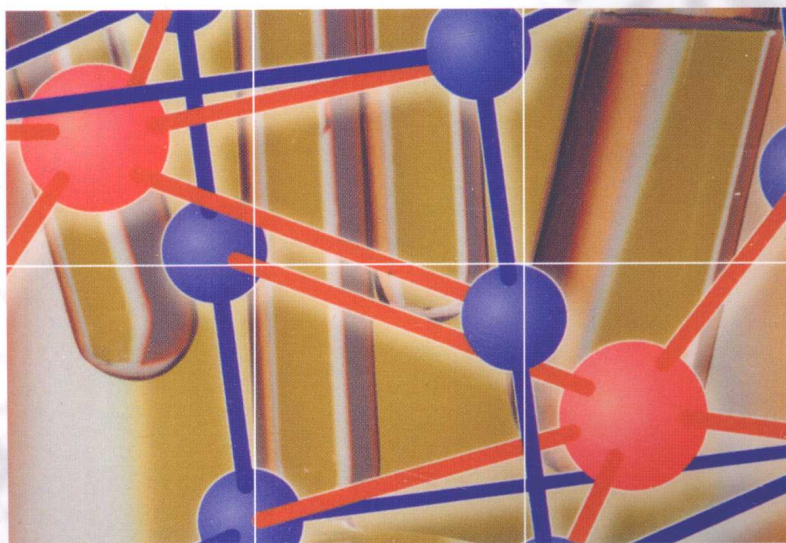


精要速览系列

Instant Notes

INORGANIC CHEMISTRY (SECOND EDITION)

无机化学 (第二版)



· 导读版 ·

P.A.Cox



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精要速览系列
Instant Notes in

Inorganic Chemistry

Second Edition

无机化学

(第二版, 导读版)

P. A. Cox

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科学出版社

北京

内 容 简 介

“精要速览系列(Instant Notes Series)”丛书是国外教材“Best Seller”榜的上榜教材。该系列结构新颖,视角独特;重点明确,脉络分明;图表简明清晰;英文自然易懂,被国内多所重点院校选用作为双语教材。

第二版在第一版基础上进行修订。全书共分为 10 大主题,图文并茂,从原子结构出发,以元素周期表为主线,涵盖了无机化学的基础和核心内容。除了包括基本的原子结构、周期性、成键及溶液化学、各族元素(包括非过渡元素和过渡元素)的较广泛的介绍外,与其他无机化学教材不同的是,此书还涉及了无机化学在元素起源、地球化学、生物化学、工业生产及环境等领域的内容。

本书适合普通高等院校生命科学、医学、化学等相关专业使用,也可作为双语教学参考教材使用。

P. A. Cox

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前 言

无机化学涉及的是化学元素(100余种)及它们所形成的极为丰富的化合物。对无机化学的描述本质上与结构的一些一般概念、成键和反应性,特别是周期表及其所描述的原子结构的概念相一致。与“精要速览”的系列丛书中的其他书一样,本书试图提供一个覆盖大学一二年级课程内容的核心知识的简明摘要。本书分为几个独立的主题,以方便教师和学生就具体的课程做出不同的选择。

A~F部分讨论了原子结构和周期性、结构和成键及溶液化学的一般概念;之后的F~I主题则是以一种更为描述性的方式介绍了周期表中的不同部分,不过在H部分也讨论了与学习过渡金属有关的一些独特概念;最后J部分描述了实验室之外,发生在自然界的无机化学的方方面面。

本书适用于对化学理论有基本了解的读者。在原子结构和成键的讨论中尽可能避免用到数学知识。对其他方面有兴趣的读者,书后为他们提供了补充读物。

本教材的第二版中新增加了三部分内容:无机反应及合成,化合物表征方法,对称性。另外还有大量的修订和补充,如关于稀有气体的新型材料。这些修订旨在为了加强合成及化学反应性的知识。本教材简明扼要概括了无机化学的基本知识,我希望这些修订能够进一步提高其使用价值。

本书的出版得到许多人直接或间接的帮助。作者特别致谢:Howard Stanbury介绍本人接手这项工作;BIOS科学出版公司的Lisa Mansell和其他员工的友谊和效率;对初稿提出有益意见的同事Bob Denning, Jenny Green和不知名的读者们;感谢本人以前的和现在的学生,他们的热情使教授无机化学成为一种享受;感谢Sue的爱和理解。

PREFACE

Inorganic chemistry is concerned with the chemical elements (of which there are about 100) and the extremely varied compounds they form. The essentially descriptive subject matter is unified by some general concepts of structure, bonding and reactivity, and most especially by the periodic table and its underlying basis in atomic structure. As with other books in the *Instant Notes* series, the present account is intended to provide a concise summary of the core material that might be covered in the first and second years of a degree-level course. The division into short independent topics should make it easy for students and teachers to select the material they require for their particular course.

Sections A–E discuss the general concepts of atomic structure, periodicity, structure and bonding, and solution chemistry. The following Sections F–I cover different areas of the periodic table in a more descriptive way, although in Section H some concepts that are peculiar to the study of transition metals are also discussed. The final section describes some aspects of inorganic chemistry in the world outside the laboratory.

I have assumed a basic understanding of chemical ideas and vocabulary, coming, for example, from an A-level chemistry course in the UK or a freshman chemistry course in the USA. Mathematics has been kept at a strict minimum in the discussion of atomic structure and bonding. A list of further reading is given for those interested in pursuing these or other aspects of the subject.

In preparing the second edition I have added three extra Topics, on reactions and synthesis, the characterization of compounds, and symmetry. A number of corrections and additions have also been made, including new material on noble gases. These changes aim to strengthen the coverage of synthesis and chemical reactivity, and I hope they will increase the usefulness of the book as a concise account of the basics of inorganic chemistry.

Many people have contributed directly or indirectly to the production of this book. I would particularly like to thank the following: Howard Stanbury for introducing me to the project; Lisa Mansell and other staff at Garland/BIOS for their friendliness and efficiency; the anonymous readers and my colleagues Bob Denning and Jenny Green for their helpful comments on the first draft; my students past and present for their enthusiasm, which has made teaching inorganic chemistry an enjoyable task; and Sue for her love and understanding.

缩 略 语

3c2e	three-center two-electron	三中心二电子
3c4e	three-center four-electron	三中心四电子
3D	three dimensional	三维
ADP	adenosine diphosphate	二磷酸腺苷
An	actinide	锕系
AO	atomic orbital	原子轨道
ATP	adenosine triphosphate	三磷酸腺苷
bcc	body-centered cubic	体心立方
BO	bond order	键级
BP	boiling point	沸点
CB	conduction band	导带
ccp	cubic close packing	立方密堆积
CN	coordination number	配位数
Cp	cyclopentadienyl(C ₅ H ₅)	环戊二烯(C ₅ H ₅)
E	unspecified(non-metallic)element	未指明原子(非金属)
EA	electron affinity	电子亲合势
EAN	effective atomic number	有效原子数
EDTA	ethylenediamine tetraacetate	乙二胺四乙酸
Et	ethyl(C ₂ H ₅)	乙基(C ₂ H ₅)
fcc	face-centered cubic	面心立方
hcp	hexagonal close packing	六方密堆积
HOMO	highest occupied molecular orbital	最高被占分子轨道
HSAB	hard and soft acid-base	硬/软酸碱
IE	(first)ionization energy	(第一)电离能
I_n	n th ionization energy($n=1,2,\dots$)	第 n 电离能($n=1,2,\dots$)
IUPAC	International Union of Pure and Applied Chemistry	国际纯粹及应用化学联合会
L	unspecified ligand	未指明配体
LCAO	linear combination of atomic orbitals	原子轨道线性组合
LFSE	ligand field stabilization energy	配位场稳定化能
LMCT	ligand \rightarrow metal charge transfer	配体到金属的电荷转移
LUMO	lowest unoccupied molecular orbital lanthanide	最低空轨道
Ln		镧系
M	unspecified(metallic)element	未指明(金属)元素
Me	methyl(CH ₃)	甲基(CH ₃)
MLCT	metal-to-ligand charge transfer	金属到配体的电荷转移
MO	molecular orbital	分子轨道
MP	melting point	熔点

Ph	phenyl(C ₆ H ₅)	苯基(C ₆ H ₅)
R	organic group(alkyl or aryl)	有机基团(烷基或芳基)
RAM	relative atomic mass	相对原子质量
SN	steric number	位阻数
UV	ultraviolet	紫外
VB	valence band	价带
VE	valence electron	价电子
VSEPR	valence shell electron pair repulsion	价层电子对互斥
X	unspecified element(often a halogen)	未指明元素(常指卤素)
Z	atomic number	原子序数

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A1 THE NUCLEAR ATOM

Key Notes

Electrons and nuclei

An atom consists of a very small positively charged nucleus, surrounded by negative electrons held by electrostatic attraction. The motion of electrons changes when chemical bonds are formed, nuclei being unaltered.

Nuclear structure

Nuclei contain positive protons and uncharged neutrons. The number of protons is the atomic number (Z) of an element. The attractive strong interaction between protons and neutrons is opposed by electrostatic repulsion between protons. Repulsion dominates as Z increases and there is only a limited number of stable elements.

Isotopes

Isotopes are atoms with the same atomic number but different numbers of neutrons. Many elements consist naturally of mixtures of isotopes, with very similar chemical properties.

Radioactivity

Unstable nuclei decompose by emitting high-energy particles. All elements with $Z > 83$ are radioactive. The Earth contains some long-lived radioactive elements and smaller amount of short-lived ones.

Related topics

Actinium and the actinides (I2)

Origin and abundance of the elements (J1)

Electrons and nuclei

The familiar planetary model of the atom was proposed by Rutherford in 1912 following experiments by Geiger and Marsden showing that nearly all the mass of an atom was concentrated in a positively charged nucleus. Negatively charged **electrons** are attracted to the nucleus by the **electrostatic force** and were considered by Rutherford to 'orbit' it in a similar way to the planets round the Sun. It was soon realized that a proper description of atoms required the quantum theory; although the planetary model remains a useful analogy from the macroscopic world, many of the physical ideas that work for familiar objects must be abandoned or modified at the microscopic atomic level.

The lightest atomic nucleus (that of hydrogen) is 1830 times more massive than an electron. The size of a nucleus is around 10^{-15} m (1 fm), a factor of 10^5 smaller than the apparent size of an atom, as measured by the distances between atoms in molecules and solids. Atomic sizes are determined by the radii of the electronic orbits, the electron itself having apparently no size at all. Chemical bonding between atoms alters the motion of electrons, the nuclei remaining unchanged. Nuclei retain the 'chemical identity' of an element, and the occurrence of chemical elements depends on the existence of stable nuclei.

Nuclear structure

Nuclei contain positively charged **protons** and uncharged **neutrons**; these two particles with about the same mass are known as **nucleons**. The number of

protons is the **atomic number** of an element (Z), and is matched in a neutral atom by the same number of electrons. The total number of nucleons is the **mass number** and is sometimes specified by a superscript on the symbol of the element. Thus ${}^1\text{H}$ has a nucleus with one proton and no neutrons, ${}^{16}\text{O}$ has eight protons and eight neutrons, ${}^{208}\text{Pb}$ has 82 protons and 126 neutrons.

Protons and neutrons are held together by an attractive force of extremely short range, called the **strong interaction**. Opposing this is the longer-range electrostatic repulsion between protons. The balance of the two forces controls some important features of nuclear stability.

- Whereas lighter nuclei are generally stable with approximately equal numbers of protons and neutrons, heavier ones have a progressively higher proportion of neutrons (e.g. compare ${}^{16}\text{O}$ with ${}^{208}\text{Pb}$).
- As Z increases the electrostatic repulsion comes to dominate, and there is a limit to the number of stable nuclei, all elements beyond Bi ($Z = 83$) being radioactive (see below).

As with electrons in atoms, it is necessary to use the quantum theory to account for the details of nuclear structure and stability. It is favorable to 'pair' nucleons so that nuclei with even numbers of either protons or neutrons (or both) are generally more stable than ones with odd numbers. The **shell model** of nuclei, analogous to the orbital picture of atoms (see Topics A2 and A3) also predicts certain **magic numbers** of protons or neutrons, which give extra stability. These are

2 8 20 28 50 82 126

${}^{16}\text{O}$ and ${}^{208}\text{Pb}$ are examples of nuclei with magic numbers of both protons and neutrons.

Trends in the stability of nuclei are important not only in determining the number of elements and their isotopes (see below) but also in controlling the proportions in which they are made by nuclear reactions in stars. These determine the abundance of elements in the Universe as a whole (see Topic J1).

Isotopes

Atoms with the same atomic number and different numbers of neutrons are known as **isotopes**. The chemical properties of an element are determined largely by the charge on the nucleus, and different isotopes of an element have very similar chemical properties. They are not quite identical, however, and slight differences in chemistry and in physical properties allow isotopes to be separated if desired.

Some elements have only one stable isotope (e.g. ${}^{19}\text{F}$, ${}^{27}\text{Al}$, ${}^{31}\text{P}$), others may have several (e.g. ${}^1\text{H}$ and ${}^2\text{H}$, the latter also being called **deuterium**, ${}^{12}\text{C}$ and ${}^{13}\text{C}$); the record is held by tin (Sn), which has no fewer than 10. Natural samples of many elements therefore consist of mixtures of isotopes in nearly fixed proportions reflecting the ways in which these were made by nuclear synthesis. The **molar mass** (also known as **relative atomic mass**, RAM) of elements is determined by these proportions. For many chemical purposes the existence of such isotopic mixtures can be ignored, although it is occasionally significant.

- Slight differences in chemical and physical properties can lead to small variations in the isotopic composition of natural samples. They can be exploited to give geological information (dating and origin of rocks, etc.) and lead to small variations in the molar mass of elements.

- Some spectroscopic techniques (especially **nuclear magnetic resonance, NMR**, see Topic B7) exploit specific properties of particular nuclei. Two important NMR nuclei are ^1H and ^{13}C . The former makes up over 99.9% of natural hydrogen, but ^{13}C is present as only 1.1% of natural carbon. These different abundances are important both for the sensitivity of the technique and the appearance of the spectra.
- Isotopes can be separated and used for specific purposes. Thus the slight differences in chemical behavior between normal hydrogen (^1H) and deuterium (^2H) can be used to investigate the detailed mechanisms of chemical reactions involving hydrogen atoms.

In addition to stable isotopes, all elements have unstable **radioactive** ones (see below). Some of these occur naturally, others can be made artificially in particle accelerators or nuclear reactors. Many radioactive isotopes are used in chemical and biochemical research and for medical diagnostics.

Radioactivity

Radioactive decay is a process whereby unstable nuclei change into more stable ones by emitting particles of different kinds. **Alpha, beta and gamma** (α , β and γ) radiation was originally classified according to its different penetrating power. The processes involved are illustrated in Fig. 1.

- An α particle is a ^4He nucleus, and is emitted by some heavy nuclei, giving a nucleus with Z two units less and mass number four units less. For example, ^{238}U ($Z = 92$) undergoes α decay to give (radioactive) ^{234}Th ($Z = 90$).
- A β particle is an electron. Its emission by a nucleus increases Z by one unit, but does not change the mass number. Thus ^{14}C ($Z = 6$) decays to (stable) ^{14}N ($Z = 7$).
- γ radiation consists of high-energy electromagnetic radiation. It often accompanies α and β decay.

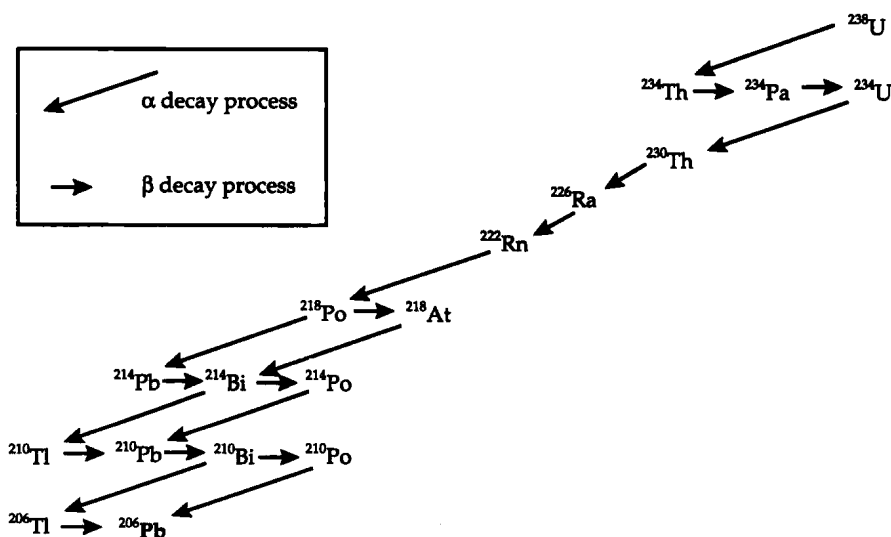


Fig. 1. The ^{238}U decay series showing the succession of α and β decay processes that give rise to many other radioactive isotopes and end with stable ^{206}Pb .

Some other decay processes are known. Very heavy elements can decay by **spontaneous fission**, when the nucleus splits into two fragments of similar mass. A transformation opposite to that in normal β decay takes place either by **electron capture** by the nucleus, or by emission of a positron (β^+) the positively charged antiparticle of an electron. Thus the natural radioactive isotope ^{40}K ($Z = 19$) can undergo normal β decay to ^{40}Ca ($Z = 20$), or electron capture to give ^{40}Ar ($Z = 18$).

Radioactive decay is a statistical process, there being nothing in any nucleus that allows us to predict when it will decay. The probability of decay in a given time interval is the only thing that can be determined, and this appears to be entirely constant in time and (except in the case of electron capture) unaffected by temperature, pressure or the chemical state of an atom. The probability is normally expressed as a **half-life**, the time taken for half of a sample to decay. Half-lives can vary from a fraction of a second to billions of years. Some naturally occurring radioactive elements on Earth have very long half-lives and are effectively left over from the synthesis of the elements before the formation of the Earth. The most important of these, with their half-lives in years, are ^{40}K (1.3×10^9), ^{232}Th (1.4×10^{10}) and ^{238}U (4.5×10^9).

The occurrence of these long-lived radioactive elements has important consequences. Radioactive decay gives a heat source within the Earth, which ultimately fuels many geological processes including volcanic activity and long-term generation and movement of the crust. Other elements result from radioactive decay, including helium and argon and several short-lived radioactive elements coming from the decay of thorium and uranium (see Topic I2). *Fig. 1* shows how ^{238}U decays by a succession of radioactive α and β processes, generating shorter-lived radioactive isotopes of other elements and ending as a stable isotope ^{206}Pb of lead. Similar decay series starting with ^{232}Th and ^{235}U also generate short-lived radioactive elements and end with the lead isotopes ^{208}Pb and ^{207}Pb , respectively.

All elements beyond bismuth ($Z = 83$) are radioactive, and none beyond uranium ($Z = 92$) occur naturally on Earth. With increasing numbers of protons heavier elements have progressively less stable nuclei with shorter half-lives. Elements with Z up to 110 have been made artificially but the half-lives beyond Lr ($Z = 103$) are too short for chemical investigations to be feasible. Two lighter elements, technetium (Tc, $Z = 43$) and promethium (Pm, $Z = 61$), also have no stable isotopes.

Radioactive elements are made artificially by bombarding other nuclei, either in particle accelerators or with neutrons in nuclear reactors (see Topic I2). Some short-lived radioactive isotopes (e.g. ^{14}C) are produced naturally in small amounts on Earth by cosmic-ray bombardment in the upper atmosphere.

A2 ATOMIC ORBITALS

Key Notes

Wavefunctions

The quantum theory is necessary to describe electrons. It predicts discrete allowed energy levels and wavefunctions, which give probability distributions for electrons. Wavefunctions for electrons in atoms are called atomic orbitals.

Quantum numbers and nomenclature

Atomic orbitals are labeled by three quantum numbers n , l and m . Orbitals are called s , p , d or f according to the value of l ; there are respectively one, three, five and seven different possible m values for these orbitals.

Angular functions: 'shapes'

s orbitals are spherical. p orbitals have two directional lobes, which can point in three possible directions. d and f orbitals have correspondingly greater numbers of directional lobes.

Radial distributions

The radial distribution function shows how far from the nucleus an electron is likely to be found. The major features depend on n but there is some dependence on l .

Energies in hydrogen

The allowed energies in hydrogen depend on n only. They can be compared with experimental line spectra and the ionization energy.

Hydrogenic ions

Increasing nuclear charge in a one-electron ion leads to contraction of the orbital and an increase in binding energy of the electron.

Related topics

Many-electron atoms (A3)

Molecular orbitals: homonuclear diatomics (C4)

Wavefunctions

To understand the behavior of electrons in atoms and molecules requires the use of **quantum mechanics**. This theory predicts the allowed **quantized** energy levels of a system and has other features that are very different from 'classical' physics. Electrons are described by a **wavefunction**, which contains all the information we can know about their behavior. The classical notion of a definite trajectory (e.g. the motion of a planet around the Sun) is not valid at a microscopic level. The quantum theory predicts only **probability distributions**, which are given by the square of the wavefunction and which show where electrons are more or less likely to be found.

Solutions of **Schrödinger's wave equation** give the allowed energy levels and the corresponding wavefunctions. By analogy with the orbits of electrons in the classical planetary model (see Topic A1), wavefunctions for atoms are known as **atomic orbitals**. Exact solutions of Schrödinger's equation can be obtained only for one-electron atoms and ions, but the atomic orbitals that result from these solutions provide pictures of the behavior of electrons that can be extended to many-electron atoms and molecules (see Topics A3 and C4–C7).