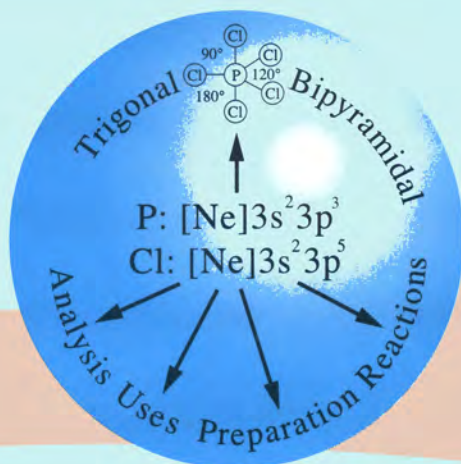


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Making the Connections

Brian Murphy, Clair Murphy
and Brian J. Hathaway



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Making the Connections

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Making the Connections

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Preface

With the passage of time, the amount of factual chemistry is continually increasing and it is now virtually impossible for one person to retain. Fortunately, it is not necessary for one person to know all of this, as long as the data can be accessed reasonably quickly. What is more important is that the underlying principles are clearly described and understood. As teachers, it is then the teaching of these principles that should be emphasised in teaching programmes and not the factual data. The latter do have a limited role as reference material, such as in 'The Elements' by J. Emsley, 1989, Oxford University Press and 'The Dictionary of Inorganic Compounds' ed. J. E. Macintyre, 1992, Chapman and Hall, London, but these texts are not appropriate for teaching the basic principles of chemistry. The preparation of textbooks has been made much easier by the improvements in the technology of book production. This has resulted in the production of much more colourfully attractive textbooks, relative to the rather drab texts of 20 years ago, but unfortunately, it has also tended to produce larger textbooks of rarely less than 1000 pages. This is particularly the case with textbooks of general and introductory chemistry. This would not be a problem if the basic principles of chemistry were still clearly identifiable. However, this is rarely the case and the principles, even when well described, are lost beneath a wealth of factually unconnected data that it is of low priority for the student to learn and gives the impression that chemistry is a boring subject. In general, these students are only taking chemistry as a subsidiary subject and will not proceed beyond the basic year.

This is particularly apparent in the sections on introductory inorganic chemistry, where the underlying electron configuration of the elements of the Periodic Table not only determines the Long Form of the Periodic Table, but also determines the physical properties of the elements, atom size, ionisation energies and electron affinities (electron attachment enthalpies), and the chemical properties, characteristic or group oxidation numbers, variable valence and the formation of ionic

and covalent bonds. From the valence shell configuration of the Main Group elements in their compounds, the Lewis structure, shape and hybridisation of the bonds in these compounds may be predicted. Equally important, from a knowledge of the valence shell configuration of the elements, the stoichiometry of the reactants and products of the reactions of these elements may be predicted. Such predictions not only form the basic principles for the understanding of preparative inorganic chemistry, they also form the basis of the reactions used in analytical chemistry, namely acid/base, precipitation and redox reactions. Without this understanding of the basic principles of preparative chemistry and chemical reactions, a knowledge of chemistry reduces to pure memory work. Unfortunately, it is this need for pure memory work in learning chemical reactions that forms the basis of teaching in many of the general chemistry textbooks.

The present text tries to overcome the limitations of the above textbooks by covering the basic principles of introductory inorganic chemistry in a structured and connected way, in a short book.

Chapter 1, 'Moles and Molarity', includes a discussion of volumetric calculations, based on *supplied* stoichiometry factors for equations, including limiting reagents. It is included as a first chapter to get students without any previous knowledge of chemistry started on a practical course for volumetric chemistry that usually accompanies an introductory inorganic lecture course.

Chapter 2 describes the 'Structure of the Atom' in terms of electrons and orbitals and the build-up process to the Long Form of the Periodic Table.

Chapter 3 briefly describes how the 'Physical Properties of the Elements' are related to the electron configuration of the elements and hence to their positions in the Periodic Table, namely, their size, ionisation potential and electron attachment enthalpies.

Chapter 4 describes how the 'Chemical Properties of the Elements' are related to their valence shell configuration, *i.e.* characteristic or group oxidation number, variable valence, ionic and covalent bonding. This chapter includes a section on the volumetric calculations used in an introductory inorganic practical course, including the *calculation* of the stoichiometry factors for chemical reactions.

Chapter 5 describes how the Lewis structures of simple Main Group molecules, cations and anions, including oxyacids and oxyanions, are calculated from a knowledge of the valence shell configuration of the central element. A Working Method is suggested for writing the Lewis structures and illustrated by examples, including double bonds and triple bonds in polyatomic molecules.

Chapter 6 describes how the shapes of simple Main Group molecules, cations and anions, including oxyacids and oxyanions, by VSEPR theory are determined from a knowledge of the valence shell configuration of the central element. A Working Method is suggested and illustrated by examples, including double bonds and triple bonds in polyatomic molecules. Given the shapes, hybridisation schemes are suggested to describe the bonding in these covalent species.

Chapter 7 uses the connectivity between the valence shell electron configurations of the elements to systematise the reactivity of the **elements** to form hydrides, oxides and halides, including their molecular stoichiometries. The further reaction of the **compounds** formed is described, using analytical chemistry reactions, *i.e.* acid/base, precipitation and redox reactions, and how the **compounds** behave with water and on heating. A Working Method to describe this *Features of Interest* approach to the descriptive chemistry of molecules is suggested and applied to a number of examples, which are then summarised as **Spider Diagrams**. The use of the Spider Diagram to outline an essay or report on the chemistry of molecules, cations and anions is described.

In University College Cork (UCC), each chapter is accompanied by an interactive computer aided learning tutorial, which briefly introduces each subject, proposes a typical examination question of the appropriate level, and then takes the student stepwise through a suggested Working Method approach to the question, made up of linked multiple-choice questions. Interactive help is provided to each multiple-choice question, with hints provided in the event of an incorrect answer, and up to two attempts are allowed before the correct answer is provided. The Working Method questions are supplemented by independent series of multiple-choice questions. The present short text has been written to discourage the student from using the CAL courseware to take down a set of notes from the computer screen, as this is considered an inappropriate use of these interactive CAL tutorials. These tutorials have been in use for the past four years at University College Cork (and more recently at Cardiff and Dublin City Universities) and are extremely well used by the 300 First Science students per year taking the course. The use of the CAL courseware is entirely optional and supplementary to the normal teaching program, of lectures, practical and large and small group tutorials, but the interactive nature of the courseware, especially for numerical problem solving, is attractive to students, particularly those with a weak chemistry background. As the courseware is based upon UCC type examination questions and also reflects the lecturer's approach to his teaching, the tutorials are not directly transferable to other third-level institutions, but copies are available for down loading

from the Internet, free of charge, at:

<http://nitec.dcu.ie/~chemlc/CAL2.html>

However, these generally follow the approach of the individual chapters in the present text and the authors firmly believe that the **best** courseware should be written in house to reflect the approach of the course lecturer involved.

March 1998 Brian Murphy, Clair Murphy and Brian Hathaway

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Contents

<i>Chapter 1</i>	
Moles and Molarity	1
Aims and Objectives	1
States of Matter	1
Elements, Atoms and Molecules	1
Elements, Mixtures and Compounds (Molecules)	2
Simple Chemical Names	3
Cations and Anions	3
Types of Chemical Formula	4
Atomic Weight	4
Avogadro's Number	5
Empirical Formula	5
Chemical Equations	6
Balancing Chemical Equations	7
Molar Solutions	8
Volumetric Reactions	9
Volumetric Titrations	10
Limiting Reactions	11
Worked Example No. 1	11
Worked Example No. 2	13
 <i>Chapter 2</i>	
The Structure of the Atom, Electron Configuration and the Build-up to the Periodic Table	14
Aims and Objectives	14
The Structure of the Atom	14
Bohr Model of the Atom	17
The Build-up Process for the Periodic Table	27

*Chapter 3***The Physical Properties of the Elements and the Periodic Table**

31

Aims and Objectives	31
The Periodic Table	31
Variation in the Atomic Radii	34
Variation in the Ionisation Potentials	34
Variation in the Electron Affinities or Attachment Enthalpies	37
Summary	38

*Chapter 4***Chemical Properties of the Elements and the Periodic Table**

39

Aims and Objectives	39
Introduction	39
Characteristic or Group Oxidation Numbers	41
Oxidation Numbers	43
Rules for the Determination of Oxidation Numbers	44
Main Group Variable Valence	44
Transition Metal Variable Valence	46
Chemical Stoichiometry	49
The Calculation of Chemical Stoichiometry Factors –	
Worked Examples	51
Redox Reactions	52
Covalent Bonds	53
Polyatomic Covalent Molecules	54
Molecular Orbital Theory of Diatomic Molecules	56
Bond Order	60

*Chapter 5***The Lewis Structures of Molecules, Cations and Anions, Including Oxyanions**

61

Aims and Objectives	61
Introduction	61
The Working Method for Drawing Lewis Structures	64
Example 1: Methane (CH_4) and Carbon Tetrachloride (CCl_4)	65
Example 2: The Ammonium Cation (NH_4^+) and the	
Tetrafluoroborate Anion (BF_4^-)	66
Example 3: Ammonia (NH_3) and Water (OH_2)	68

Example 4: Beryllium Dihydride (BeH_2) and Boron Trifluoride (BF_3)	69
Example 5: Phosphorus Pentchloride (PCl_5) and Sulfur Hexafluoride (SF_6)	70
Example 6: 1,1,-Dichloromethanone (Cl_2CO) and Ethene (C_2H_4)	71
Example 7: Ethyne (C_2H_2)	73
The Oxyacids and Oxyanions of the Main Group Elements	74
The Position of the Hydrogen Atoms in the Oxyacids	74
The Free Valence of the Terminal Oxygen Atoms	76
Resonance in the Structures of the Oxyanions	78
The Application of the Working Method to the Lewis Structures of the Oxyanions	79
Example 1: Carbonic Acid, H_2CO_3	79
Example 2: Sulfuric Acid, H_2SO_4	81
The Use of Formal Charges	84
Summary	86

Chapter 6

Shape and Hybridisation 88

Aims and Objectives	88
The Shapes of Covalent Molecules	88
The Working Method for Using VSEPR Theory	92
Deviations from Regular Shapes	94
The Advantages of VSEPR Theory	95
The Disadvantages of VSEPR Theory	95
The Shape of Dinuclear Molecules	95
Hybridisation of Atomic Orbitals	99
Hybridisation in Polynuclear Molecules	104
Summary	106

Chapter 7

A Features of Interest Approach to Systematic Inorganic Chemistry 107

Aims and Objectives	107
Introduction	107
The Preparation of Simple Compounds from the Elements	109
The Reactions of Simple Compounds	113
Reaction with Water	113
Volumetric Reactions	114
The Effect of Heat	115

Features of Interest of Simple Compounds – Working Method	116
The Application of the Working Method to a Selection of Simple Compounds	
Example 1: Methane, (CH ₄)	119
Example 2: Hydrochloric Acid (HCl)	120
Example 3: Sodium Chloride (NaCl)	121
Example 4: Phosphorus Pentachloride (PCl ₅)	122
Example 5: Copper (II) Oxide, (CuO)	123
Example 6: Iron (II) Chloride (FeCl ₂)	124
Example 7: Iron (II) Sulfate Hexahydrate ([Fe(OH ₂) ₆]SO ₄)	125
Example 8: Carbonic Acid (H ₂ CO ₃)	126
Writing an Essay or Report from a Spider Diagram	128
Conclusions	130
Suggested Ways Forward	130
Phase II – Features of Interest	130
Phase III – Features of Interest	131
The Advantages of the Features of Interest Approach	139
The Disadvantages of the Features of Interest Approach	139
Appendices	144
Periodic Table of the Elements	148
Subject Index	149

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Chapter 1

Moles and Molarity

AIMS AND OBJECTIVES

This introductory chapter describes the simple ideas of atoms and molecules, types of chemical formula and their molecular weight for students who have not studied chemistry before. Chemical equations and balanced chemical equations are introduced through the reactions used in an introductory practical laboratory course. The concepts of molarity and molar solutions are introduced through solving volumetric problems, to enable the student to start a laboratory course in practical Inorganic Chemistry.

STATES OF MATTER

Chemistry is the science and study of the material world. It is generally accepted that there are three states of matter, solid, liquid and gaseous, and the chemicals that make up the materials of the world involve the chemical elements or molecules.

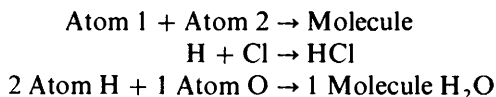
ELEMENTS, ATOMS AND MOLECULES

The physical state of an element relates to the three states of matter, and the precise state for an element is largely determined by the temperature. Thus at room temperature the element iron is a solid, bromine is a liquid and fluorine is a gas.

In the gaseous state at room temperature helium (He) is a mono-atomic gas, and the formula of the element helium is written as He. However, the gaseous form of hydrogen and oxygen at room temperature involves diatomic molecules, namely, H_2 and O_2 . This difference is largely determined by the individual electron configuration of the el-

ements, and their ability to form bonds to each other, rather than remain (in the gaseous state) as atomic species of the elements.

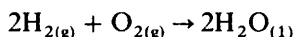
The way in which the elements of the **Periodic Table** react together is largely determined by the electron configuration of the individual elements as this determines the ratio in which two elements combine to form a molecule:



The number of atoms of each element in a molecule determines the ratio of the elements in the molecule and is referred to as the stoichiometry of the molecule. In the molecule of HCl the ratio of H:Cl is 1:1, and the molecule has a stoichiometry of 1:1. In H₂O the ratio of H:O is 2:1, and its stoichiometry is 2:1.

ELEMENTS, MIXTURES AND COMPOUNDS (MOLECULES)

An **element** consists of only one type of atom, *i.e.* helium, hydrogen or iron. A **mixture** may contain more than one type of substance that can be physically separated into its components, whereas a compound contains more than one type of element, usually with a definite stoichiometry, and cannot be separated into its elements by any simple physical method. Thus the element iron may be obtained as a magnetic black powder that can be mixed with yellow sulfur to give a blackish yellow mixture, from which the iron metal can be separated by means of a magnet. However, if the mixture is heated, a reaction occurs to give a black solid of FeS, iron(II) sulfide, on cooling, from which the iron present cannot be separated by the use of a magnet. The black solid FeS is referred to as a **compound** of Fe and S which has lost the properties of the elemental Fe and S and has unique properties of its own. Similarly, molecules of H₂ and O₂ react to give molecules of water, H₂O:



but while H₂ and O₂ are gases at room temperature, H₂O is a liquid. In these new **compounds** the compound elements are said to have reacted chemically together to give a new compound, FeS and H₂O, respectively, with definite stoichiometries between the atoms, namely, 1:1 in FeS and 2:1 in H₂O.