-2}$ |
| Energy | joule | J | N m |
| Power | watt | W | J s$^{-1}$ |
| Pressure | pascal | Pa | N m$^{-2}$ = J m$^{-3}$ |
| Electric charge | coulomb | C | A s |
| Electric potential difference | volt | V | J A$^{-1}$ s$^{-1}$ |
| Electric resistance | ohm | Ω | V A$^{-1}$ |
| Electric conductance | siemens | S | Ω$^{-1}$ |
| Electric capacitance | farad | F | A V$^{-1}$ s |
| Magnetic flux | weber | Wb | V s |
| Inductance | henry | H | V A$^{-1}$ s |
| Magnetic flux density | tesla | T | V s m$^{-2}$ |

**TABLE 1.3**

**APPROVED PREFIXES USED IN SI**

| Prefix | Symbol | Fraction | Prefix | Symbol | Multiple |
|--------|--------|----------|--------|--------|----------|
| deci   | d      | $10^{-1}$ | deka  | da     | $10$ |
| centi  | c      | $10^{-2}$ | hecto | h      | $10^{2}$ |
| milli  | m      | $10^{-3}$ | kilo  | k      | $10^{3}$ |
| micro  | $\mu$  | $10^{-6}$ | mega  | M      | $10^{6}$ |
| nano   | n      | $10^{-9}$ | giga  | G      | $10^{9}$ |
| pico   | p      | $10^{-12}$ | tera  | T      | $10^{12}$ |
| femto  | f      | $10^{-15}$ |       |        | |
| atto   | a      | $10^{-18}$ |       |        | |

The changes in these basic equations of electrostatics and electromagnetism are significant when one needs to relate magnetic and electric properties to other derived SI units. Worked examples at appropriate places in the text will illustrate the use of these equations (e.g. 3.2.4 and 4.2.3).

There are several units which are used in this book which have special names and symbols in the international system. A list of these, with their definitions, is given in Table 1.2.

Table 1.3 gives the prefixes which have been agreed internationally for fractions and multiples of SI units. Thus 1 pm is $10^{-12}$ m and 1 kJ is $10^{3}$ J. It will be noted that, apart from the range $10^{-2}$ to $10^{2}$, all the indices are divisible by 3. Thus the measure of a very large quantity or a very small one can always be expressed as a number between 1 and 1000 if a prefix is used. A typical ionic radius of $1.45 \times 10^{-10}$ m can be conveniently expressed as 145 pm, for example.

## 1.5. Tabulation of Numerical Values

To avoid needless repetition of units, it is convenient to place only figures in the body of a table. When this is done, the headings must also be dimensionless, and this is achieved by showing the symbol for the physical quantity (in italics) divided by the unit in which it is expressed (in ordinary upright print). Thus the figure 525, in a column headed $I(1)/\text{kJ mol}^{-1}$ means that the value of the first ionisation energy there tabulated is 525 kJ mol$^{-1}$. A similar convention is used for labelling the axes of graphs.

SI units have been used almost exclusively in the presentation of tables and in graphs. Thus, for example, all m.p. and b.p. are expressed in kelvins and all pressures in pascals. In a very few cases other units such as the electronvolt and the Bohr magneton have been used, but they are defined in the text in terms of SI units. Furthermore the coherent SI units are used in all calculations so that the advantages of the method known as quantity calculus (see references 2 and 3) are obtained.

## References

1. The Royal Society, Quantities, units and symbols, London, 1971.
2. M.L. McGlashan, Physico-chemical quantities and units, Royal Institute of Chemistry Monograph for Teachers No. 15, 2nd edition, London, 1971.
3. R.B. Heslop and Gillian M. Wild, SI units in chemistry, Applied Science Publishers Ltd., London, 1971.
4. Policy for NBS usage of SI units, J. Chem. Ed., 48, 469 (1971).
5. M.L. McGlashan, Internationally recommended names and symbols for physico-chemical quantities and units, Ann. Rev. Phys. Chem., 24, 51 (1973).

## 1.6. Symmetry

The shapes and spatial arrangements of orbitals, atoms, and molecules provide a simple fundamental basis on which a great deal of Inorganic Chemistry can be rationalised. Such a study requires an elementary knowledge of symmetry so that the shape of any object such as a molecule can be measured quantitatively and described unambiguously.

Symmetry elements are the units of symmetry, and their precise definitions are best understood in conjunction with their associated symmetry operations. Thus a symmetry operation can be defined as doing something (actually or notionally) to an object (whose symmetry one wishes to detail) which leaves the object in an indistinguishable (not necessarily identical) situation. Hence a symmetry operation is an action which demonstrates the existence of a symmetry element. There are five types which can be described as:

1. *Rotation* (the symmetry operation) about an *axis* of symmetry, $C$ (the symmetry element). The order $n$ of the rotation $C_n$ is defined as $360°$ divided by the angle of rotation.
2. *Reflection* (operation) through a *plane* of symmetry, $\sigma$ (the symmetry element).
3. *Reflection* (operation) through a *centre of inversion*, $i$ (the symmetry element). This is essentially a three-dimensional analogue of the two-dimensional plane of symmetry. Any point which can be described by the co-ordinates $+x$ $+y$ $+z$ will have a corresponding point at $-x$ $-y$ $-z$.
4. *Rotation followed by reflection* in a plane perpendicular to the axis (operation) defines the element of symmetry known as an *improper* axis of symmetry, $S$.
5. Finally, the operation of *rotation* through $360°$ (or alternatively doing nothing) is the symmetry element of *identity*, $E$. Such an operation must result in an identical situation to the starting position.

Consider the octahedral $SF_6$ molecule. Rotation through $90°$ about the vertical axis through F—S—F would leave the molecule with a configuration in space indistinguishable from its original one. This proper axis of symmetry is called a four-fold axis and labelled $C_4$ (Fig. 1.1). Rotation about the same axis through $180°$ is a $C_2$ axis while other $C_2$ axes bisect F—S—F bond angles
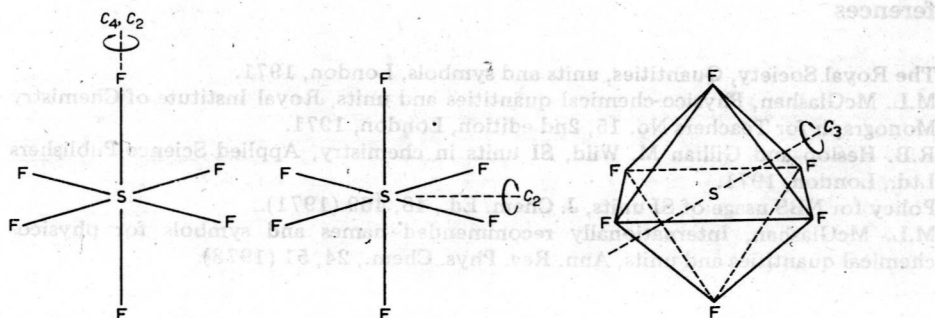
Fig. 1.1. Proper axes of symmetry in the $SF_6$ molecule.

and $C_3$ axes pass through the centre of each face of the octahedron formed by the F atoms. The order of rotation $n$ is determined by dividing $360°$ by the angle of rotation.

The principal axis is that with the highest order of rotation (the $C_4$ axis in $SF_6$) which is usually drawn vertically in a representation of the molecule and designated the $z$ axis in Cartesian coordinates.

Planes of symmetry $\sigma$ are usually further defined as vertical, horizontal, and dihedral with respect to the principal axis. In $SF_6$, there are three planes ($3 \sigma_h$) horizontal to the principal axis and six dihedral planes ($6 \sigma_d$) which bisect the different two-fold axes (Fig. 1.2).

$SF_6$ has a centre of symmetry at S, because any F atom moved from its origin through S to a position diametrically opposite and equidistant from S finishes in the position of another F atom.

The improper rotation axis $S_6$ arises when a rotation through $60°$ is carried out along the axis through the centre of any face of an octahedron (if $SF_6$ is drawn in a cube, the F atoms lie at the centre points of each face, the $S_6$ axes are the four cube diagonals), followed by reflection in a plane perpendicular to the axis (the plane contains the centre points of four diametrically opposed edges) (Fig. 1.3).

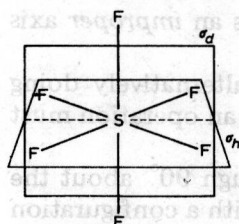The total number of symmetry operations and their associated elements



Fig. 1.2. $SF_6$ molecule, illustrating $\sigma_d$ and $\sigma_h$ planes of symmetry.
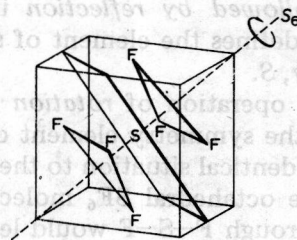


Fig. 1.3. $SF_6$ molecule, illustrating an $S_6$ axis.

of symmetry can be used to classify objects into point groups. The Schoenflies system of point group symbols provides a convenient shorthand notation by which objects of similar symmetry can be recognised. Apart from the special point groups $I_h$, $O_h$, $T_d$, which refer to icosahedral, octahedral, and tetrahedral symmetry, most inorganic molecules are described by the $C$ and $D$ point groups. Classification into these groups can be achieved simply by determining which axes of rotation and planes of symmetry are present. The presence of an $n$-fold axis indicates the point group $C_n$; if in addition there is a horizontal plane of symmetry, the group is $C_{nh}$, but if there are only vertical planes, the group is $C_{nv}$. The presence of 2-fold axes perpendicular to the principal axis $C_n$ is the basis of the $D_n$ group. Again, if in addition there is a horizontal plane, the group is $D_{nh}$, but if there are dihedral planes (planes which bisect the 2-fold axes), the group is $D_{nd}$.

The absence of axes of symmetry indicates lower orders of $C$ group symmetry such as $C_s$, which contains only one plane of symmetry, $C_i$, which has a centre of inversion as its only element of symmetry, and $C_1$ which has no elements of symmetry other than identity. $S$ groups are less common and contain both proper and improper axes of rotation but no planes.

TABLE 1.4

Examples of some common point groups

| Point group | Elements of symmetry | Molecules |
|---|---|---|
| $C_1$ | $E$ | CHFClBr |
| $C_i$ | $E$, $i$ | CHClBr—CHClBr (staggered) |
| $C_s$ | $E$, $\sigma$ | $SO_2BrF$, HOCl |
| $C_2$ | $E$, $C_2$ | $H_2O_2$ |
| $C_{2v}$ | $E$, $C_2$, $2\,\sigma_v$ | $SnCl_2$, $SiH_2Cl_2$ |
| $C_{3v}$ | $E$, $C_3$, $3\,\sigma_v$ | $PCl_3$, $H_3GeCl$ |
| $C_{4v}$ | $E$, $C_4$, $4\,\sigma_v$ | $IF_5$, $SF_5Cl$ |
| $C_{\infty v}$ | $E$, $C_\infty$, $\infty\,\sigma_v$ | NO, HCN |
| $C_{2h}$ | $E$, $C_2$, $\sigma_h$, $i$ | trans-$N_2F_2$ |
| $C_{3h}$ | $E$, $C_3$, $\sigma_h$, $i$ | $B(OH)_3$ |
| $D_{2d}$ | $E$, $C_2$, $2\,C_2$ (perp), $2\,\sigma_d$, $S_4$ | $H_2C{=}C{=}CH_2$ |
| $D_{3d}$ | $E$, $C_3$, $3\,C_2$, $3\,\sigma_d$, $i$, $S_6$ | $C_2Cl_6$ (staggered) |
| $D_{4d}$ | $E$, $C_4$, $4\,C_2$, $4\,\sigma_d$, $S_8$ | $S_8$ |
| $D_{2h}$ | $E$, $C_2$, $2\,C_2$ (perp), $2\,\sigma_v$, $\sigma_h$, $i$ | $B_2Cl_4$, $B_2H_6$ |
| $D_{3h}$ | $E$, $C_3$, $3\,C_2$, $3\,\sigma_v$, $\sigma_h$, $S_3$ | $BCl_3$, $PCl_5$ |
| $D_{4h}$ | $E$, $C_4$, $4\,C_2$, $4\,\sigma_v$, $\sigma_h$, $i$, $S_4$ | $XeF_4$, $PtCl_4^{2-}$ |
| $D_{\infty h}$ | $E$, $C_\infty$, $\infty\,C_2$, $\infty\,\sigma_v$, $i$ | $CO_2$, $Cl_2$ |

Experience at recognising symmetry elements leads to a speedy way of determining point groups (Table 1.4). However the complete symmetry description of a point group is found in its character table.

| Point group | Symmetry operations | |
|---|---|---|
| Irreducible representations or symmetry species | Characters in rows O L U M N S | Rotational, translational assignments and Cartesian transformations |

For example:

| $D_{3d}$ | $E$ | $2C_3$ | $3C_2$ | $i$ | $2S_6$ | $3\sigma_d$ | | |
|---|---|---|---|---|---|---|---|---|
| $A_{1g}$ | 1 | 1 | 1 | 1 | 1 | 1 | | $x^2+y^2, z^2$ |
| $A_{2g}$ | 1 | 1 | −1 | 1 | 1 | −1 | $R_z$ | |
| $E_g$ | 2 | −1 | 0 | 2 | −1 | 0 | $(R_x, R_y)$ | $(x^2-y^2, xy)(xz, yz)$ |
| $A_{1u}$ | 1 | 1 | 1 | −1 | −1 | −1 | | |
| $A_{2u}$ | 1 | 1 | −1 | −1 | −1 | 1 | $T_z$ | |
| $E_u$ | 2 | −1 | 0 | −2 | 1 | 0 | $(T_x, T_y)$ | |

Character tables have been constructed for all point groups and those of some chemically important symmetry groups are included for reference (Appendix I). However, chemists will want to use character tables rather than dwell on the mathematical subtleties of matrix algebra and group theory to arrive at their fundamental derivation, although the rules and conditions which such tables uniquely satisfy can be readily demonstrated. As the name implies, the table is made up of characters (which are usually integers), the significance of which will be made clear in later applications (5.3.4), arranged in vertical columns under each type of symmetry operation which the particular point group possesses. A horizontal row of characters constitutes an irreducible representation (which describes the symmetry of a particular part of an object described by the point group), collectively known by the symbol $\Gamma$ but designated individually by a symbol $A$, $B$, $E$, or $T$ and often referred to as a symmetry species. $A$ and $B$ both refer to one-dimensional representations, $E$ and $T$ refer to two- and three-dimensional representations (doubly and triply degenerate species), respectively, as indicated by the character in the identity column. The subscripts $g$ and $u$ (German gerade and ungerade, in this context meaning symmetric and antisymmetric) are included in terms for the irreducible representations of shapes which have a centre of symmetry, and indicate the sign of the character in the inversion centre column. Other subdivisions are designated by subscript numerals, primes and double primes.

To the right of the character table, it has become the convention to indi-

cate the irreducible representations to which the rotational $R_x$ $R_y$ $R_z$ and translational $T_x$ $T_y$ $T_z$ modes correspond, as well as showing how the binary functions of $x$ $y$ $z$ such as $xy$, $x^2 - y^2$ transform. Such information is useful when discussing the symmetry of orbitals in bonding as well as in interpreting infrared and Raman spectra. The application of symmetry and group theory to each of these topics will be explained in the appropriate section.

**Reference**

G. Davidson, Introductory Group Theory for Chemists, Elsevier, Amsterdam, 1971.

## 1.7. Suggestions for Further Reading

Appended to every chapter in the book is a short list of references which will be found useful in extending the reader's knowledge of particular aspects of the subjects treated in that chapter. More generally there are two recent publications containing reviews of inorganic chemistry written by experts in their respective fields: *Comprehensive Inorganic Chemistry*, Executive Editor, A.F. Trotman-Dickenson, 5 vols., Pergamon Press, Oxford, 1973, and *Inorganic Chemistry: Series One and Two* (*M.T.P. International Review of Science*), Consultant Editor, H.J. Emeléus, 10 vols., Butterworths, London, 1973 and 1975.

Useful review articles will be found in *Advances in Inorganic Chemistry and Radiochemistry*, Eds. H.J. Emeléus and A.G. Sharpe, published annually since 1959 by Academic Press, New York, and in *Progress in Inorganic Chemistry*, also published annually since 1959 by Interscience, New York. The *Chemical Reviews* have been published by the American Chemical Society since 1901; the *Quarterly Reviews of the Chemical Society* were published by the Chemical Society of London from 1947 to 1971 and have been succeeded by the *Chemical Society Reviews* which also appear quarterly. The reader's attention is also drawn to *Accounts of Chemical Research*, published since 1968 by the American Chemical Society, and to the international edition in English of *Angewandte Chemie*, published since 1962 by Verlag Chemie at Weinheim. This journal contains less specialised articles of particular value to undergraduate students, as do the *Journal of Chemical Education*, published monthly by the American Chemical Society and *Education in Chemistry*, published six times a year by the Chemical Society of London.

More specialised articles of greater interest to research workers will be found in *Advances in Organometallic Chemistry*, Eds. F.G.A. Stone and R. West, published annually from 1963 by Academic Press, New York, and *Coordination Chemistry Reviews*, Ed. A.B.P. Lever, published since 1966 by Elsevier, Amsterdam.

Practical aspects of inorganic chemistry are well covered in *Inorganic Syntheses*, McGraw-Hill, New York, of which fourteen volumes have appeared since 1939, and in *Techniques of Inorganic Chemistry*, Eds. H.B. Jonassen