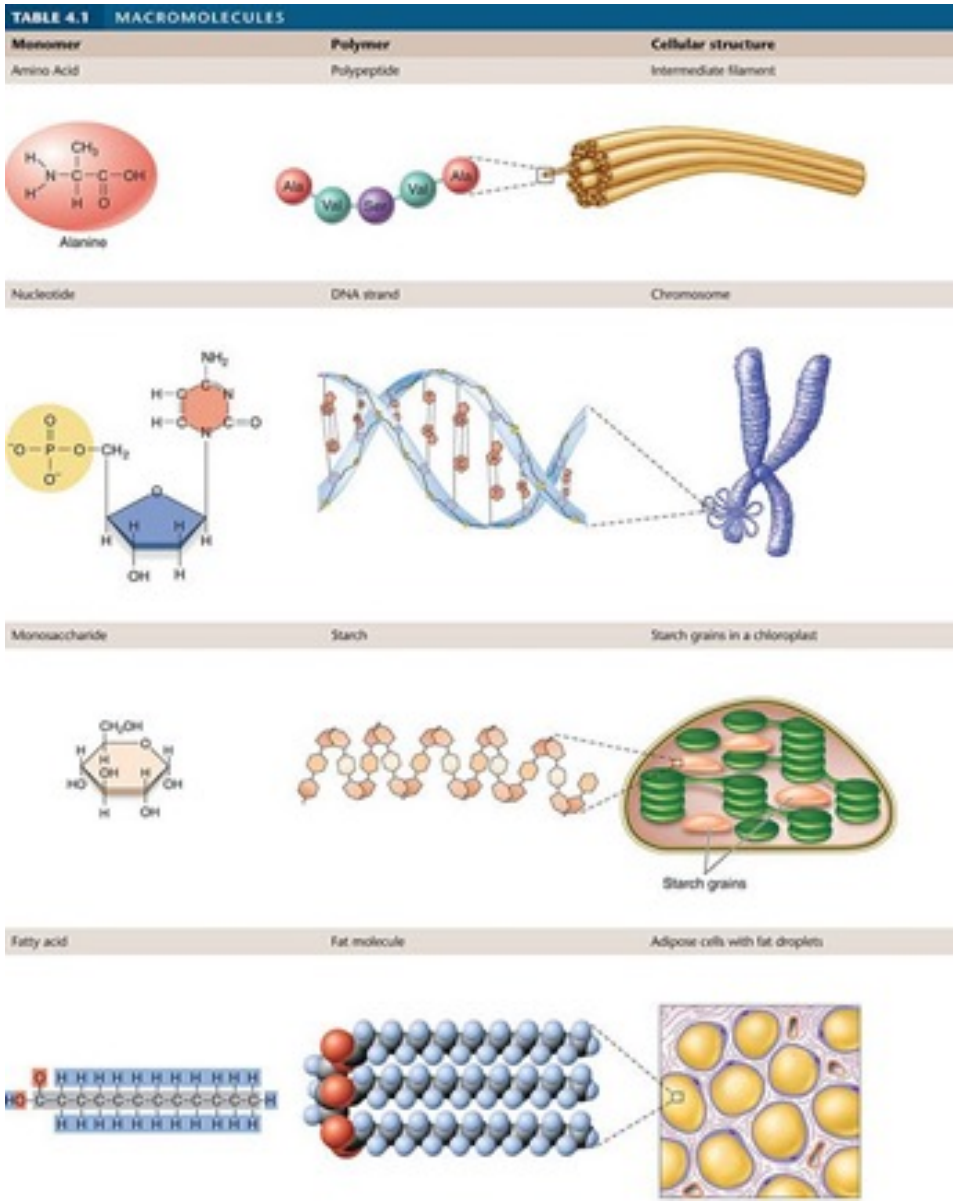
Some Basic Chemistry: Elements and Compounds

Dr Joanna Ho
joannaho@hku.hk
School of Biomedical Sciences
LKS Faculty of Medicine
HKU

Elements for life



You could start really small...
- Particles of matter
- Atoms
→ - Elements
→ - Molecules
→ - Macromolecules
→ - Cell organelles
- Cells
- Tissues
- Organs
- Systems
- Organisms
- Populations
- Ecosystems
- Biospheres
- Planets
- Planetary Systems with Stars
- Galaxies
- The Universe
.And finish really big.

https://www.youtube.com/watch?v=0fKBhvDjuy0

- Learning Objectives
  - *Explain* the anatomy of an atom.
    - Know the general structure of an atom
    - Understand the meaning of relative atomic weight, in that an atom may have isotopes.
  - *Recognise* the elements of life.
    - List the four common elements of life
    - Aware the other less common and trace elements of life
  - *Show* different types of chemical bonds.
    - Know Ionic bonds / covalent bonds / hydrogen bonds
    - Aware of the term electronegativity
  - *Illustrate* how atoms are organized into molecules.
    - Know the terms of cations and anions
    - Understand van der waals interaction / hydrophobic force
    - Know about different molecular states

From atoms to molecules

Atom is

- a unit of matter,
- the smallest component of an element,
- shares the chemical properties of the element,
- has a nucleus (with neutrons, protons) and electrons.

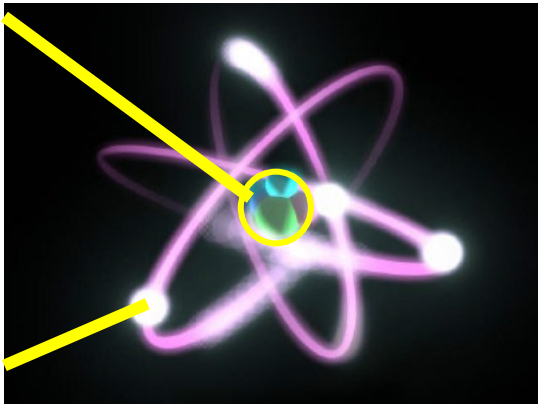
Element is

- a substance that cannot be broken down into simpler substances by chemical means,
- it is composed of atoms having an identical number of protons in each nucleus,
- today 117 elements are known, of which 92 are known to occur in nature,

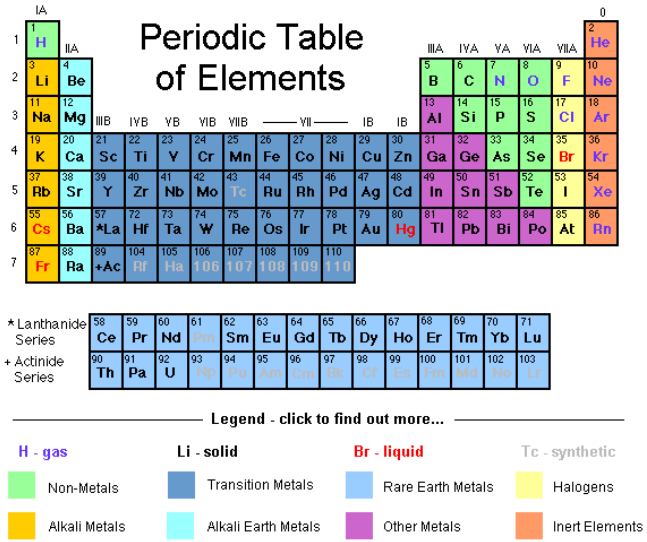
ATOM

nucleus [protons (+) and neutrons]

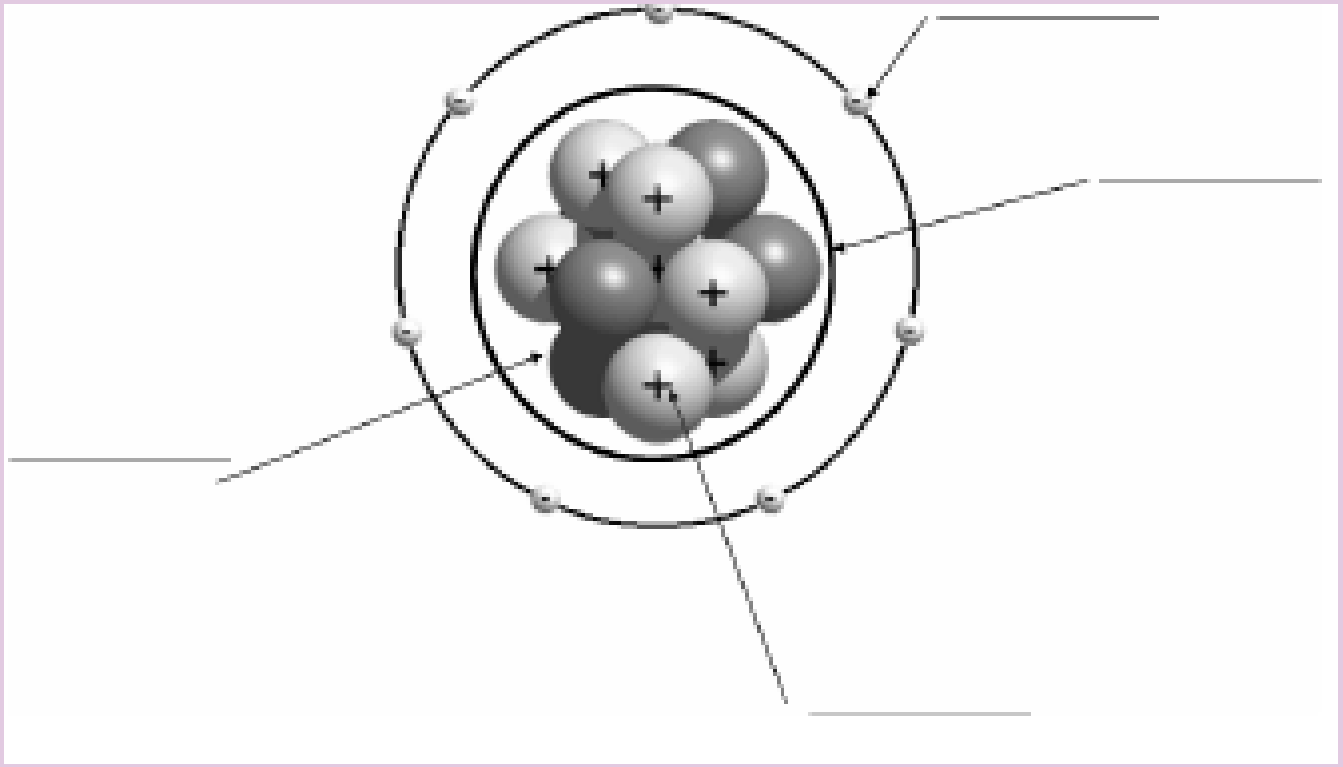
electrons (-)



e.g. hydrogen and oxygen are examples of element that have an atom



Anatomy of an atom



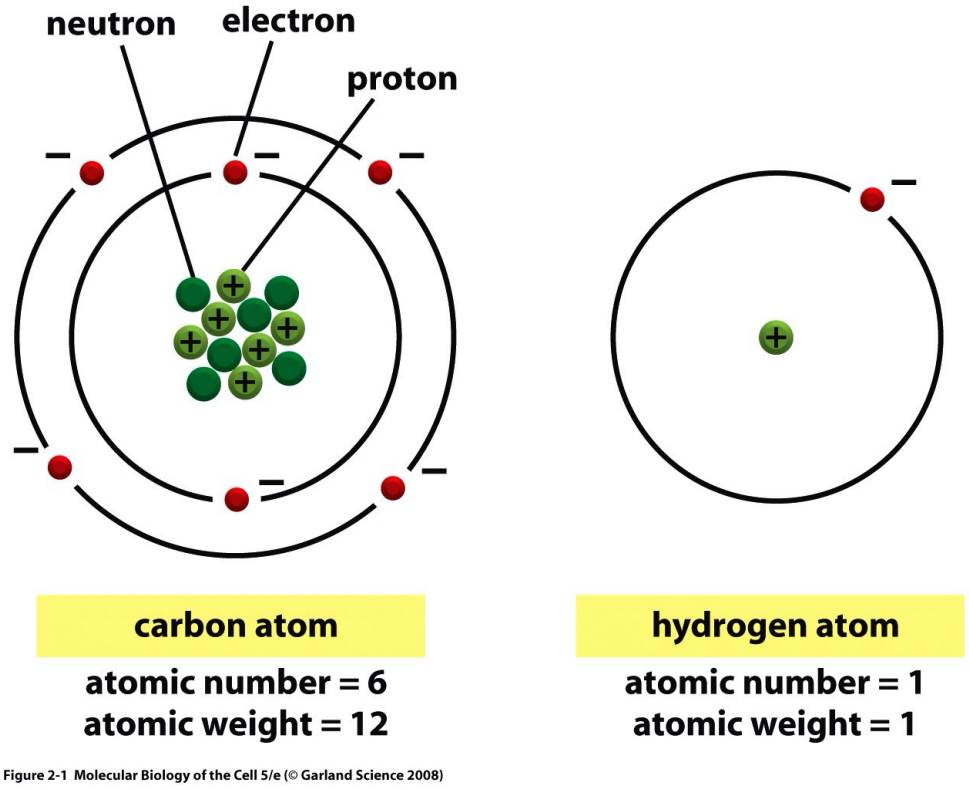


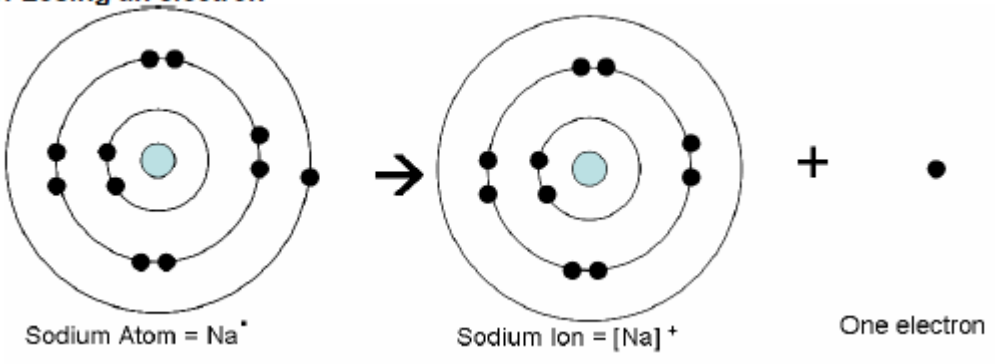
Figure 2-1 Molecular Biology of the Cell 5/e (© Garland Science 2008)

Atomic number:
The number of protons in the nucleus of an atom of an element.

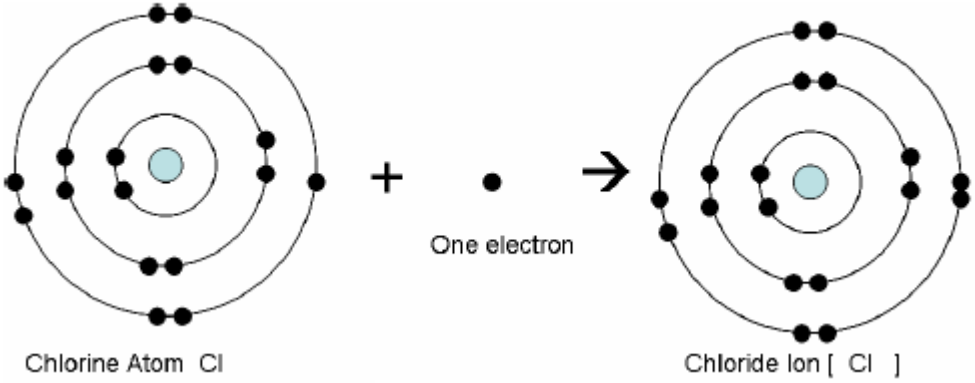
Atomic weight:
The average mass of an atom of an element, usually expressed relative to the atomic mass of carbon 12.

- Protons are positively charged and in the nucleus of the atom
- Neutrons are uncharged in the nucleus of the atom
- Electrons are negatively charged and in orbitals around the nucleus

Case 1: Losing an electron



Case 2: Gaining an electron



Types of Bonds:

1. **Ionic bond** = form between a metal and a non-metal and have opposite charges. (I.e. sodium and chloride ions). They generally form **compounds**.
2. **Metallic bond** = form when metal atoms share their pooled electrons (i.e. silver atoms)
3. **Covalent Bond** = form between non-metals when they shared electrons. (Cl_2 – chlorine molecule, or SO_3 – sulfur trioxide). They generally form **molecules.**

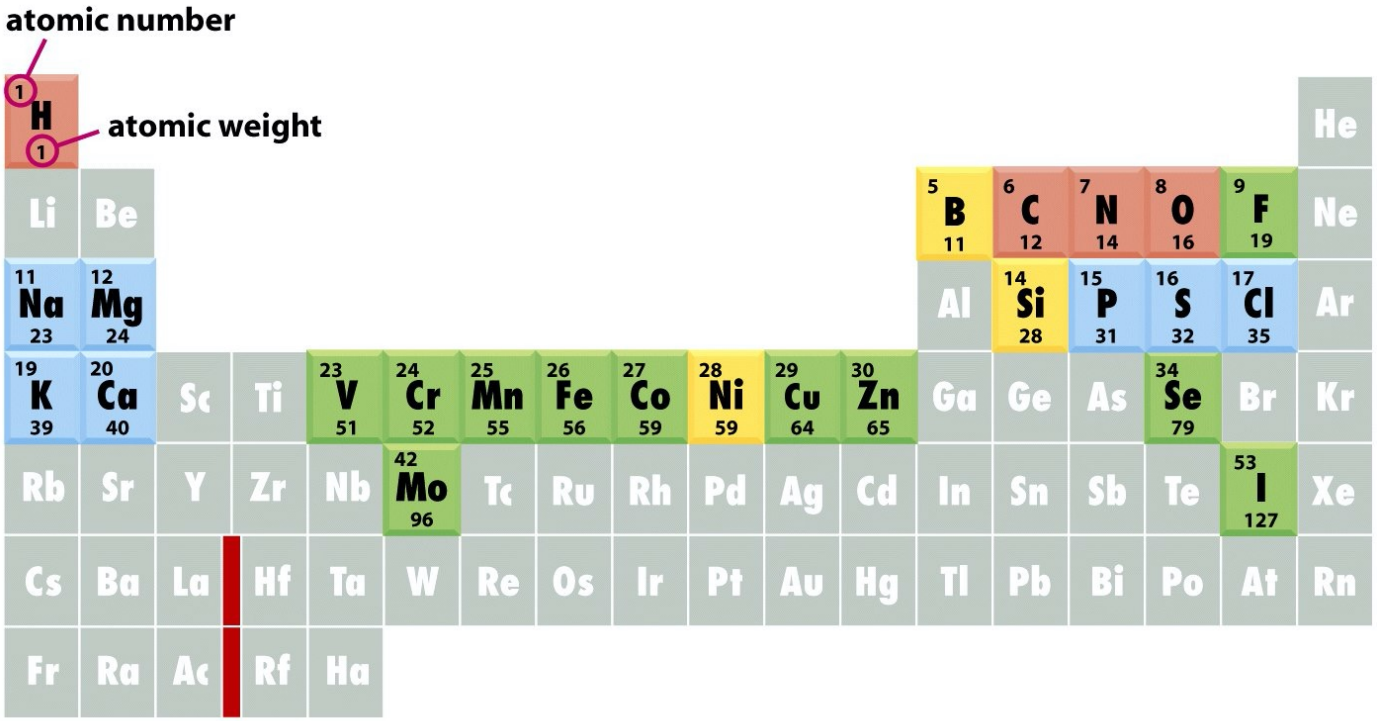


Figure 2-6 Molecular Biology of the Cell 5/e (© Garland Science 2008)

Common

Hydrogen (H)
Carbon (C)
Nitrogen (N)
Oxygen (O)

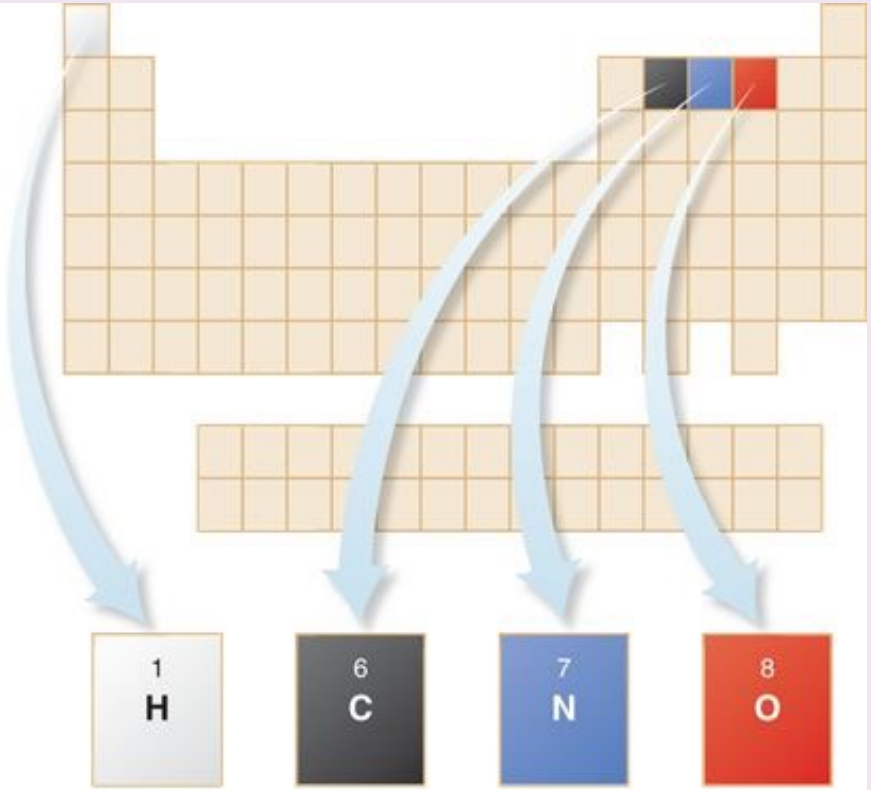
Less common

Sodium (Na)
Magnesium (Mg)
Phosphorus (P)
Sulphur (S)
Chloride (Cl)
Potassium (K)
Calcium (Ca)

Trace

Fluorine (F)
Vanadium (V)
Chromium (Cr)
Manganese (Mn)
Iron (Fe)
Cobalt (Co)
Copper (Cu)
Zinc (Zn)
Selenium (Se)
Molybdenum (Mo)
Iodine (I)

caffeine
($C_8H_{10}N_4O_2$)



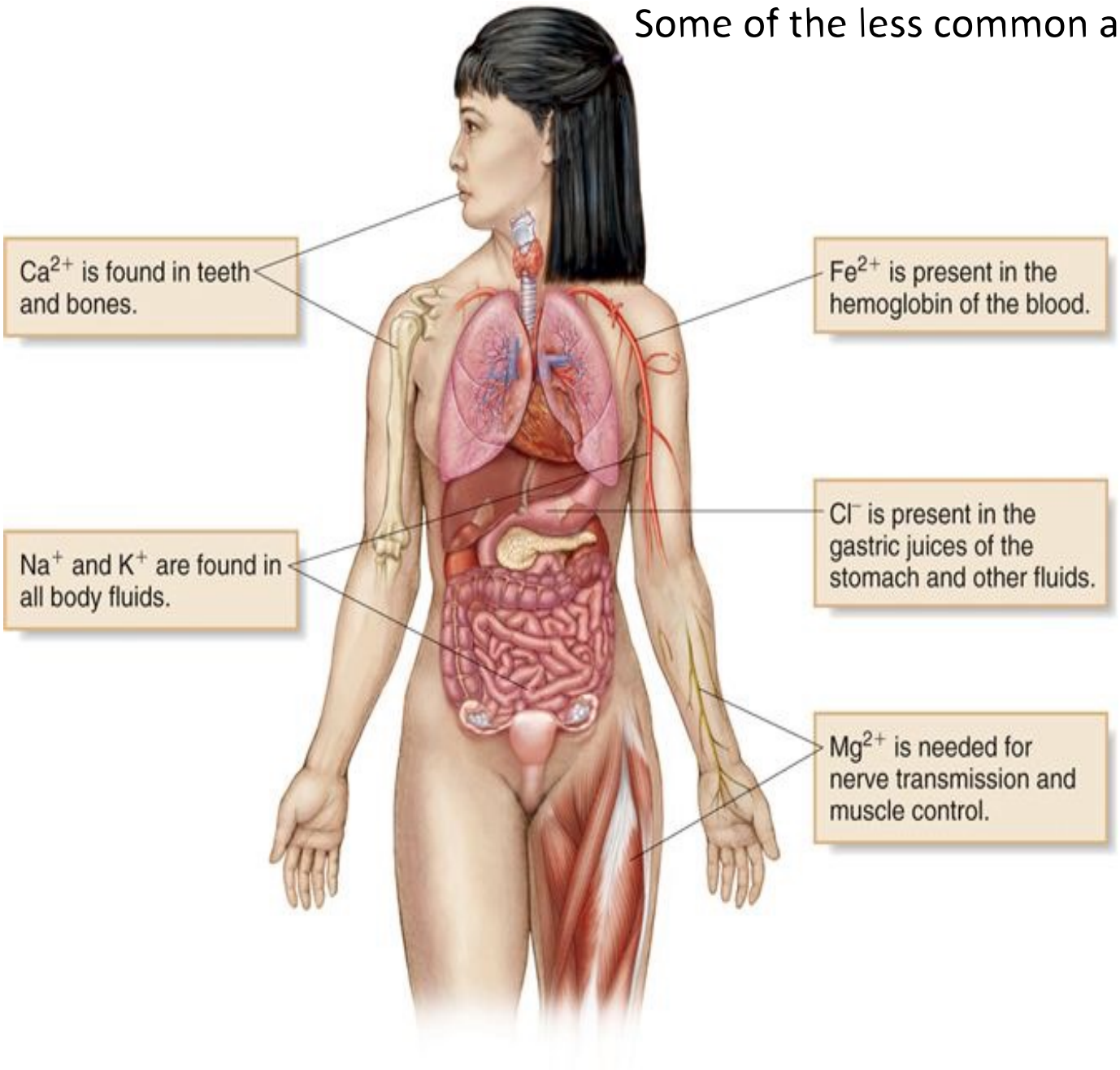
Element	Hydrogen	Carbon	Nitrogen	Oxygen
Atomic number	1	6	7	8
Mass number	1	12	14	16
Number of protons	1	6	7	8
Number of electrons	1	6	7	8
Number of neutrons	0	6	7	8

Atomic composition of four building-block elements

- **Carbon (C)**
  - Form backbones of organic molecules; can form four bonds with other atoms
- **Nitrogen (N)**
  - Component of all proteins and nucleic acids
- **Oxygen (O)**
  - For cellular respiration; found in most organic compound, eg. food stuff
- **Hydrogen (H)**
  - Present in all organic compounds; maintain acid-base balance

Elements that make up the human body

Some of the less common and trace elements



Elements that make up the human body

- **Sodium (Na)**
  - Major positive ions in tissue fluid; vital in fluid balance; vital for conduction of nerve impulses
- **Magnesium (Mg)**
  - Needed in blood and other body tissues; vital as a co-enzyme
- **Phosphorus (P)**
  - Part of nucleic acids; structural part of bone and cell walls; vital in energy transfer
- **Sulpur (S)**
  - Part of most proteins; activation of enzymes
- **Chlorine (Cl)**
  - Major negative ion in tissue fluid; vital for fluid balance; part of NaCl and gastric juice
- **Potassium (K)**
  - Major positive ion within the cells; vital in nerve function; affect muscle contraction, fluid and electrolyte balance
- **Calcium (Ca)**
  - Structural component of bones and teeth; acid-base balance; vital in muscle contraction; conduction of nerve impluses and blood clotting

Approx. composition by weight

- O 65%
- C 18%
- H 10%
- N 3%
- Common elements

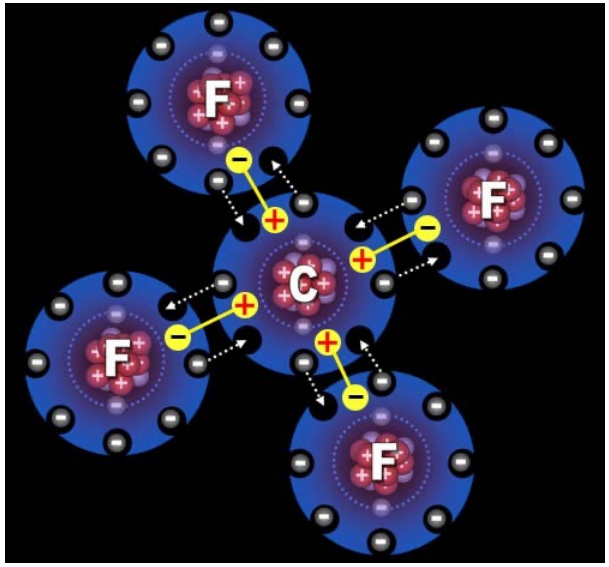
- Ca 1.5%
- P 1%
- K 0.4%
- S 0.3%
- Na 0.2%
- Mg 0.1%
- Cl 0.1%
- Less common elements

The trace Elements in the human body

- **Fluorine (F)**
  - Incorporated into the tooth enamel, and into bone structure
- **Vanadium (V)**
  - *In vitro* and animal studies suggest in function as an oxidation-reduction catalyst, and may regulate the sodium, potassium and adenosine triphosphatase enzyme, however, this has not been proven.
- **Chromium (Cr)**
  - Helps to maintain blood sugar level by assisting insulin to uptake of glucose into cells
- **Manganese (Mn)**
  - It is a co-factor for many several enzymes, found mostly in liver and kidney, and specifically in mitochondria
- **Iron (Fe)**
  - Component of hemoglobin and myoglobin; and certain enzymes
- **Cobalt (Co)**
  - It is part of vitamin B12, which is required for maturation of red blood cells (erythrocytes)

The trace Elements in the human body

- **Copper (Cu)**
  - It is part of several enzymes used for oxidation
- **Zinc (Zn)**
  - It is part of many enzymes; needed in saliva for the taste buds development; vital for growth, sexual development and taste awareness, also has roles in protein synthesis and cell division
- **Selenium (Se)**
  - It is believed to be closely linked to function of vitamin E; part of the glutathione peroxidase, which removes hydrogen peroxide and organic peroxides
- **Molybdenum (Mo)**
  - Part of some enzymes, has similar functions to copper, ie oxidation
- **Iodine (I)**
  - Part of the thyroid hormones



How do atoms hold together?

- The answer is by chemical bonds
- These bonds is all about how the outer shell of electrons of an atom interact with the electrons of another atom.

https://www.youtube.com/watch?v=_M9khs87xQ8

CHEMICAL BONDS FOR MOLECULES

- Covalent bonds happen when two atoms **share** electrons - kind of like 2 atoms holding hands. When at least 2 atoms get together by sharing electrons, they form a *molecule*.

- Four types of non-covalent interactions to bring molecules together in a cell
    i. Ionic bonds
    ii. Hydrogen bonds
    iii. van der Waals attraction
    iv. Hydrophobic force

http://www.yellowtang.org/animations/bond_types.swf

Chemical bonds for molecules

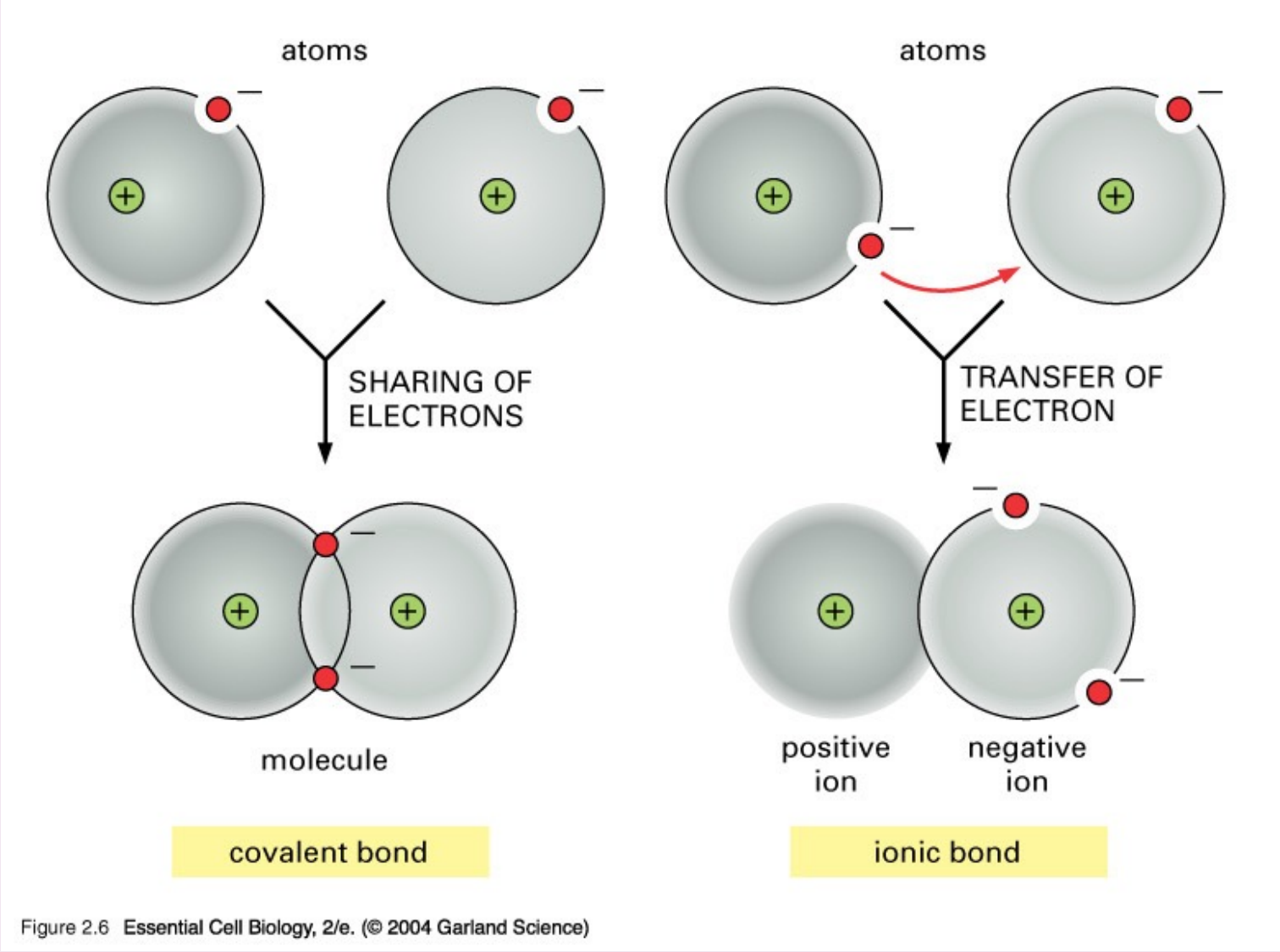
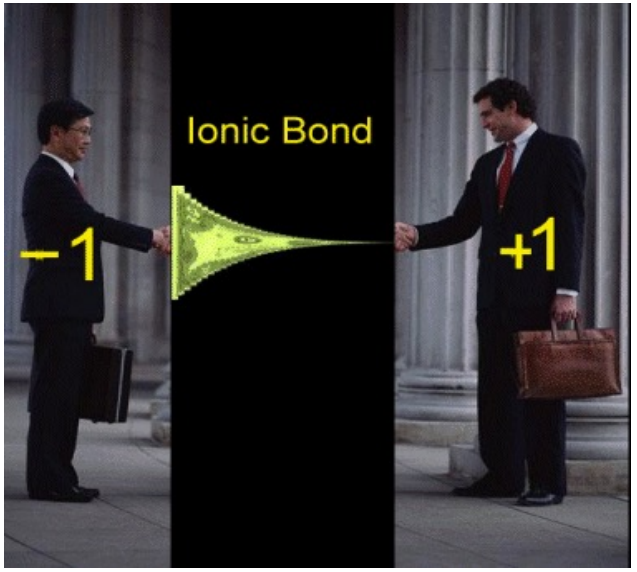


Figure 2.6 Essential Cell Biology, 2/e. (© 2004 Garland Science)

Chemical bonds for molecules



- *Electronegativity* is a measure of an atom's attraction for electrons in a bond.
- Electronegativity tells us how much a particular atom "*wants*" electrons.

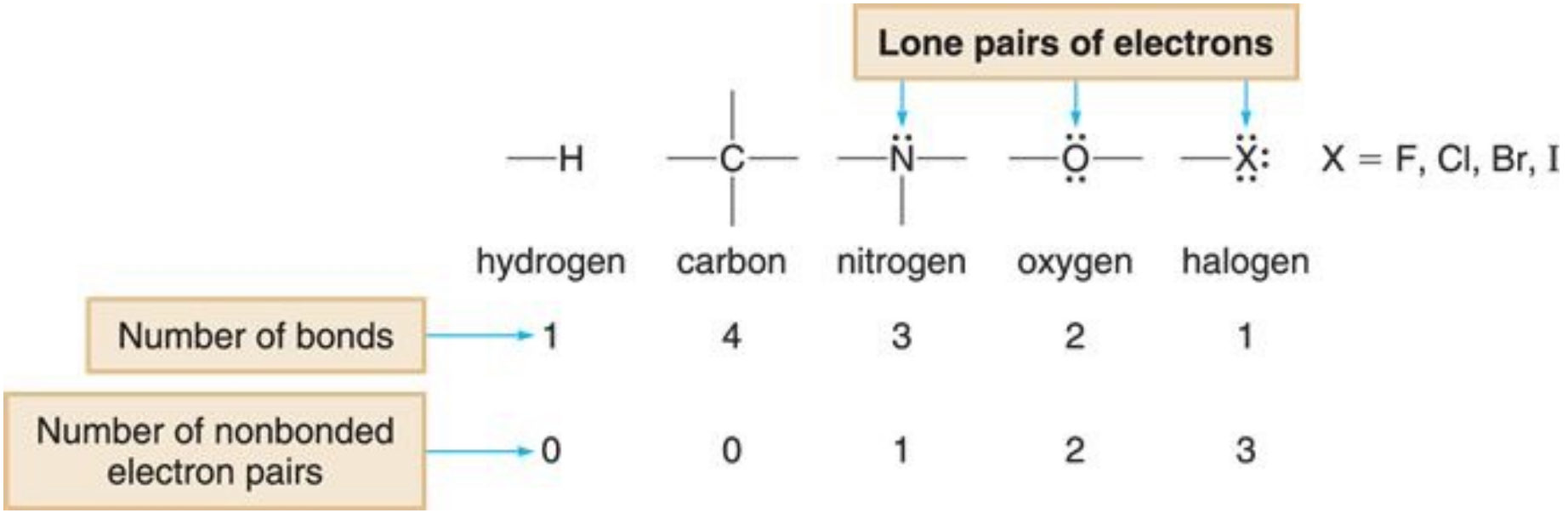
- The symbol δ^+ is given to the less electronegative atom.
- The symbol δ^- is given to the more electronegative atom.

Covalent bonds and covalent compounds

Covalent bonds

Electronegativity Difference and Bond Type

Electronegativity Difference	**Bond Type**	**Electron Sharing**
Less than 0.5 units	Nonpolar	Electrons are equally shared.
0.5–1.9 units	Polar covalent	Electrons are unequally shared; they are pulled towards the more electronegative element.
Greater than 1.9 units	Ionic	Electrons are transferred from the less electronegative element to the more electronegative element.



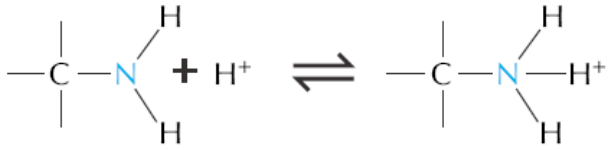
Covalent bonds

Commonly seen C-N chemical groups in biochemistry

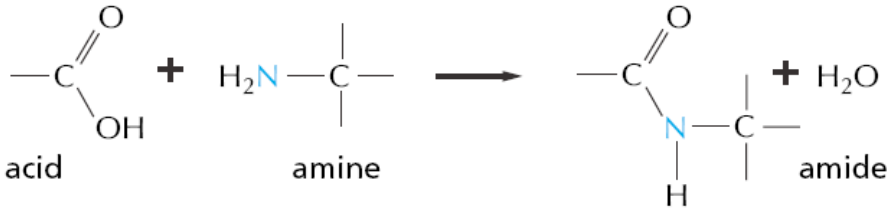
C–N CHEMICAL GROUPS

Amines and amides are two important examples of compounds containing a carbon linked to a nitrogen.

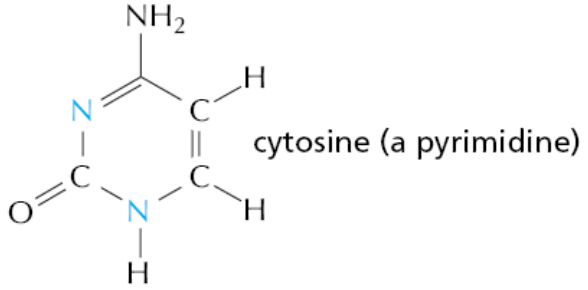
Amines in water combine with an H^+ ion to become positively charged.



Amides are formed by combining an acid and an amine. Unlike amines, amides are uncharged in water. An example is the peptide bond that joins amino acids in a protein.

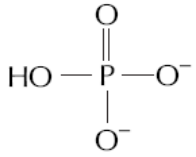


Nitrogen also occurs in several ring compounds, including important constituents of nucleic acids: purines and pyrimidines.

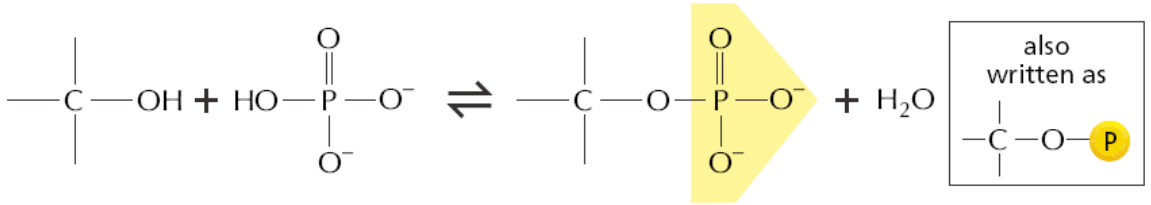


Commonly seen phosphate groups in biochemistry

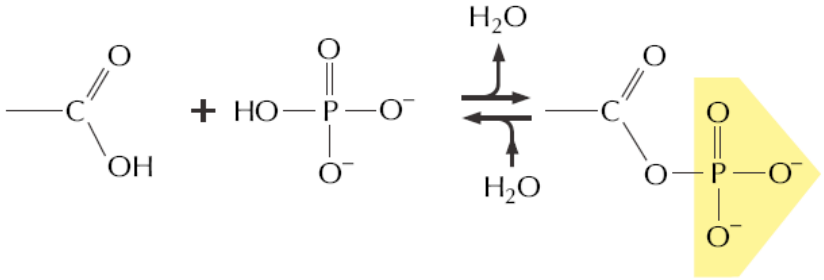
Inorganic phosphate is a stable ion formed from phosphoric acid, H_3PO_4. It is often written as P_i.



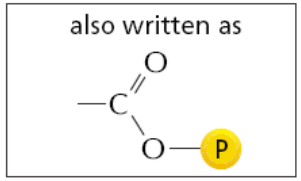
Phosphate esters can form between a phosphate and a free hydroxyl group. Phosphate groups are often attached to proteins in this way.

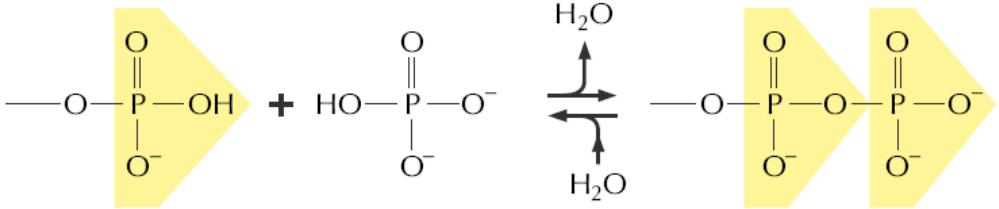


The combination of a phosphate and a carboxyl group, or two or more phosphate groups, gives an acid anhydride.

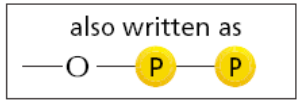


high-energy acyl phosphate bond (carboxylic–phosphoric acid anhydride) found in some metabolites

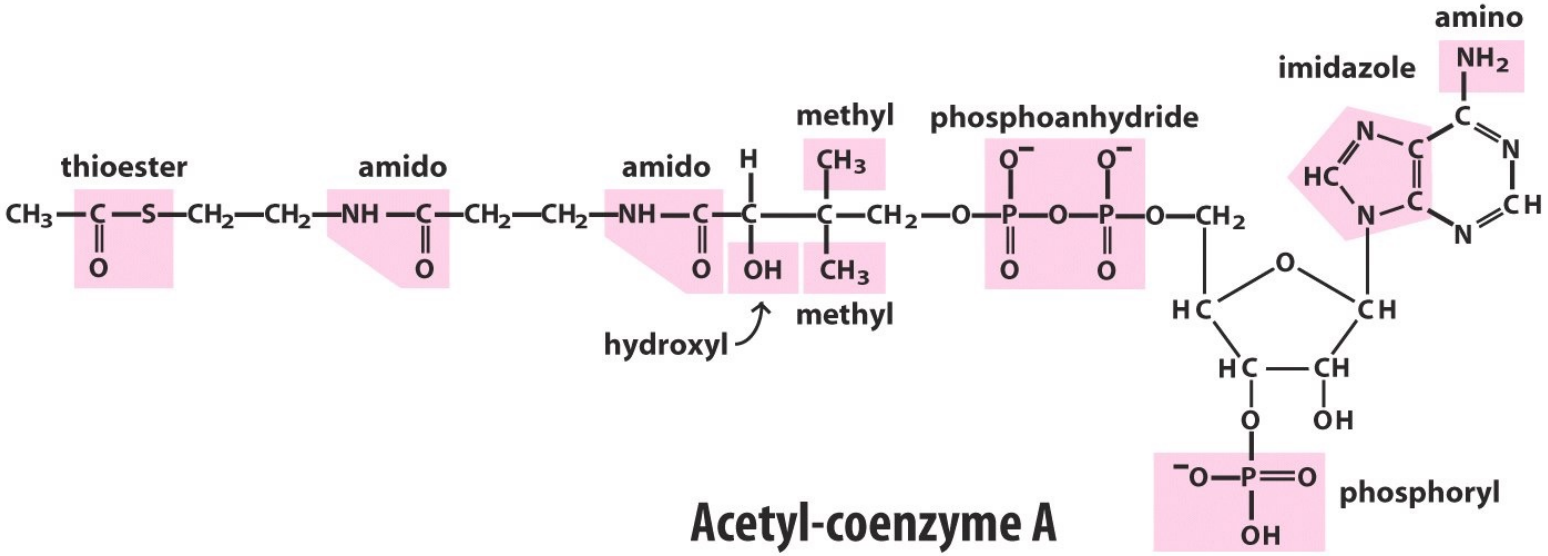




phosphoanhydride—a high-energy bond found in molecules such as ATP



A typical molecule and its functional groups

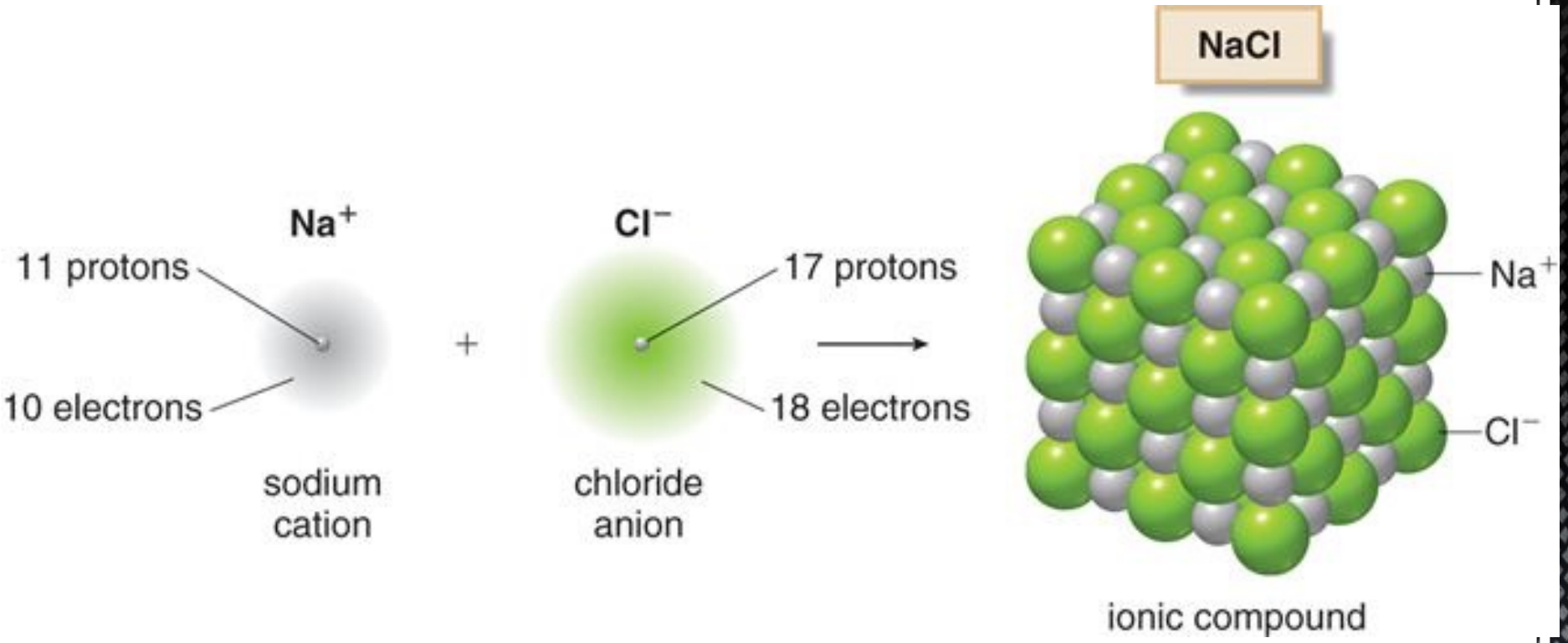


Ionic bonds and ionic compounds

- *Ionic bonds* result from the transfer of electrons from one element to another.
- *Cations* are positively charged ions. A cation has fewer electrons than protons.
- *Anions* are negatively charged ions. An anion has more electrons than protons.
- *Ionic compounds* consist of oppositely charged ions that have a strong electrostatic attraction for each other.

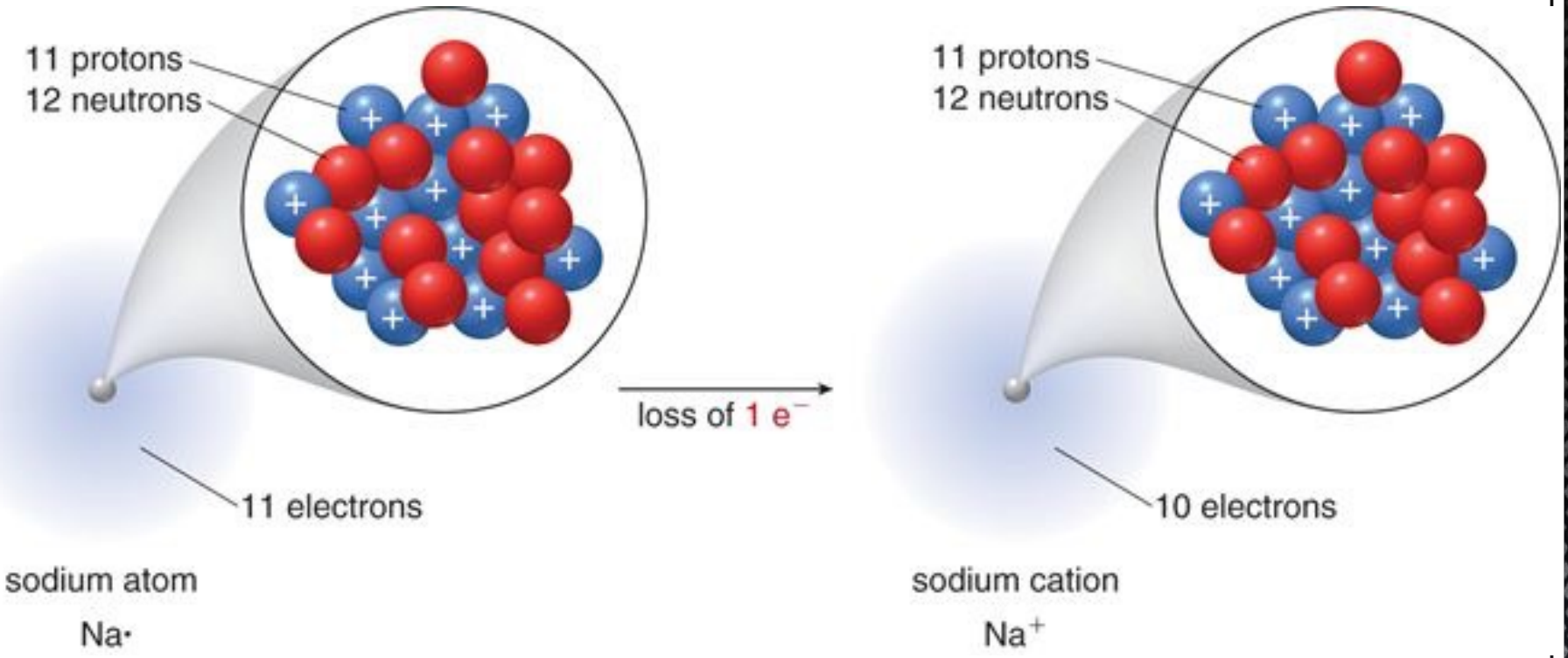
Ionic compound contain anions and cations

Note: the overall sum of charge should be zero!



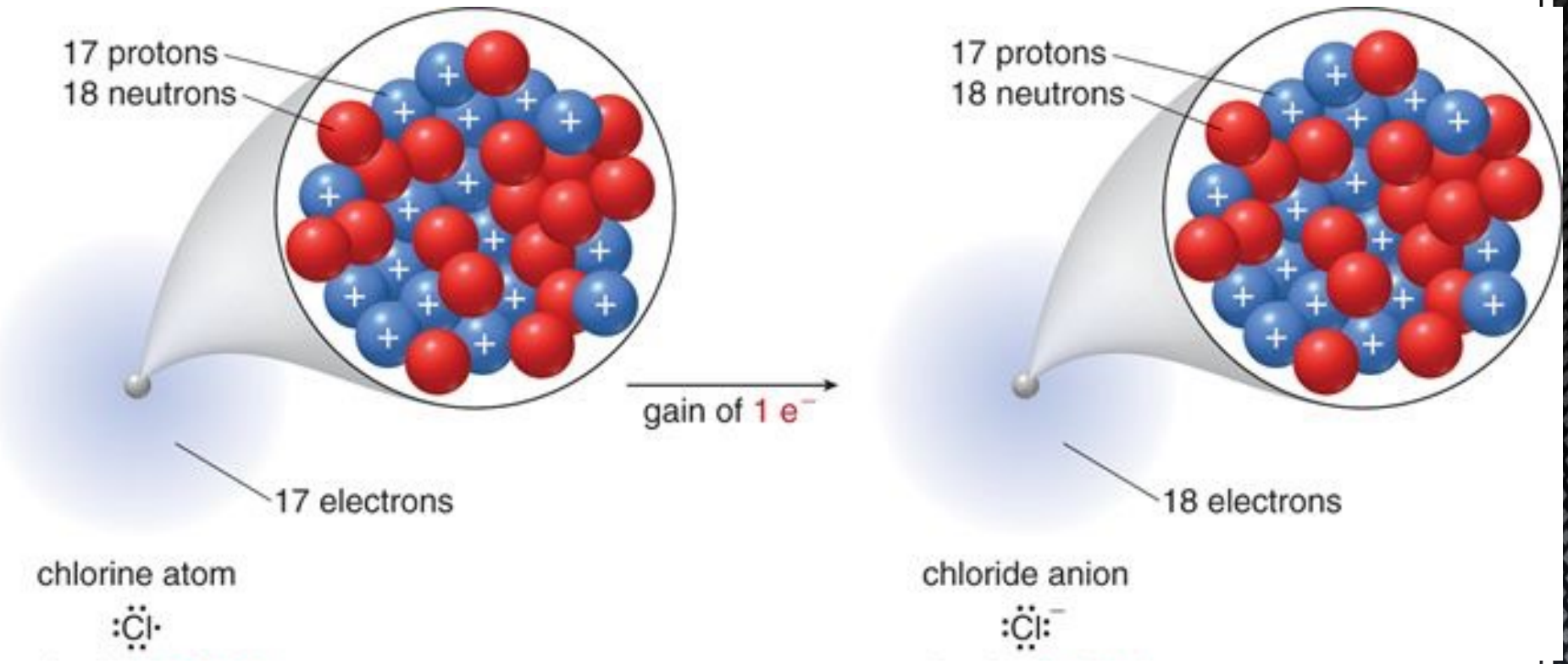
Examples of Ions

Cations

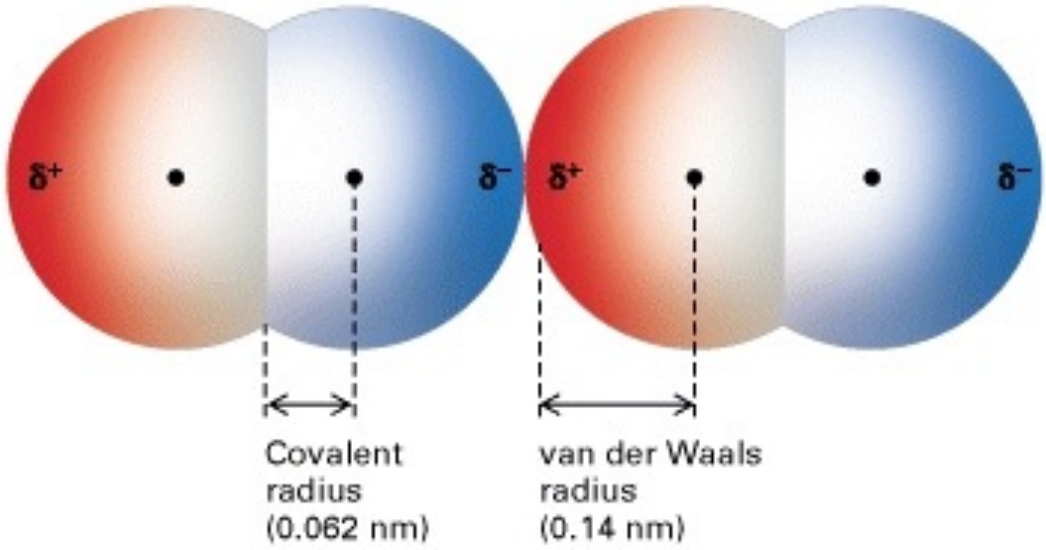


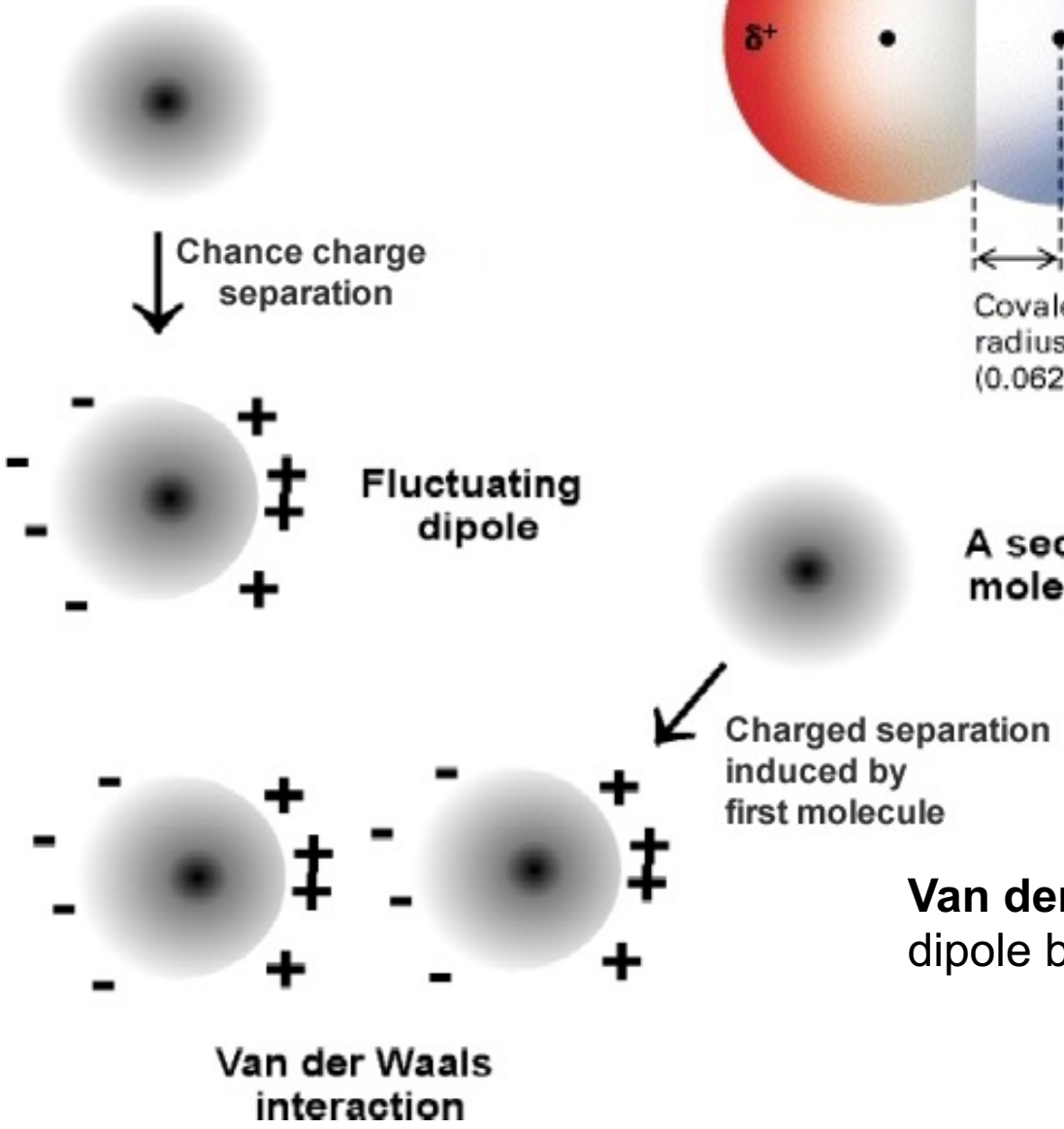
Examples of Ions

Anions



Chemical bonds for molecules





Van der Waals interaction – flickering dipole between nonpolar atoms

Hydrogen bonds

Electropositive hydrogen partially shared with two electronegative atoms.

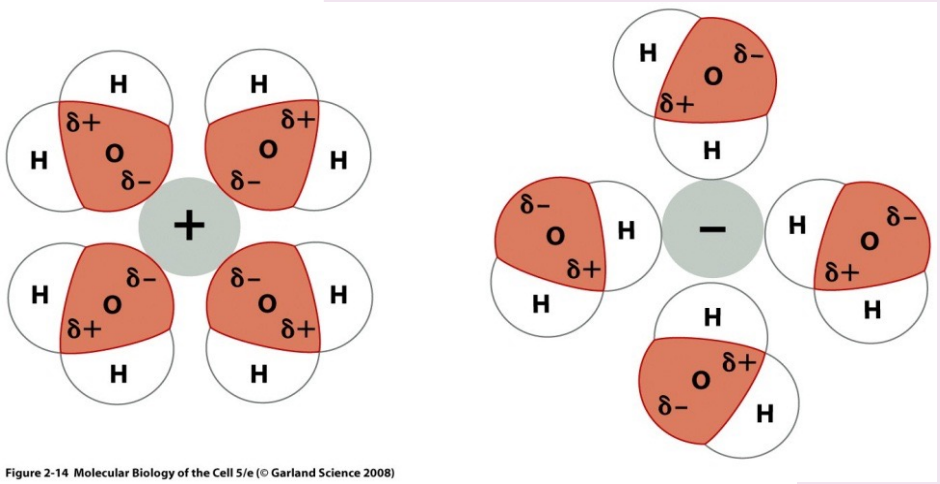


Figure 2-14 Molecular Biology of the Cell 5/e (© Garland Science 2008)

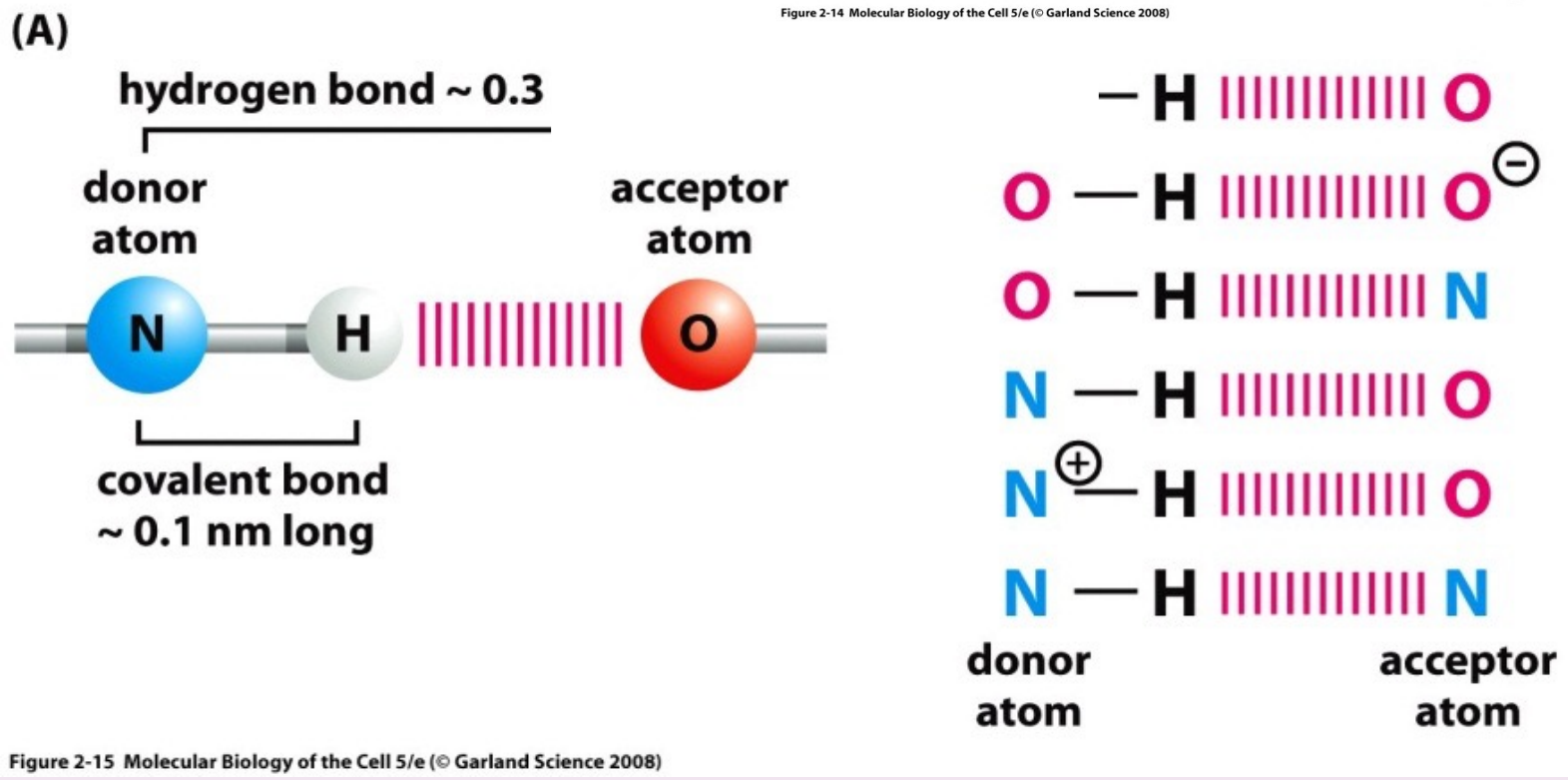
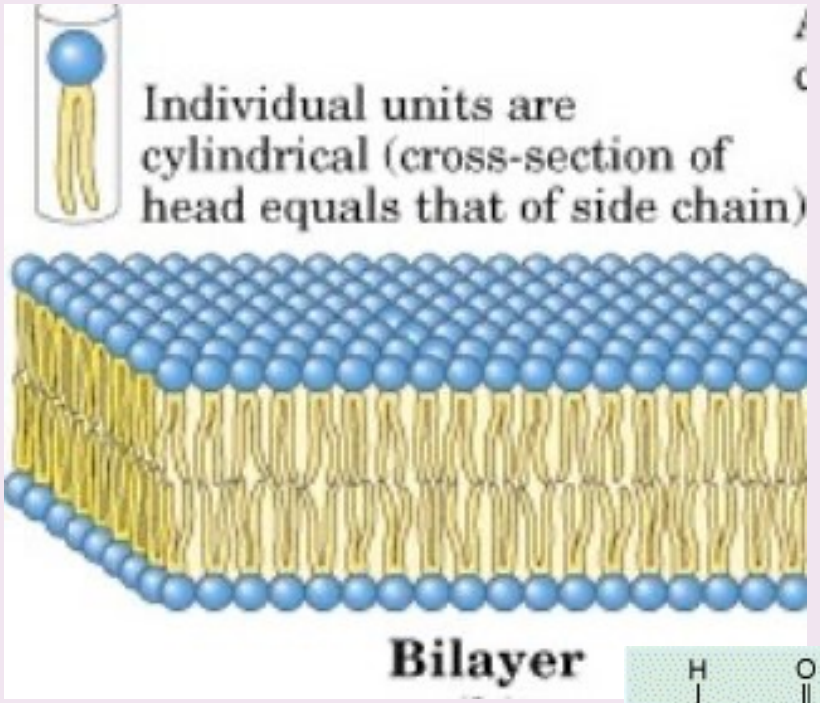
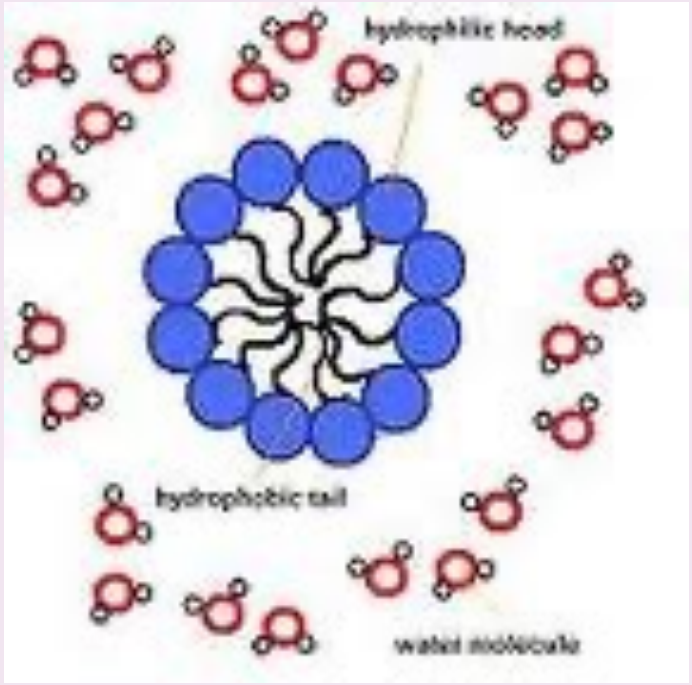
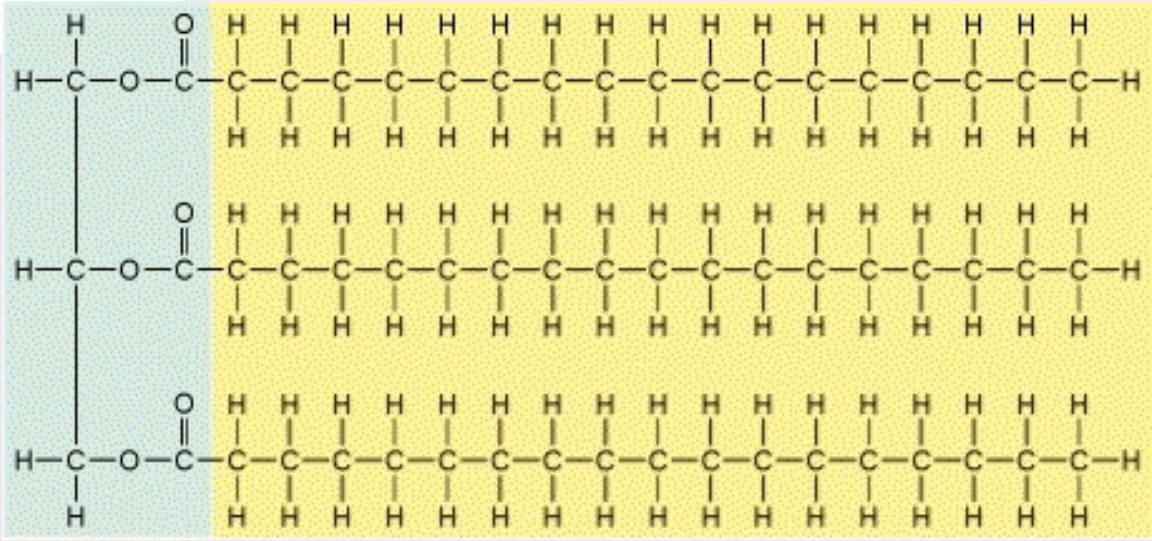


Figure 2-15 Molecular Biology of the Cell 5/e (© Garland Science 2008)

Chemical bonds for molecules







Hydrophobic forces – pushing nonpolar surfaces out of hydrogen-bonded water network

- Learning Objectives
  - *Explain* the anatomy of an atom.
    - Know the general structure of an atom
    - Understand the meaning of relative atomic weight, in that an atom may have isotopes.
  - *Recognise* the elements of life.
    - List the four common elements of life
    - Aware the other less common and trace elements of life
  - *Show* different types of chemical bonds.
    - Know Ionic bonds / covalent bonds / hydrogen bonds
    - Aware of the term electronegativity
  - *Illustrate* how atoms are organized into molecules.
    - Know the terms of cations and anions
    - Understand van der waals interaction / hydrophobic force
    - Know about different molecular states

From atoms to molecules