Class Syllabus

- Instructor:

- Dr. Khalid Alrashidi
- Office location: 2 A 103 – B5
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- Course information:

- Bioinorganic Chemistry
- 418 Chem
- 2 credit hours

- Resources:

- class notes

- Office hours:

- Everyday at noon 12-1 or after lecture time

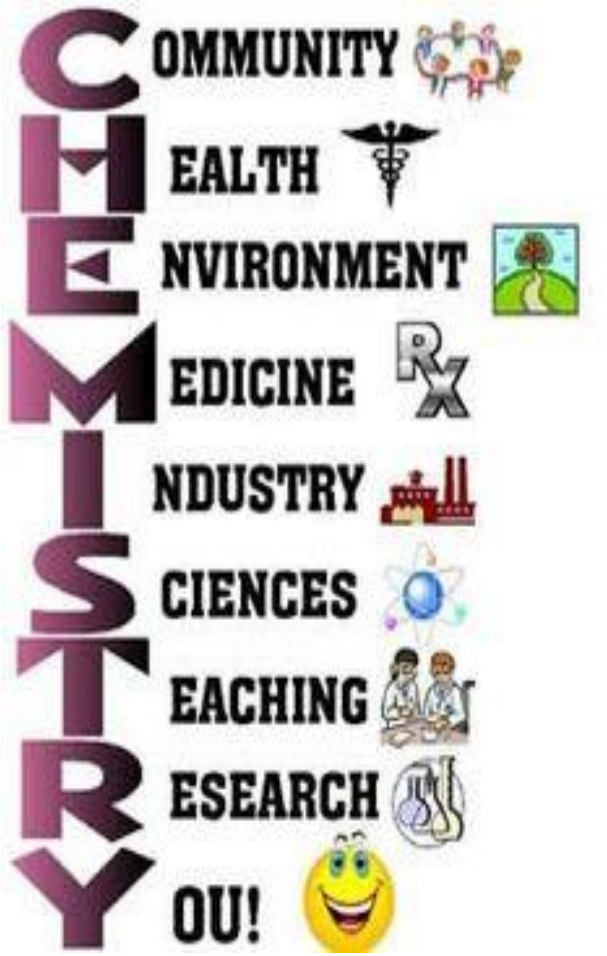
(an appointments should be scheduled prior to office hours by email)

- Attendance Policy:

- Attendance is mandatory for lectures (be on time)
- **University policy:** absence of 25% of classes will result in denial form in the final

- Course grade

- 2 midterm exams, 20 points each (total 40 points)
- 20 points assignments, quiz and attendances
- 40 points final exam



418 Chem.
Bioinorganic Chemistry

Part I : Overview

Dr. Khalid Alrashidi

Outline- Part I

- Introduction
- The inorganic composition of cells
- Terminology
- The biological functions of elements
- Analytical techniques

Bioinorganic Chemistry links **Inorganic Chemistry** to **Biochemistry**, where it:

- Describes the relationship between these two disciplines.
- Discusses the structure and function of inorganic elements, ions, coordination compounds and mineralization in living systems
- Covers the use of inorganics in medicinal fields for therapy and diagnosis.

An interdisciplinary science

Organic chemistry: restricted to carbon compounds

Biochemistry: chemical components of living systems

Inorganic chemistry: no covalent carbon components

Bioinorganic chemistry: biochemical function of "inorganic elements".

Exploitation of chemical properties

- Different elements are taken up selectively by different cells and intercellular compartments.

- The main focus is on metal ions, where we are interested in:

- Their interaction with biological ligands.

- The important chemical properties they are able to exhibit and impart to an organism.

Chemical properties and biological interaction include:

- Ligand binding

The interaction between a metal ion and a ligand (likely and typically organic), which play a role in catalysis, signaling, and structural support.

- Catalysis

The acceleration of a chemical reaction by a catalyst. Metal ions can act as catalysts in a variety of biological reactions, including photosynthesis, respiration, and DNA synthesis.

- Signaling

the process by which cells communicate with each other. Metal ions can play a role in signaling by binding to specific proteins and activating or inhibiting their activity.

- Regulation

The control of biological processes. Metal ions can play a role in regulation by binding to DNA and RNA and affecting gene expression.

- Sensing

The ability of cells to detect changes in their environment. Metal ions can play a role in sensing by binding to specific molecules and triggering a signal transduction pathway.

- Defense

The ability of cells to protect themselves from harmful invaders. Metal ions can play a role in defense by binding to toxins and rendering them harmless.

- structural support.

The provision of physical support for cells and tissues. Metal ions can play a role in structural support by binding to proteins and forming metal-protein complexes.

History

- Bulk inorganic elements have long been known to be essential.
- Blood known to contain iron since 17^{th} century
- Bioinorganic chemistry developed as a field after 1960.
- First inorganic biochemistry symposium in 1970
- Society of Biological Inorganic Chemistry was formed in 1995

Coordination Chemistry

- Central atom is bound to a large number of ligands

- Usually discrete species in solution and solid

- Properties of central atoms (transition metals):

1. Large charge/radius ratio
2. Variable oxidation states
3. Meta-stable high oxidation states, s-electrons are removed first.
4. Compounds are often paramagnetic (unpaired electrons).
5. Formation of colored ions and compounds.

Coordination chemistry

- Compounds with profound catalytic activity.
- Formation of stable complexes (HSAB theory)
- Trend to metal-metal bonding (clusters, not important in biology).

Coordination chemistry

- Properties of ligands
  1. Monodentate: Chloride ion (Cl-)
  2. Polydentate: Ethylenediamine (en)
  3. Ambidentate Thiocyanate ion (SCN-)

  *It can bind to a metal ion through either the sulfur atom or the nitrogen atom

- HSAB theory

The principle of hard and soft acids and bases (HSAB) is used to rationalize observed patterns in complex stability.

HSAB principle

Pearson stated that cations (Lewis acids) and ligands (Lewis bases) were classed as being either ‘hard’ or ‘soft’, hence:

- Hard acids (hard metal cations) form more stable complexes with hard bases (hard ligands)
- Soft acids (soft metal cations) show a preference for soft bases (soft ligands).

Hard vs Soft

The terms ‘hard’ and ‘soft’ acids arise from a description of the polarizabilities of the metal ions.

- Hard acids are typically either small monocations with a relatively high charge density or are highly charged, again with a high charge density. These ions are not very polarizable and show a preference for hard ligands.

- Hard bases with donor atoms that are also not very polarizable

- Soft acids tend to be large monocations with a low charge density, and are very polarizable. They prefer to form coordinate bonds with soft bases.

- Soft bases contain donor atoms that are also highly polarizable.

Note the relationships between the classifications of the ligands and the relative electronegativities of the donor atoms in the series next.

	Ligands (Lewis bases)	Metal centres (Lewis acids)
Hard; class (a)	F^-, Cl^-, H_2O, ROH, R_2O, $[OH]^-$, $[RO]^-$, $[RCO_2]^-$, $[CO_3]^{2-}$, $[NO_3]^-$, $[PO_4]^{3-}$, $[SO_4]^{2-}$, $[ClO_4]^-$, $[ox]^{2-}$, NH_3, RNH_2	Li^+, Na^+, K^+, Rb^+, Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}, Sn^{2+}, Mn^{2+}, Zn^{2+}, Al^{3+}, Ga^{3+}, In^{3+}, Sc^{3+}, Cr^{3+}, Fe^{3+}, Co^{3+}, Y^{3+}, Th^{4+}, Pu^{4+}, Ti^{4+}, Zr^{4+}, $[VO]^{2+}$, $[VO_2]^+$
Soft; class (b)	I^-, H^-, R^-, $[CN]^-$ (*C*-bound), CO (*C*-bound), RNC, RSH, R_2S, $[RS]^-$, $[SCN]^-$ (*S*-bound), R_3P, R_3As, R_3Sb, alkenes, arenes	Zero oxidation state metal centres, Tl^+, Cu^+, Ag^+, Au^+, $[Hg_2]^{2+}$, Hg^{2+}, Cd^{2+}, Pd^{2+}, Pt^{2+}, Tl^{3+}
Intermediate	Br^-, $[N_3]^-$, py, $[SCN]^-$ (*N*-bound), $ArNH_2$, $[NO_2]^-$, $[SO_3]^{2-}$	Pb^{2+}, Fe^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, Os^{2+}, Ru^{3+}, Rh^{3+}, Ir^{3+}

Hard and Soft Acids and Bases

Lowry-Bronstead Concept

- An acid is a proton donor and a base is a proton acceptor.
- Weak acids in solution exists as an equilibrium mixture of the undissociated acid and the ions formed by dissociation.
- In an acid base reaction, the equilibrium is always in favor of the weak acid and weak base.

Hard and Soft Acids and Bases

Lowry-Bronstead Concept

But:

the theory cannot explain features of certain reactions

$$HgCl_2 + H_2S \longrightarrow 2HCl + HgS$$

- The above reaction takes place spontaneously and the reaction is almost complete.

- This means it is in favor of the product side which include a strong acid and a strong base.

- This can be explained by using the ***Hard and Soft Acid Base theory (HSAB theory).***

Hard and Soft Acids and Bases

Hard and Soft Acids and Bases

1965- Ralph Pearson introduced the hard-soft-acid-base (HSAB) principle.

"Hard acids prefer to coordinate the hard bases and soft acids to soft bases"

According to this theory a soft acid will react with a soft base more easily. Similarly a hard acid will react with a hard base.

Hg^{2+} is a ***soft acid*** and ***S^{2-}*** is a ***soft base***. So interaction between these two takes place very easily.

$$HgCl_2 + H_2S \longrightarrow 2HCl + HgS$$

Hard and Soft Acids and Base

- This concept is classified into ***hard***, ***soft*** and ***borderline*** acids bases.
- ***Hard*** acids and bases have a tendency to form ***ionic bonds*** while ***soft*** ones form ***covalent bonds***.
- Interactions between soft acid and soft base or hard acid and hard base are more effective.

- HSAB theory endeavors to help one decide if

$$AB + CD \longrightarrow AC + BD$$

goes to the left or the right

(also helps you to know if AB + CD forms AC + BD or AD + BC)

Hard and Soft Acids and Bases

	Acid (The acceptor atoms)	Base (The donor atoms)
Hard	**Hard acids** and **hard bases** tend to have: • small atomic/ionic radius • high oxidation state • low polarizability • high electronegativity • energy low-lying HOMO (bases) or energy high-lying LUMO (acids). **The affinity of hard acids and hard bases for each other is mainly ionic in nature.*	
Soft	**Soft acids** and **soft bases** tend to have: • large atomic/ionic radius • low or zero oxidation state • high polarizability • low electronegativity • energy high-lying HOMO (bases) and energy-low lying LUMO (acids). *∗The affinity of soft acids and bases for each other is mainly covalent in nature.*	

Hard and Soft Acids and Bases

Acids				Bases			
hard		soft		hard		soft	
Hydronium	H^+	Mercury	CH_3Hg^+, Hg^{2+}, Hg_2^{2+}	Hydroxyl	OH^-	Hydride	H^-
Alkali metals	Li^+,Na^+,K^+	Platinum	Pt^{2+}	Alkoxide	RO^-	Thiolate	RS^-
Titanium	Ti^{4+}	Palladium	Pd^{2+}	Halogens	F^-,Cl^-	Halogens	I^-
Chromium	Cr^{3+},Cr^{6+}	Silver	Ag^+	Ammonia	NH_3	Phosphine	PR_3
Boron trifluoride	BF_3	borane	BH_3	Carboxylate	CH_3COO^-	Thiocyanate	SCN^-
Carbocation	R_3C^+	P-chloranil		Carbonate	CO_3^{2-}	carbon monoxide	CO
		bulk Metals	M^0	Hydrazine	N_2H_4	Benzene	C_6H_6
		Gold	Au^+				

Table 1. Hard and soft acids and bases

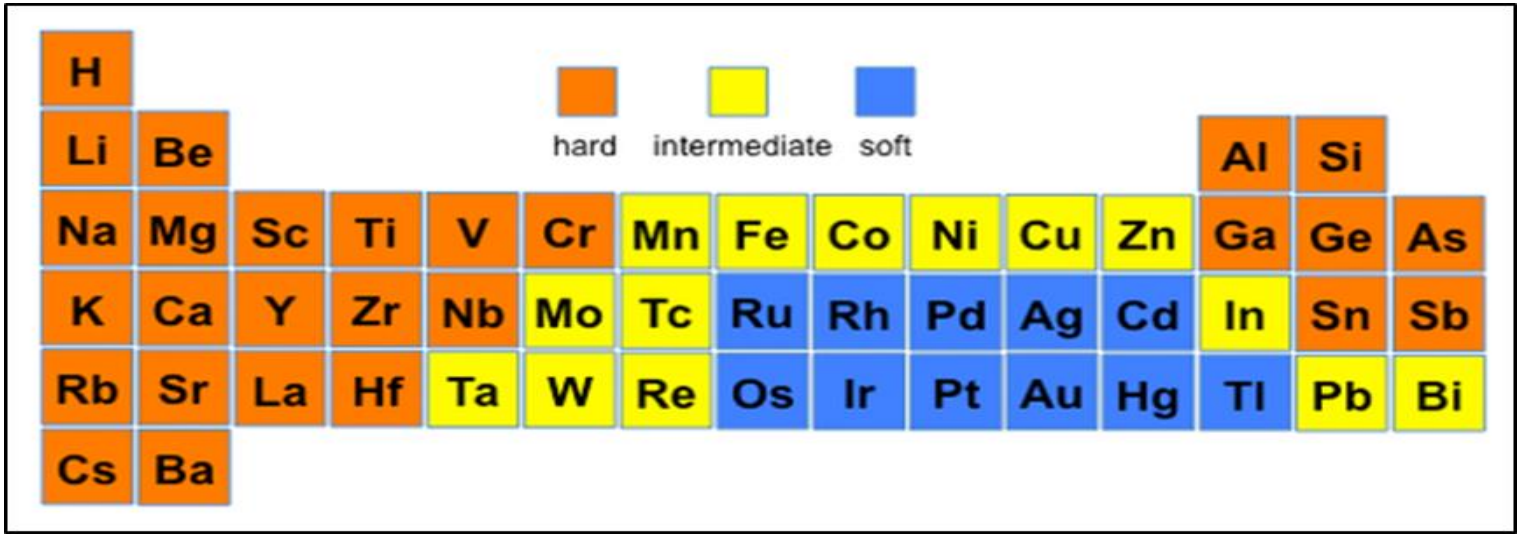
Hard and Soft Acids and Bases

Hard Acids	Borderline	Soft Acids
H^+, Li^+, Na^+, K^+		
Be^{2+}, Mg^{2+}, Ca^{2+}		
BF_3, BCl_3, $B(OR)_3$	BBr_3,$B(CH_3)_3$	BH_3,Tl^+, $Tl(CH_3)_3$
Al^{3+},$Al(CH_3)_3$,$AlCl_3$,AlH_3		
Cr^{3+},Mn^{2+}, Fe^{3+}, Co^{3+}	Fe^{2+},Co^{2+},Ni^{2+}	Cu^+,Ag^+, Au^+,
	Cu^{2+},Zn^{2+},Rh^{3+}	Cd^{2+},Hg_2^{2+},
	Ir^{3+}, Ru^{3+}, Os^{2+}	Hg^{2+}, Pd^{2+},Pt^{2+},
SO_3	SO_2	Pt^{4+}

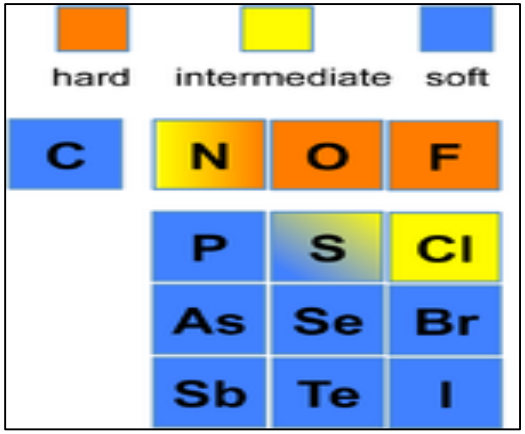
Hard and Soft Acids and Bases

Hard Bases	Borderline	Soft Bases
F^-, Cl^-	Br^-	H^-, I^-
H_2O, OH^-, O^{2-}		H_2S, HS^-, S^{2-}
ROH, RO^-, R_2O, $CH_3CO_2^-$		RSH, RS^-, R_2S
NO_3^-, ClO_4^-	NO_2^-, N_3^-, N_2	SCN^-, CN^-, RNC, CO
CO_3^{2-}, SO_4^{2-}, PO_4^{3-}	SO_3^{2-}	$S_2O_3^{2-}$
NH_3, RNH_2	$C_6H_5NH_2$, pyr	R_3P, C_6H_6

Hard and Soft Acids and Bases



Hard-soft trends for acids



Hard-soft trends for bases

Hard and Soft Acids and Bases

Hard acids (non-metals)	Borderline acids (non-metals)	Soft acids (non-metals)
H^+, $B(OR)_3$, BF_3, BCl_3, RCO^+, CO_2, NC^+, R_3Si^+, Si^{4+}, RPO_2^+, $ROPO_2^+$, As^{3+}, RSO_2^+, $ROSO_2^+$, SO_3, Se^{3+}, Cl^{7+}, I^{7+}, I^{5+}	BR_3, R^+ (softer $CH_3^+ > RCH_2^+ > R_2CH^+ > R_3C^+ >$ vinyl$^+ \approx C_6H_5^+ \approx RC{\equiv}C^+$ harder), RCHO, R_2CO, $R_2C{=}NR$, NO^+, SO_2	BH_3, Ar–Z, C=C–Z, quinones, carbenes, HO^+, RO^+, RS^+, RSe^+, RTe^+, Br_2, Br^+, I_2, I^+
Hard acids (metals)	**Borderline acids (metals)**	**Soft acids (metals)**
Li^+, Na^+, K^+, $BeMe_2$, Be^{2+}, RMgX, Mg^{2+}, Ca^{2+}, Sr^{2+}, $AlCl_3$, $AlMe_3$, AlH_3, $Al(OR)_3$, Al^{3+}, $GaMe_3$, Ga^{3+}, $InMe_3$, In^{3+}, SnR_3^+, $SnMe_2^{2+}$, Sn^{2+}, Sc^{3+}, La^{3+}, $Ti(OR)_4$, Ti^{4+}, Zr^{4+}, VO_2^+, Cr^{3+}, Fe^{3+}, Co^{3+}, Ir^{3+}, Th^{4+}, UO_2^{2+}, Pu^{4+}, Yb^{3+}	GaH_3, $Sn(OR)_4$, $SnCl_4$, Pb^{2+}, Sb^{3+}, Bi^{3+}, $Sc(OTf)_3$, $ScCl_3$, Fe^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, RZn^+, Zn^{2+}, $Yb(OTf)_3$, $YbCl_3$	Cs^+, $TlMe_3$, Tl^+, Tl^{3+}, $Pd(PAr_3)_2$, $Pd(PAr_3)_2^{2+}$, Pd^{2+}, Pt^{2+}, Cu^+, Ag^+, Au^+, CdR^+, Cd^{2+}, HgR^+, Hg^+, Hg^{2+}, M^0
Hard bases	**Borderline bases**	**Soft bases**
NH_3, RNH_2, R_2N^-, N_2H_4, H_2O, OH^-, ROH, RO^-, R_2O, RCO_2^-, CO_3^{2-}, NO_3^-, PO_4^{3-}, SO_4^{2-}, ClO_4^-, F^-, Cl^-	AlH_4^-, N_2, N_3^-, $PhNH_2$, R_3N, C_5H_5N, $R_2C{=}NR$, NO_2^-, SO_3^{2-}, Br^-	H^-, BH_4^-, R^- (softer $RC{\equiv}C^-$ > vinyl$^-$ > R_3C^- harder), C_6H_6, $R_2C{=}CR_2$, $RC{\equiv}CR$, CN^-, RNC, CO, PR_3, $P(OR)_3$, AsR_3, RS^-, SCN^-, RSH, R_2S, $S_2O_3^{2-}$, RSe^-, I^-

Hard and Soft Acids and Bases

Example: a given base, B, may be classified as hard or soft based on the equilibrium:

$$BH^+ + CH_3Hg^+ \rightleftharpoons CH_3HgB^+ + H^+$$

There is a competition here between the acid H^+ and CH_3Hg^+.

- ✓ If B is soft then → to the right
- ✓ If B is hard then ← to the left

- ❖ Important to remember that the listings in the tables do not have a sharp dividing line between them. These terms, "hard" & "soft", are relative.

- ❖ Some are borderline and even though within the same category are not all of the same degree of "hardness" and "softness"

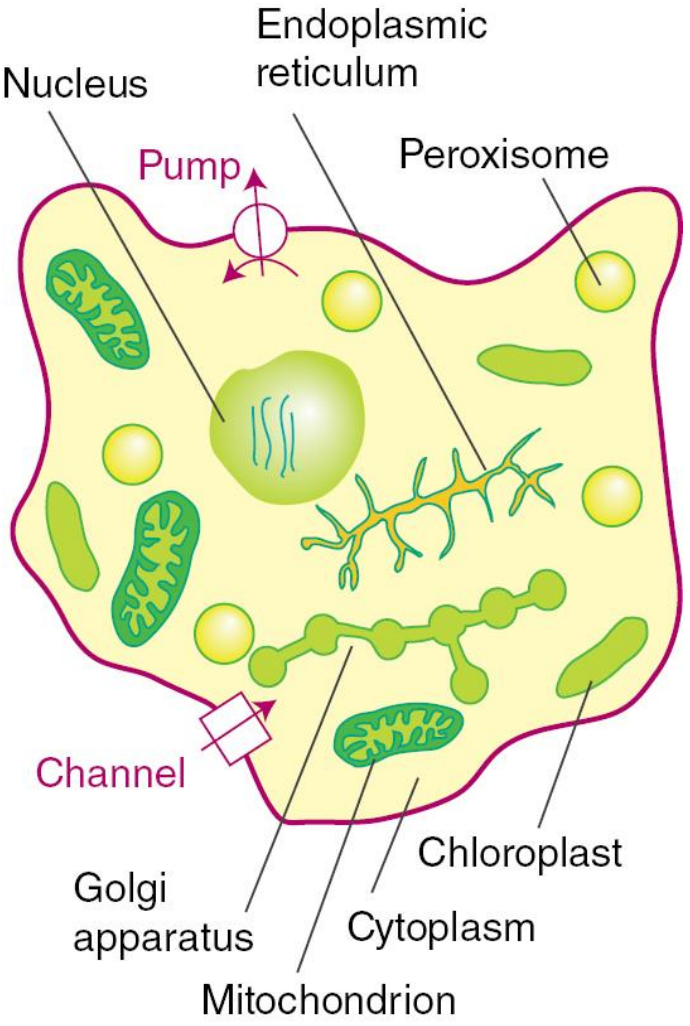
e.g. although all alkali metals in ionic form M^+ are "hard", the larger, more polarizable, Cs^+ ion is much softer than Li^+

Outline- Part I

- Introduction
- The inorganic composition of cells
- Terminology
- The biological functions of elements
- Analytical techniques

The cell

- **The cell** is the basic structural and functional unit of life forms
- Every cell consists of a cytoplasm enclosed within a membrane, and contains many biomolecules such as proteins, DNA and RNA, as well as many small molecules of nutrients and metabolites
- Living cells and organelles are enclosed by membranes.
- The **concentrations** of specific **elements** may vary greatly between different compartments.
- The biologically essential elements can be classified as **trace** or **essential.**



The physical structure of cells

- The cell is the basic unit of any living organism (ranges from complex to simple).

- It is found in prokaryotes (bacteria and bacteria-like) and much larger and more complex examples found in eukaryotes (includes animals and plants).

- Membranes act as **barriers** to water and ions and manage all mobile species and the electrical currents.

The physical structure of cells

- **Membranes are lipid bilayers** (~ 4 nm thick) in which are embedded protein molecules and other components.

- The long hydrocarbon chains of lipids make the membrane interior very hydrophobic and impermeable to ions, which must instead travel through specific **channels**, **pumps**, and other receptors.

- The structure of a cell also depends on osmotic pressure, which is maintained by high concentrations of solutes, including ions, imported during active transport by pumps.

The Elements of life

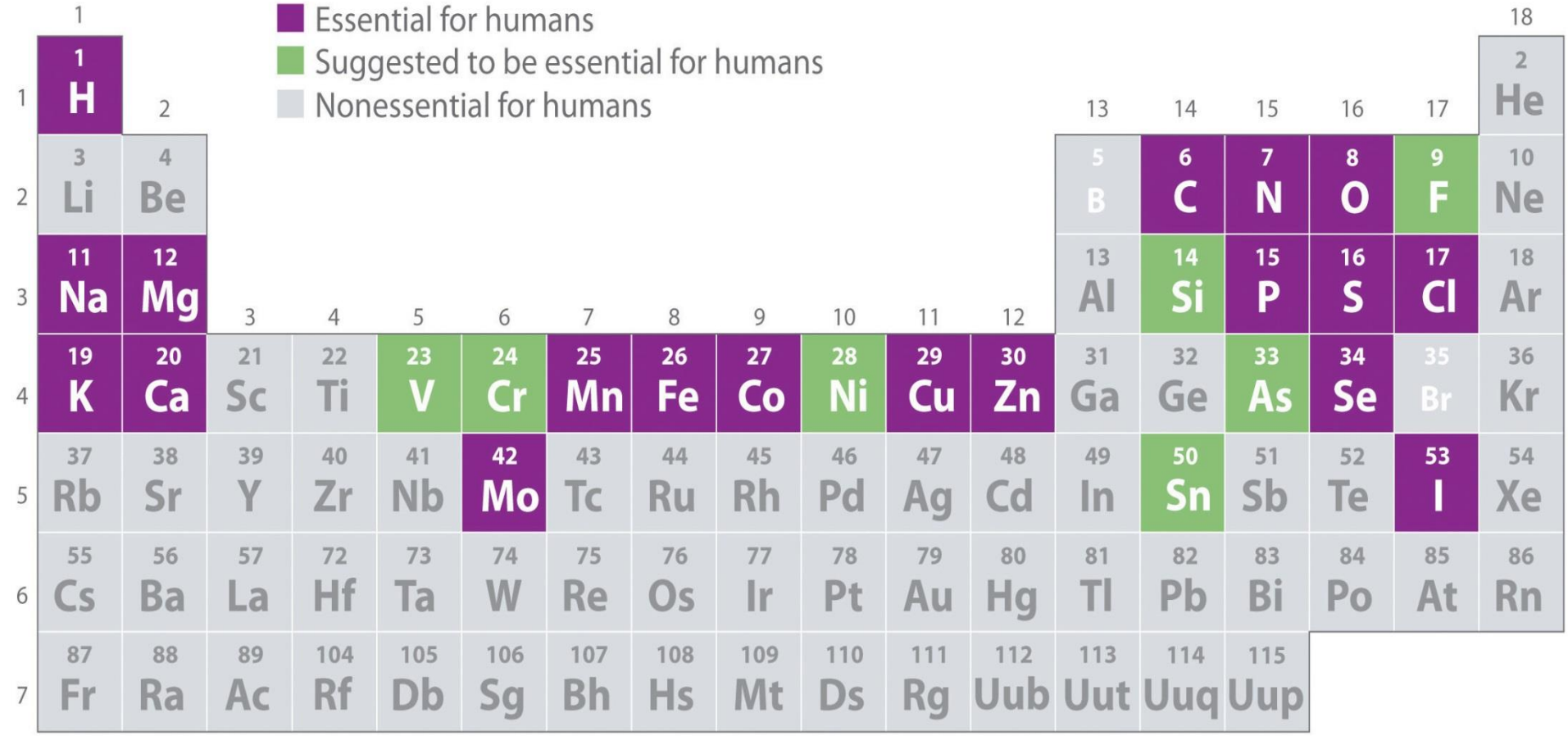
- **Essential Elements**

➢ C, H, N O, P and S are the **fundamental essential** elements that make up the building blocks of biomolecules.

➢ **Less abundant**, **essential** elements are Na, K, Cl, Mg and Ca.

- **Trace elements** are V, Cr, Mn, Fe, Co, Ni, Cu, Zn Mo (metals), and B, Si, Se, F, I (non-metals)

The periodic table of life



Compartmentalization

- Compartmentalization Is the distribution of elements inside and outside a cell and between different internal compartments.

- Different elements are strongly segregated inside and outside a cell and among different internal compartments

- The maintenance of constant ion levels in different biological zones is achieved by ***membranes being barriers to passive ion flow.***

Compartmentalization

Two important issues arise in the context of compartmentalization.

1. The process **requires energy** (ions must be pumped against an adverse gradient of chemical potential), and once a concentration difference has been established, there is a difference in electrical potential across the membrane dividing the two regions.

Compartmentalization

2. The selective transport of ions must occur through **ion channels** built from membrane-spanning proteins:

- Some release ions on receipt of an electrical or chemical signal.

- Others, the **transporters** and **pumps**, transfer ions against the concentration gradient by using energy provided by ATP (energy compound) hydrolysis.

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Some new terms

[GLOSSARY OF TERMS USED IN BIOINORGANIC CHEMISTRY, IUPAC]

- **Binding site:**

A specific region (or atom) in a molecular entity capable of entering into a stabilizing interaction with another molecular entity (e.g. **an *active site*** in an ***enzyme*** with its ***substrate).*** Typical forms of interaction are by:

- hydrogen bonding
- *coordination*
- ion pair formation

Some new terms

- **Biomass:** Material produced by the growth of micro-organisms, plants or animals

- **Biomineralization:** The synthesis of inorganic crystalline or amorphous mineral-like materials by living organisms. For example: bones formation of calcium carbonate (bones) as protective shells. iron oxide to store Iron in animal cells,

- **Biopolymers:** Macromolecules (including proteins, ***nucleic acids*** and polysaccharides) formed by living organisms.

Some new terms

- **Biosensor:** A device that uses specific biochemical reactions to detect chemical compounds, usually by electrical, thermal or optical signals.

- **Chelation therapy:** using ***chelating*** agents to remove toxic amounts of metal ions from living organisms such as heavy metals (lead, Arsenic, mercury, iron, Copper, nickel).

- **Coenzyme:** A low-molecular-weight, non-protein organic compound participating in ***enzymatic*** reactions.

Some new terms

- **Cofactor:** An organic molecule or ion (usually a metal ion) that is required by an ***enzyme*** for its activity, and may be attached either loosely ***(coenzyme)*** or tightly ***(prosthetic*** group).

- **Contrast agent:** ***Paramagnetic*** (or ***ferromagnetic)*** metal complex or particle causing a decrease in the relaxation times of nuclei detected in an ***image***.

Some new terms

- **Cooperativity:** The phenomenon that binding of a species to a biological system either enhances or diminishes the binding of a successive molecule, of the same or different kind, to the same system.

- **Element abundance** : a large amount of the element.

Some new terms

- **Enzyme:** A macromolecule that functions as a ***biocatalyst*** by increasing the reaction rate, frequently containing or requiring one or more metal ions.

- **Ion channel:** enable ions to flow rapidly through membranes in a thermodynamically **downhill** direction after an electrical or chemical impulse.

Some new terms

- **Ion pumps:** enable ions to flow through membranes in a thermodynamically **uphill** direction by the use of an energy source such as ***ATP*** or light.

- **Metalloenzyme:** **a**n ***enzyme*** that, in the active state, contains one or more metal ions which are essential for its biological function.

- **Zwitterionic compound:** A neutral compound having electrical charges of opposite sign, delocalized or not, on adjacent or nonadjacent atoms. like amino acid or water

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The roles of elements

➢ The Essential elements

1. Fundamental essential

- (C, H, N and O) make up the building blocks of biomolecules (e.g. amino acids, peptides, carbohydrates, proteins, lipids and nucleic acids).
- P is playing its part (e.g., in ATP and DNA)
- S is being the key to the coordinating abilities of cysteine residues in proteins.

The roles of elements

2. The less abundant

but essential- elements include:

- osmotic control and nerve action (Na, K and Cl),
- Mg^{2+} in chlorophyll Mg^{2+}-containing enzymes involved in phosphate hydrolysis,
- structural functions of Ca^{2+} (e.g. bones, teeth, shells) and triggering actions of Ca^{2+} (e.g. in muscles).

The roles of elements

➢ The trace metals

Which are important to life and can be summarized as follows:

- V: Enzymes (nitrogenases , haloperoxidases)
- Cr: may be essential in glucose metabolism in higher mammals.
- Mn: Enzymes (phosphatase, mitochondrial superoxide dismutase, glycosyl transferase); photoredox activity in Photosystem II
- Co: Vitamin B12 coenzyme.

The roles of elements

- Fe: Electron-transfer systems; O^{2-} storage and transport; Fe storage and transport; in enzymes (e.g. nitrogenases, hydrogenases).
- Ni: Enzymes (urease, some hydrogenases).
- Cu: Electron transfer systems; O^{2} storage and transport; transport proteins.
- Zn: Acts as a Lewis acid (e.g. in hydrolysis processes); structural roles.
- Mo: Enzymes (nitrogenases, reductases, hydroxylases)

Concentrations of some elements in different biological zones

Element	External fluids (seawater)	Free ions in external fluids (blood plasma)	Cytoplasm (free ions)	Comments on status in cell
Na	$>10^{-1}$	10^{-1}	$<10^{-2}$	Not bound
K	10^{-2}	4×10^{-3}	$\leq 3\times10^{-1}$	Not bound
Mg	$>10^{-2}$	10^{-3}	c.10^{-3}	Weakly bound as ATP complex
Ca	$>10^{-3}$	10^{-3}	c.10^{-7}	Concentrated in some vesicles
Cl	10^{-1}	10^{-1}	10^{-2}	Not bound
Fe	10^{-17} (Fe(III))	10^{-16} (Fe (III))	$<10^{-7}$ (Fe(II))	Too much unbound Fe is toxic (Fenton chemistry) in and out of cells
Zn	$<10^{-8}$	10^{-9}	$< 10^{-11}$	Totally bound, but may be exchangeable
Cu	$<10^{-10}$ (Cu(II))	10^{-12}	$<10^{-15}$ (Cu(I))	Totally bound, not mobile; mostly outside cytoplasm
Mn	10^{-9}		c.10^{-6}	Higher in chloroplasts and vesicles
Co	10^{-11}		$< 10^{-9}$	Totally bound (cobalamin)
Ni	10^{-9}		$< 10^{-10}$	Totally bound
Mo	10^{-7}		$< 10^{-7}$	Mostly bound

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Analytical Techniques

Common physical methods adopted in bioinorganic chemistry are:

- X-ray crystallography:

  X-ray absorption (XAS) with 3 regions:

  - **near-edge region:** the chemical bonding and oxidation state of the atoms in the material
  - **Absorption Fine Structure (EXAFS):** distances between atoms and the coordination numbers of the atoms.
  - **X-ray absorption Near Edge Structure (XANES):** valence electrons of the atoms in the material

- Magnetic Resonance

  - **Electron paramagnetic resonance (EPR)**
  - **Nuclear magnetic resonance (NMR)**

Analytical techniques

- Mössbauer (MB): It is used to study the structure, dynamics, and chemical bonding of materials.
- Optical Spectroscopy: Optical spectroscopy works by shining light on a sample and measuring the way the light is absorbed or emitted by the sample.
  - **Electronic absorption (UV-vis)**
  - **Circular dichroism (CD)**
  - **Magnetic circular dichroism (MCD)**
  - **Luminescence (fluorescence & phosphorescence)**
  - **Infrared (IR)**
  - **Resonance Raman (RR)**
- Electrochemistry: Relationship between electricity and chemical reactions.

Analytical techniques- What do they tell?

- **IR and Resonance Raman spectroscopy**

- Increasingly used in bioinorganic chemistry for characterization and assignment of vibrations directly connected with the species of interest.

- Information on functional groups, bond length, binding metal, etc., can be elucidated.

Analytical techniques

- **Extended X-ray absorption fine structure (EXAFS)**

Arise of electron scattering by atoms surrounding a particular atom of interest as it absorbs X-rays and emits electrons.

This technique is a probe of the local structure.

Bond lengths and local symmetry, *coordination* numbers, … may be derived

Analytical techniques

- **Nuclear magnetic resonance (NMR) spectroscopy**

NMR spectroscopy makes it possible to discriminate nuclei, typically protons, in different chemical environments.

Structural information can be obtained about a paramagnetic site in proteins.

Analytical techniques

- **Magnetic resonance imaging (MRI)**

The visualization of the distribution of nuclear spins (usually water) in a body by using a magnetic field gradient.

It is NMR imaging that create detailed image of the body.

Analytical techniques

- **Mössbauer effect**

Resonance absorption of gamma radiation by specific nuclei arranged in a crystal lattice in such a way that the recoil momentum is shared by many atoms.

Studies ***coordinated*** metal ions; in bioinorganic chemistry mostly studied is ^{57}Fe nucleus, and provides information about the oxidation, spin and ***coordination*** state of the iron.