BIOL2107, Spring ’23

Lecture 16

C H O N P S

Abundance in cells

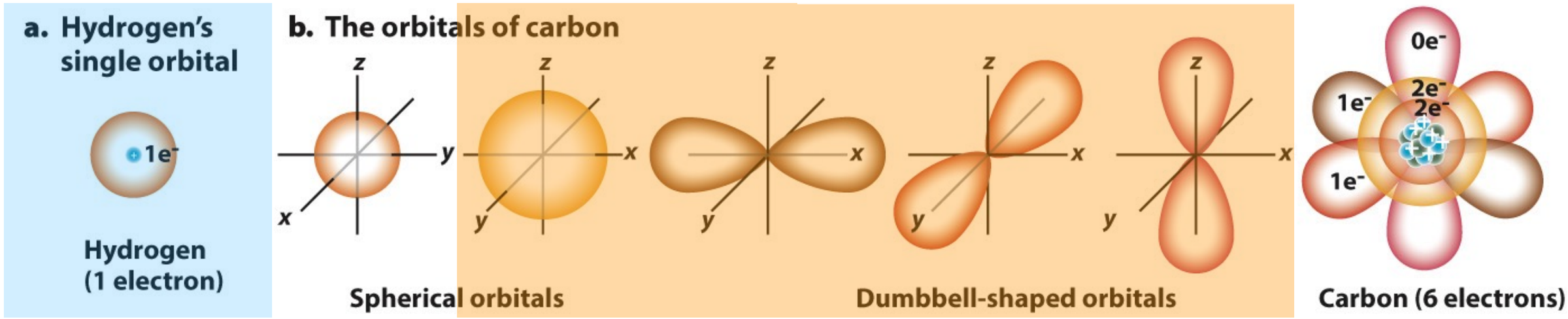
- High
- Low
- Trace
- None

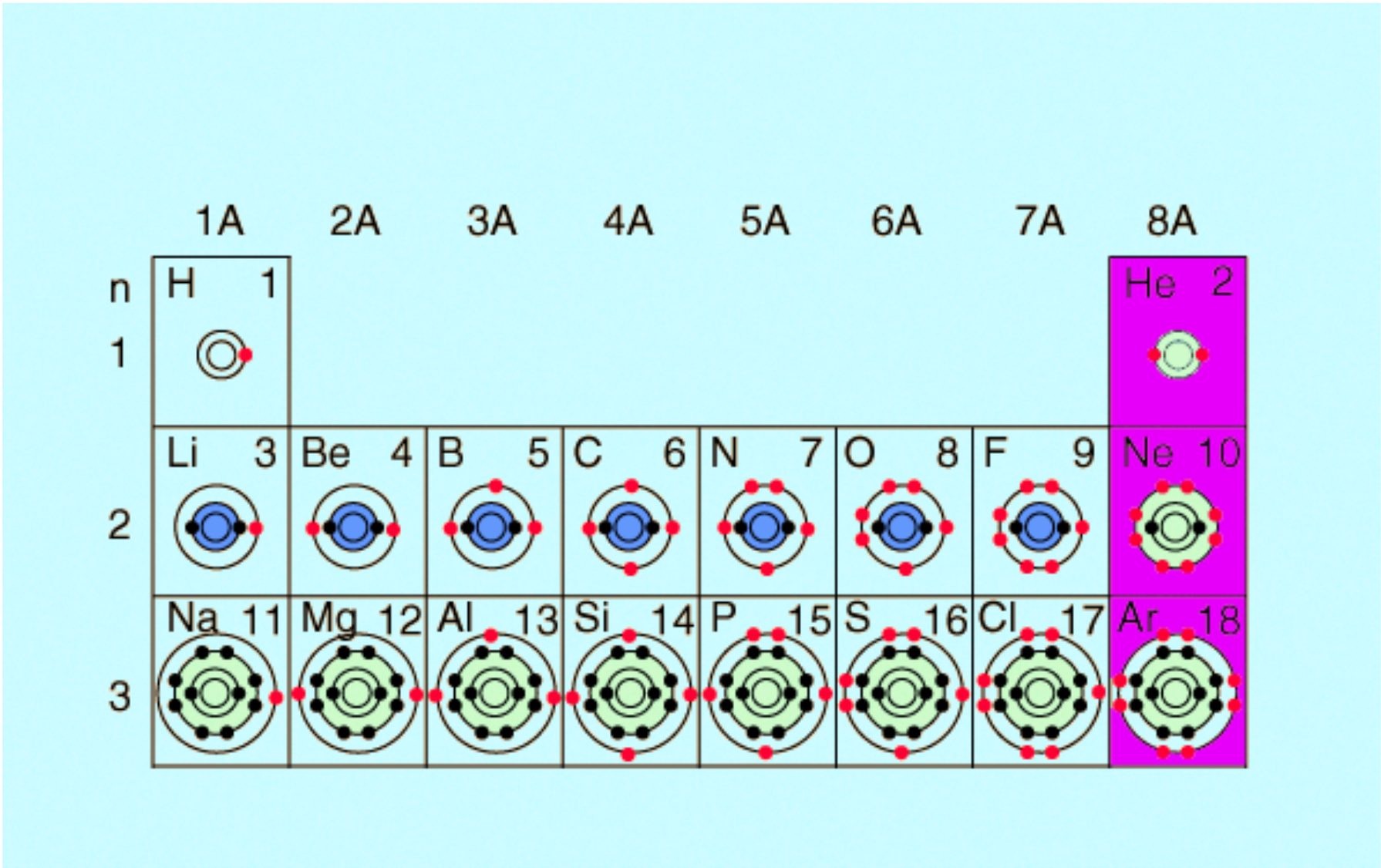
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71 La-Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103 Ac-Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

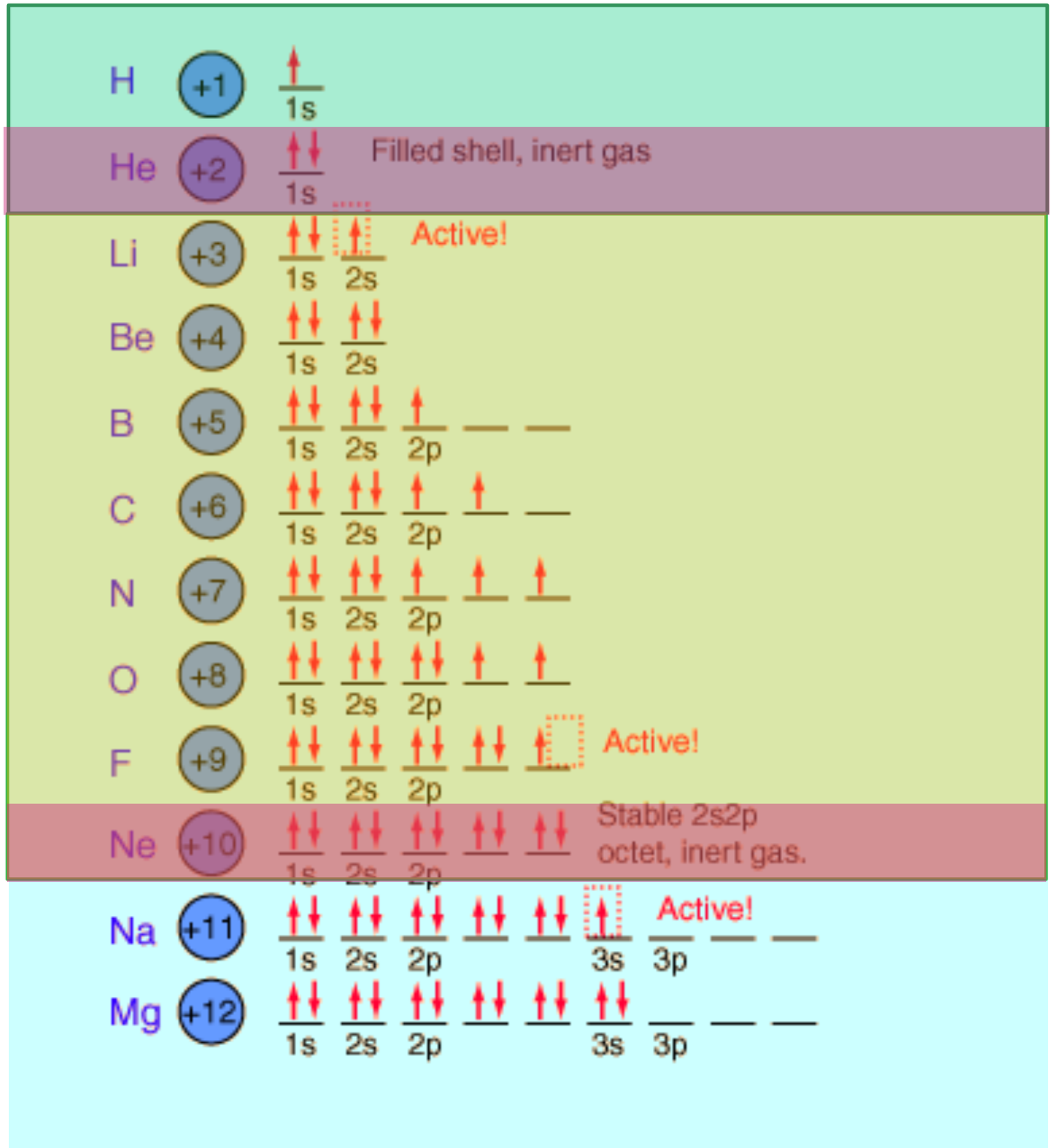
57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

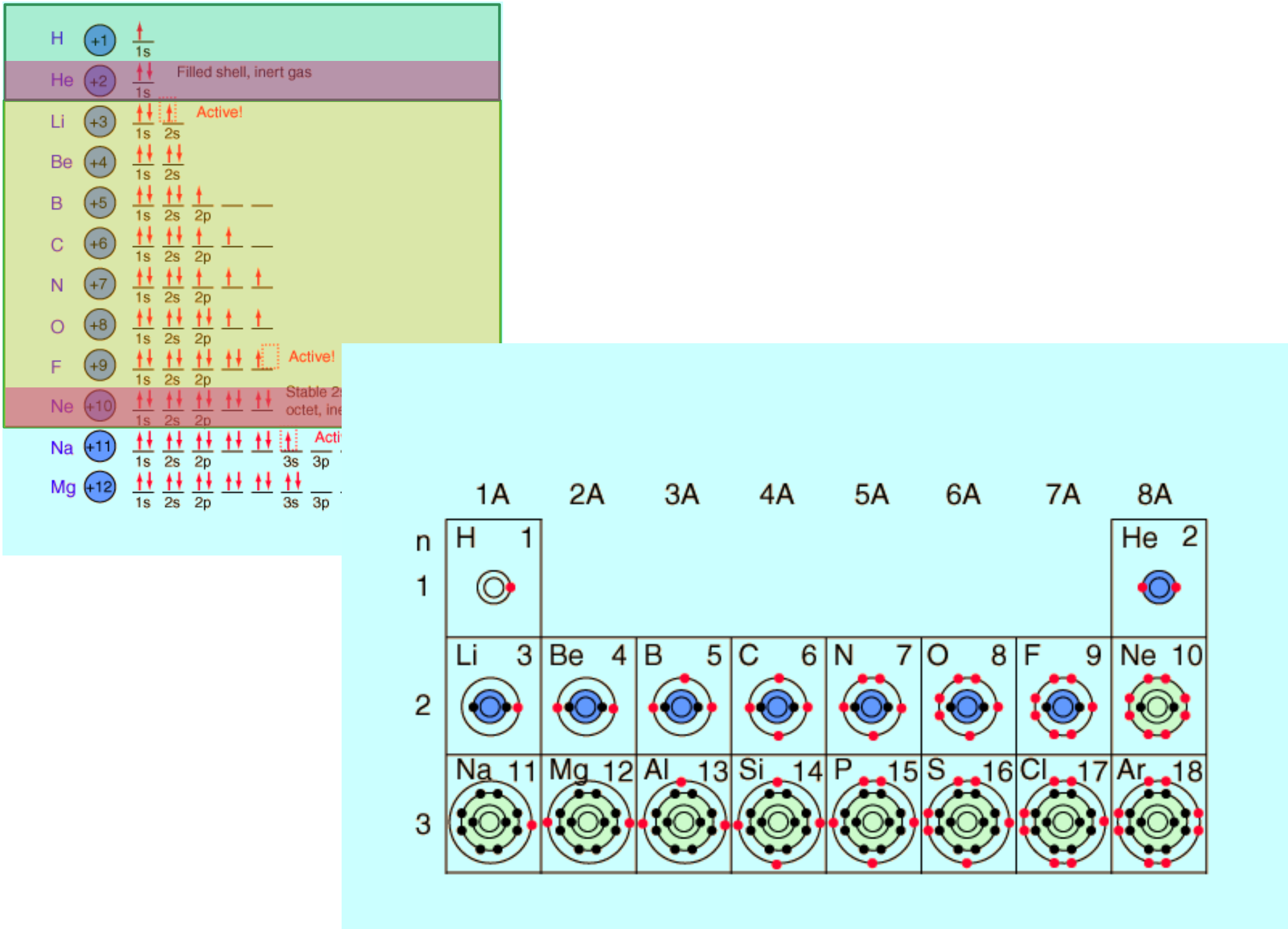
The first electron shell consists of a single spherical orbital.

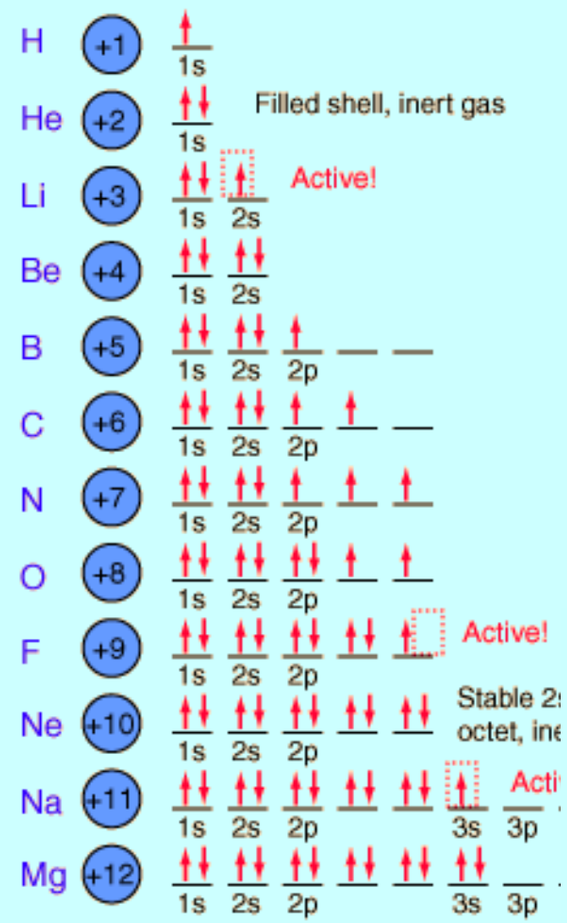
The second electron shell consists of four orbitals: the larger spherical orbital and three dumbbell-shaped orbitals.




1A
2A
3A
4A
5A
6A
7A
8A
n
1
2
3
H 1
He 2
Li 3
Be 4
B 5
C 6
N 7
O 8
F 9
Ne 10
Na 11
Mg 12
Al 13
Si 14
P 15
S 16
Cl 17
Ar 18


H
+1
1s
He
+2
1s
Filled shell, inert gas
Li
+3
1s
2s
Active!
Be
+4
1s
2s
B
+5
1s
2s
2p
C
+6
1s
2s
2p
N
+7
1s
2s
2p
O
+8
1s
2s
2p
F
+9
1s
2s
2p
Active!
Ne
+10
1s
2s
2p
Stable 2s2p
octet, inert gas.
Na
+11
1s
2s
2p
3s
3p
Active!
Mg
+12
1s
2s
2p
3s
3p


H +1 1s
He +2 1s Filled shell, inert gas
Li +3 1s 2s Active!
Be +4 1s 2s
B +5 1s 2s 2p
C +6 1s 2s 2p
N +7 1s 2s 2p
O +8 1s 2s 2p
F +9 1s 2s 2p Active!
Ne +10 1s 2s 2p
Na +11 1s 2s 2p 3s 3p
Mg +12 1s 2s 2p 3s 3p
1A 2A 3A 4A 5A 6A 7A 8A
n
1
2
3
H 1
He 2
Li 3
Be 4
B 5
C 6
N 7
O 8
F 9
Ne 10
Na 11
Mg 12
Al 13
Si 14
P 15
S 16
Cl 17
Ar 18


H +1 1s
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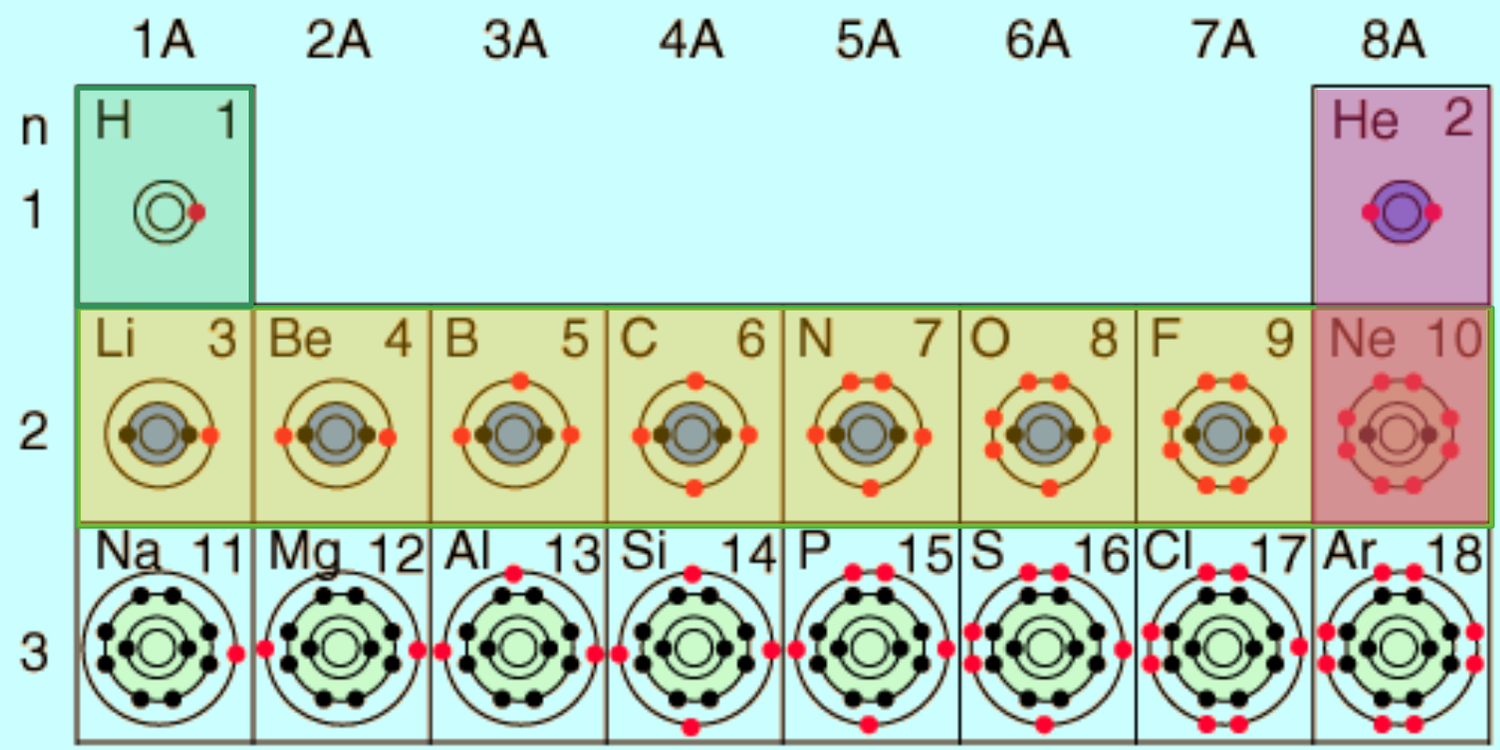
C +6 1s 2s 2p
N +7 1s 2s 2p
O +8 1s 2s 2p
F +9 1s 2s 2p Active!
Ne +10 1s 2s 2p Stable 2s octet, ine
Na +11 1s 2s 2p 3s 3p Acti
Mg +12 1s 2s 2p 3s 3p


1A 2A 3A 4A 5A 6A 7A 8A
n
1
2
3
H 1
He 2
Li 3
Be 4
B 5
C 6
N 7
O 8
F 9
Ne 10
Na 11
Mg 12
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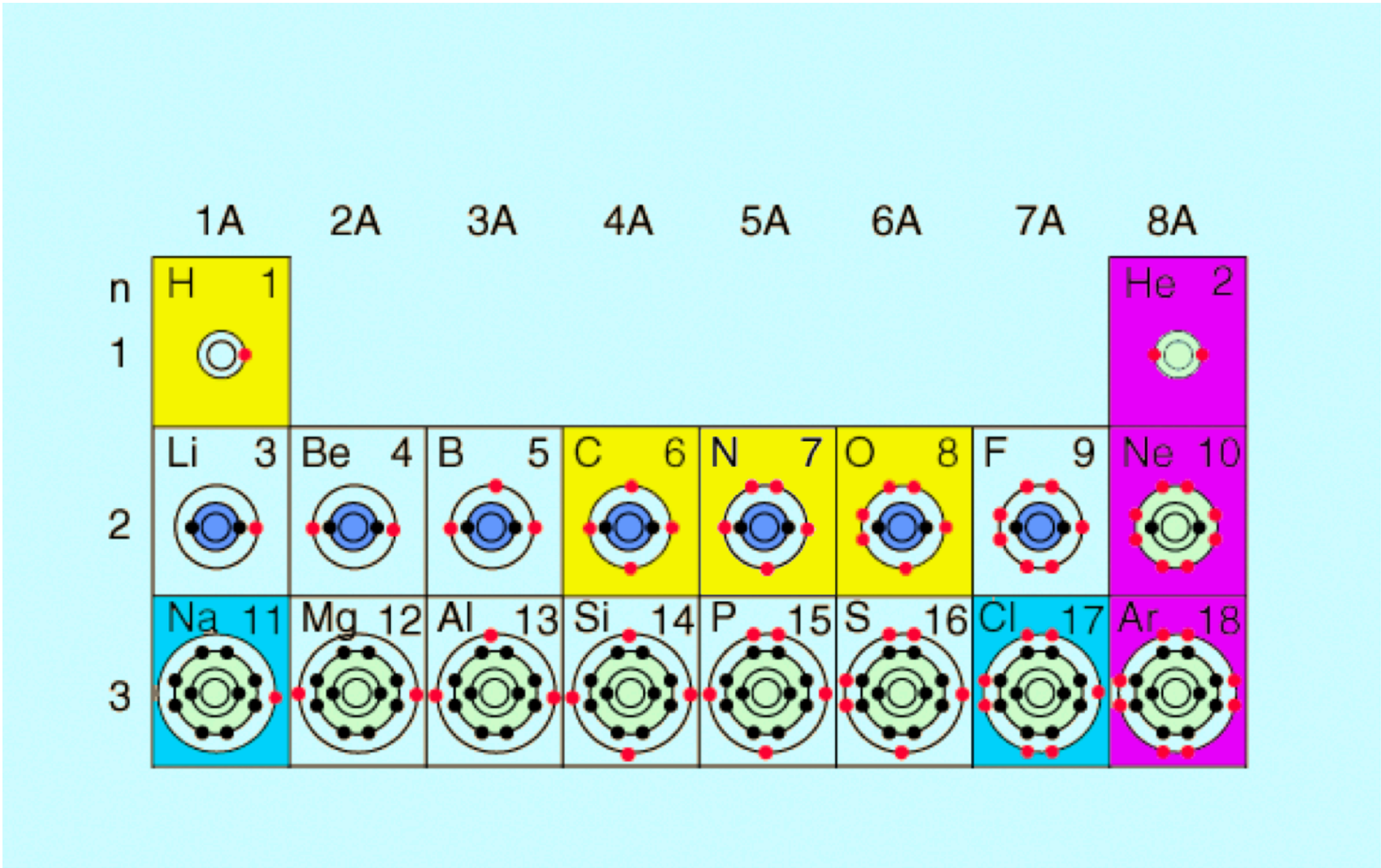
1A
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3A
4A
5A
6A
7A
8A
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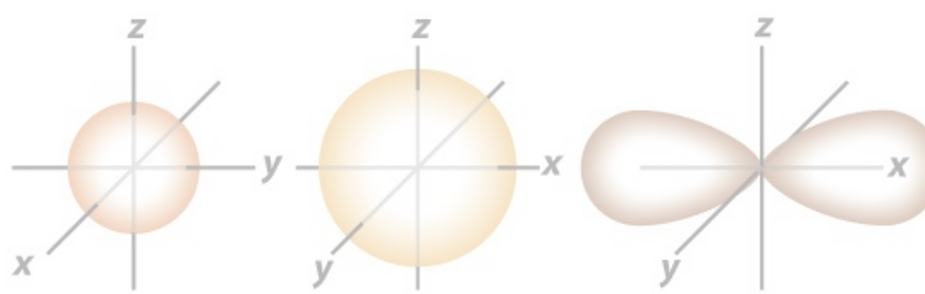
The first electron shell consists of a single spherical orbital.

The second electron shell consists of four orbitals: the larger spherical orbital and three dumbbell-shaped orbitals.

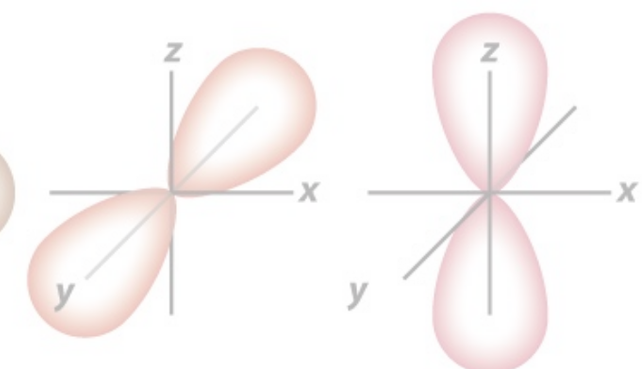
a. Hydrogen's single orbital

Hydrogen (1 electron)

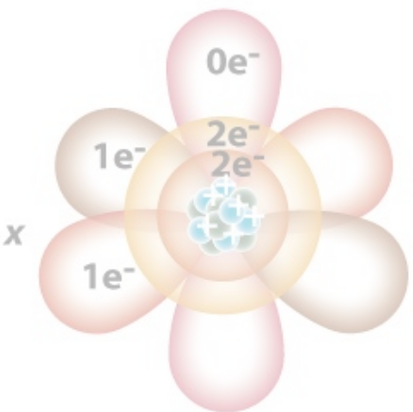
b. The orbitals of carbon



Spherical orbitals

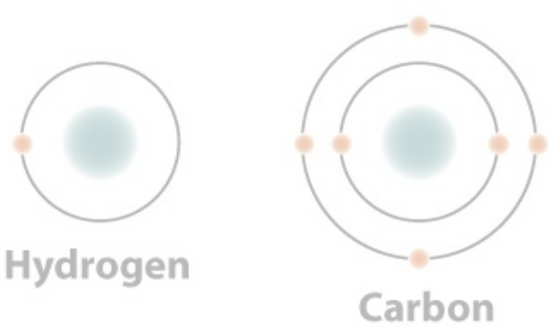


Dumbbell-shaped orbitals



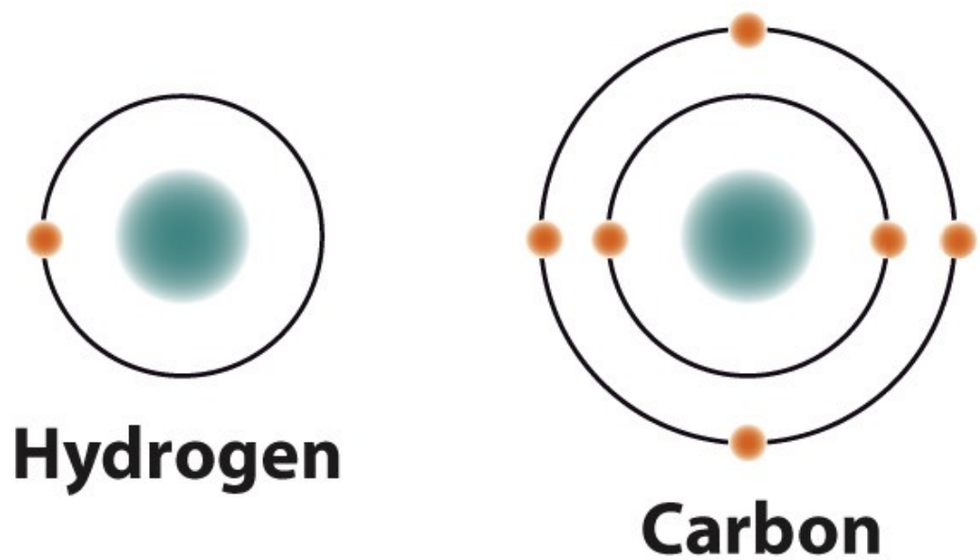
Carbon (6 electrons)

c. Energy levels of hydrogen and carbon



In this simplified diagram, the electron energy levels (shells) are depicted as circles and the electrons that occupy them as dots. The cloud in the center is the nucleus.

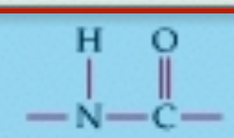
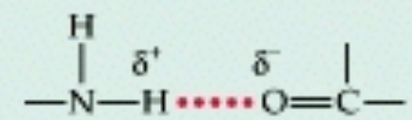
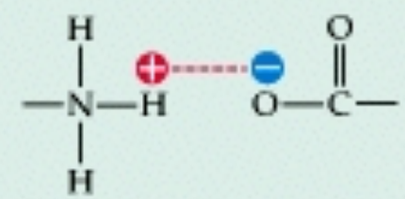
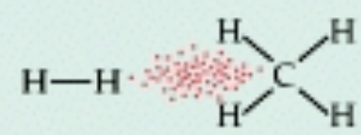
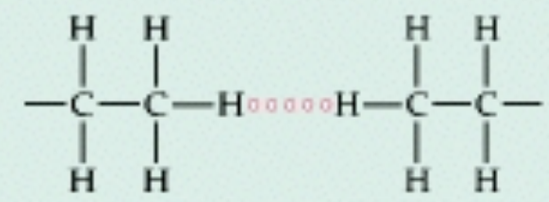
Energy levels of hydrogen and carbon



In this simplified diagram, the electron energy levels (shells) are depicted as circles and the electrons that occupy them as dots. The cloud in the center is the nucleus.

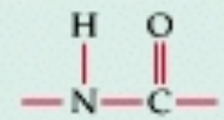
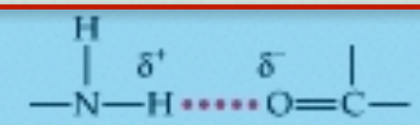
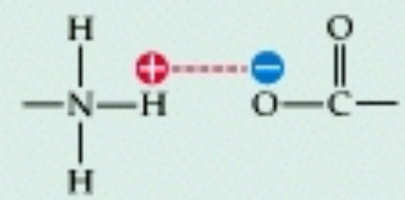
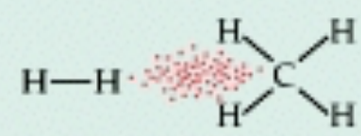
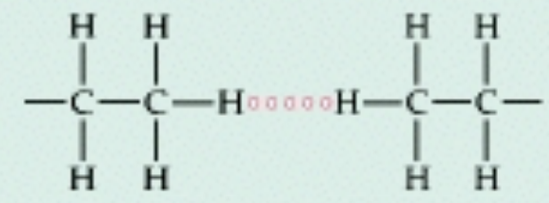
Figure 2.2c
Biology: How Life Works, Second Edition

2.1 Chemical Bonds and Interactions

NAME	BASIS OF INTERACTION	STRUCTURE	BOND ENERGY[a] (KCAL/MOL)
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	Weak electrostatic interactions		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

[a]*Bond energy* is the amount of energy needed to separate two bonded or interacting atoms under physiological conditions.

2.1 Chemical Bonds and Interactions

NAME	BASIS OF INTERACTION	STRUCTURE	BOND ENERGY[a] (KCAL/MOL)
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	Weak electrostatic interactions		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

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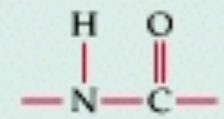
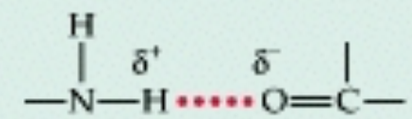
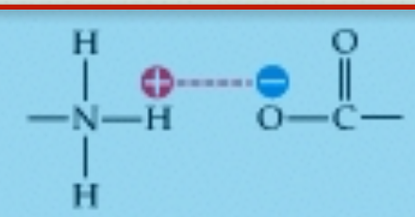
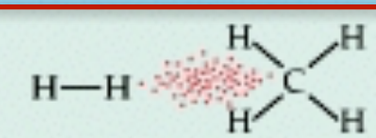
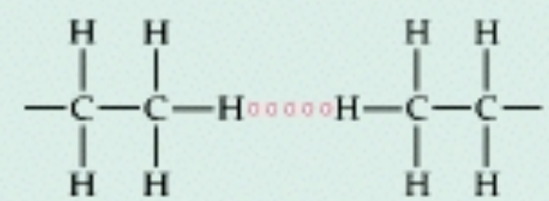
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	Weak electrostatic interactions		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

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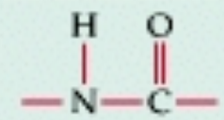
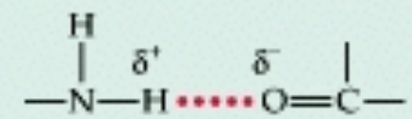
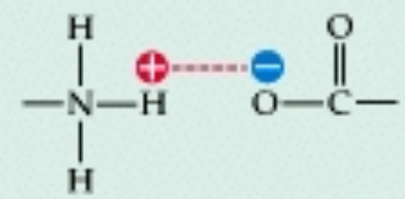
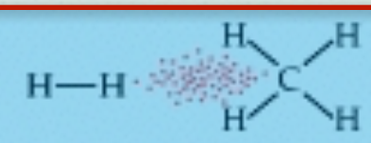
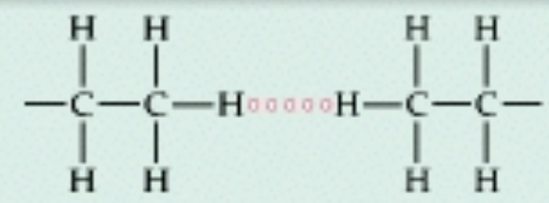
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	**Weak electrostatic interactions**		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

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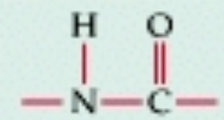
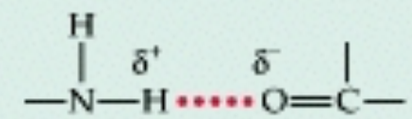
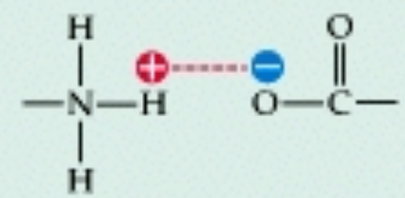
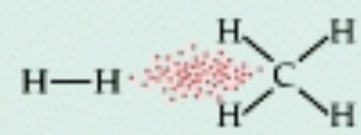
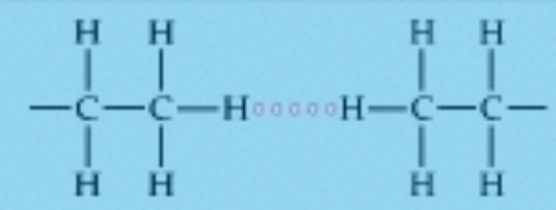
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	**Weak electrostatic interactions**		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

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The London dispersion force	Temporary attractive force Induced dipoles	in 2 adjacent atoms	< 1

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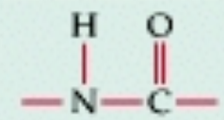
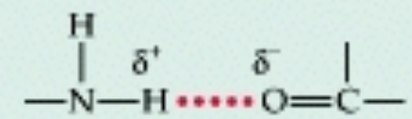
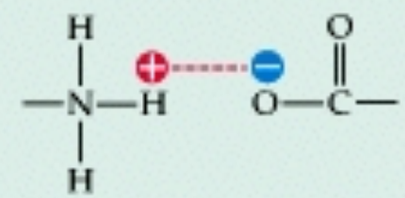
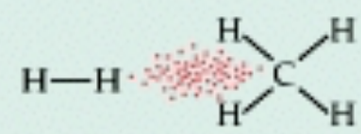
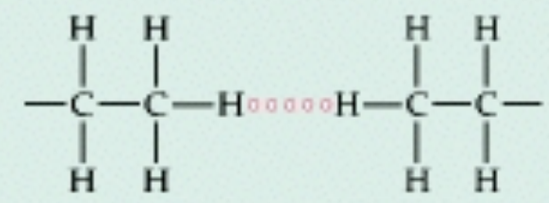
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	Weak electrostatic interactions		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

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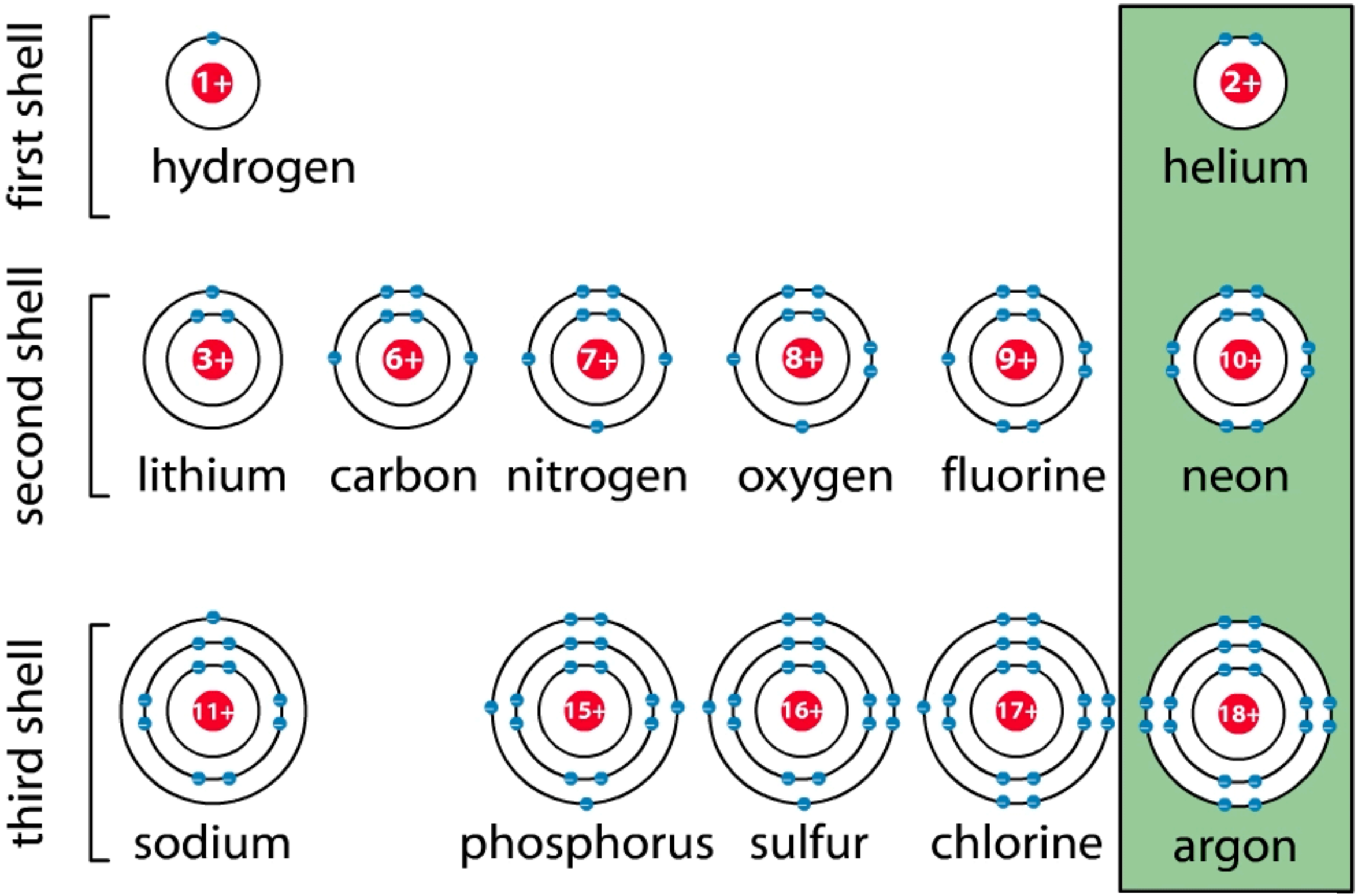
Electron Shells and Chemical Reactivity



2.1 Chemical Bonds and Interactions

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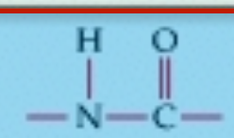
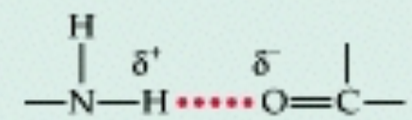
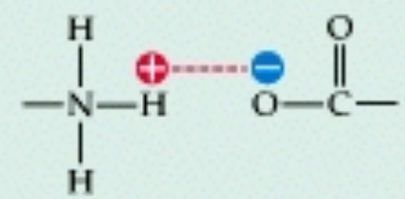
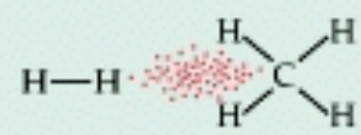
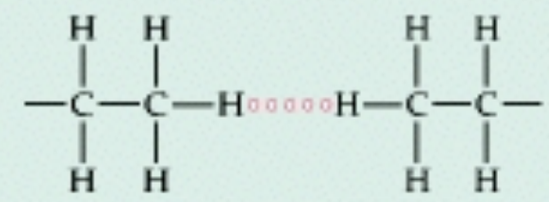
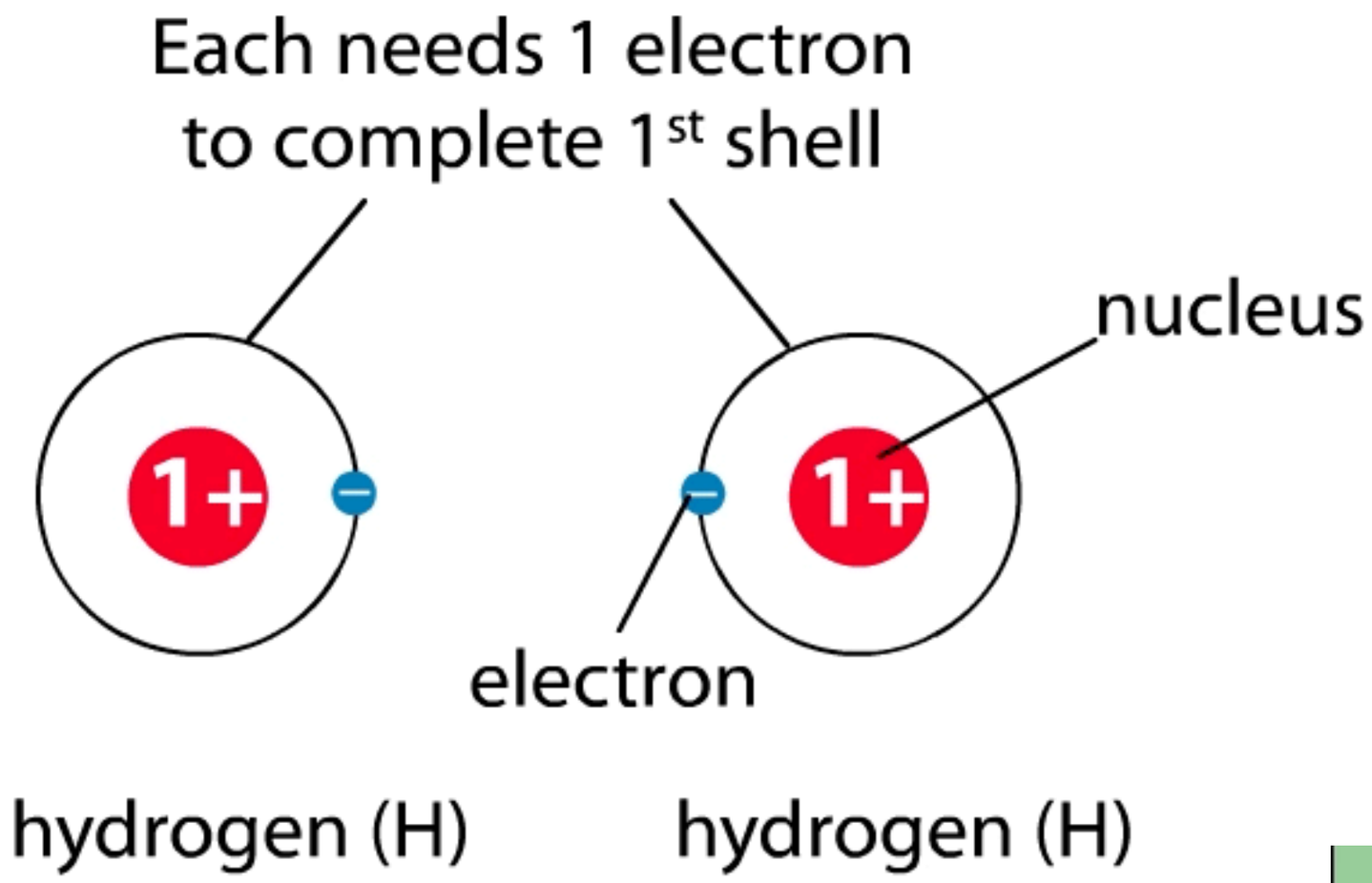
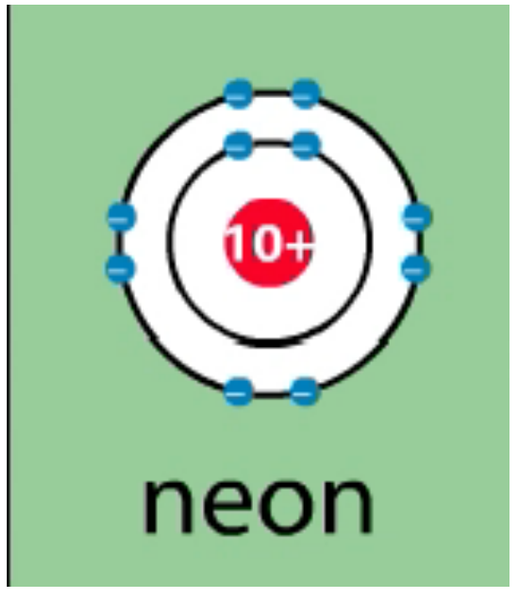
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	Weak electrostatic interactions		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

[a]*Bond energy* is the amount of energy needed to separate two bonded or interacting atoms under physiological conditions.

Covalent Bonds





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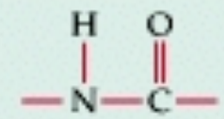
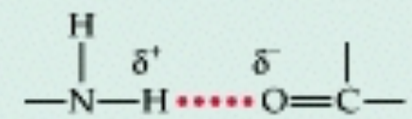
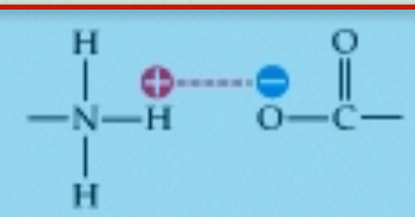
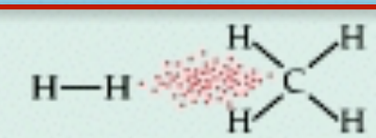
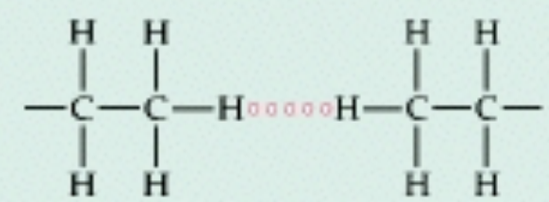
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	Weak electrostatic interactions		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

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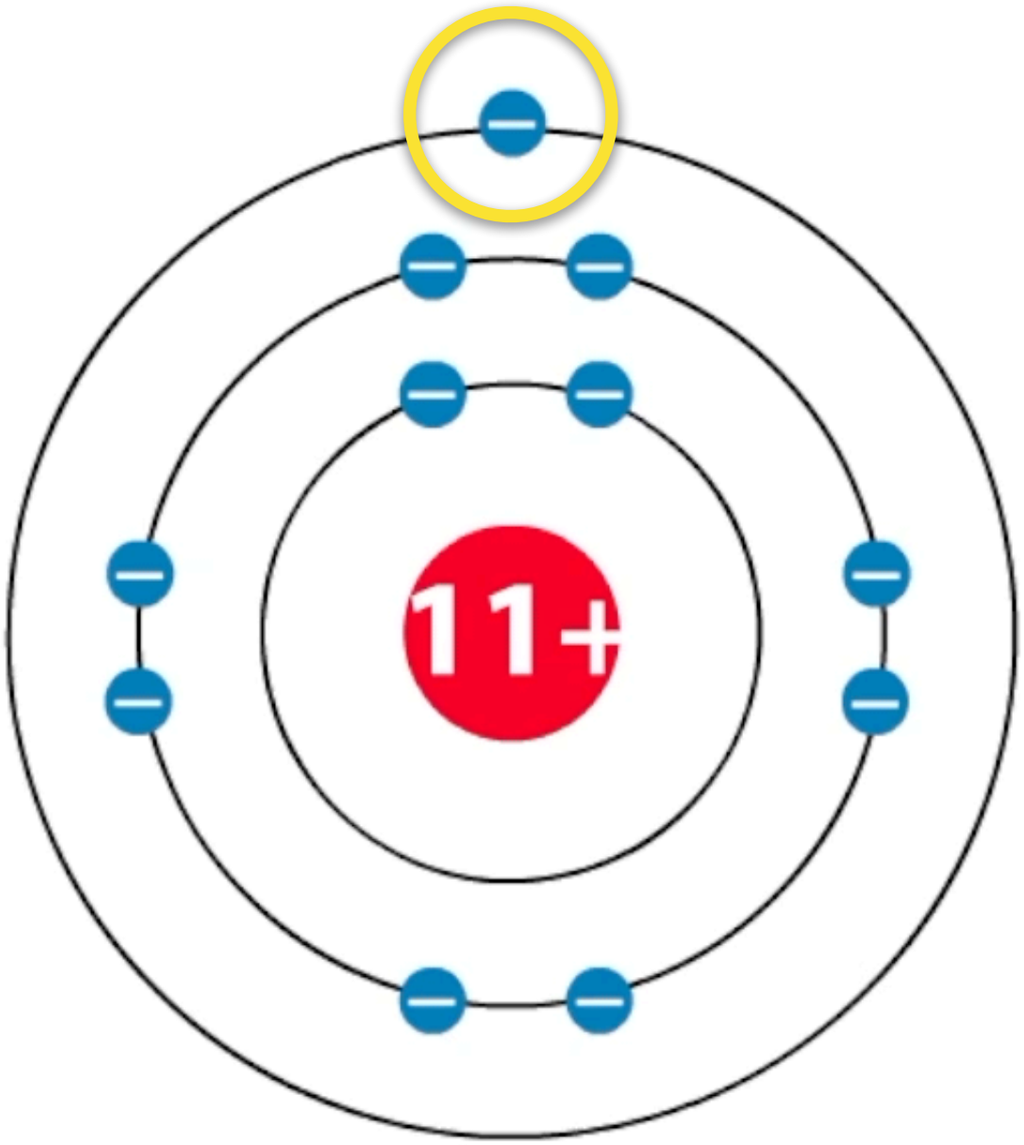
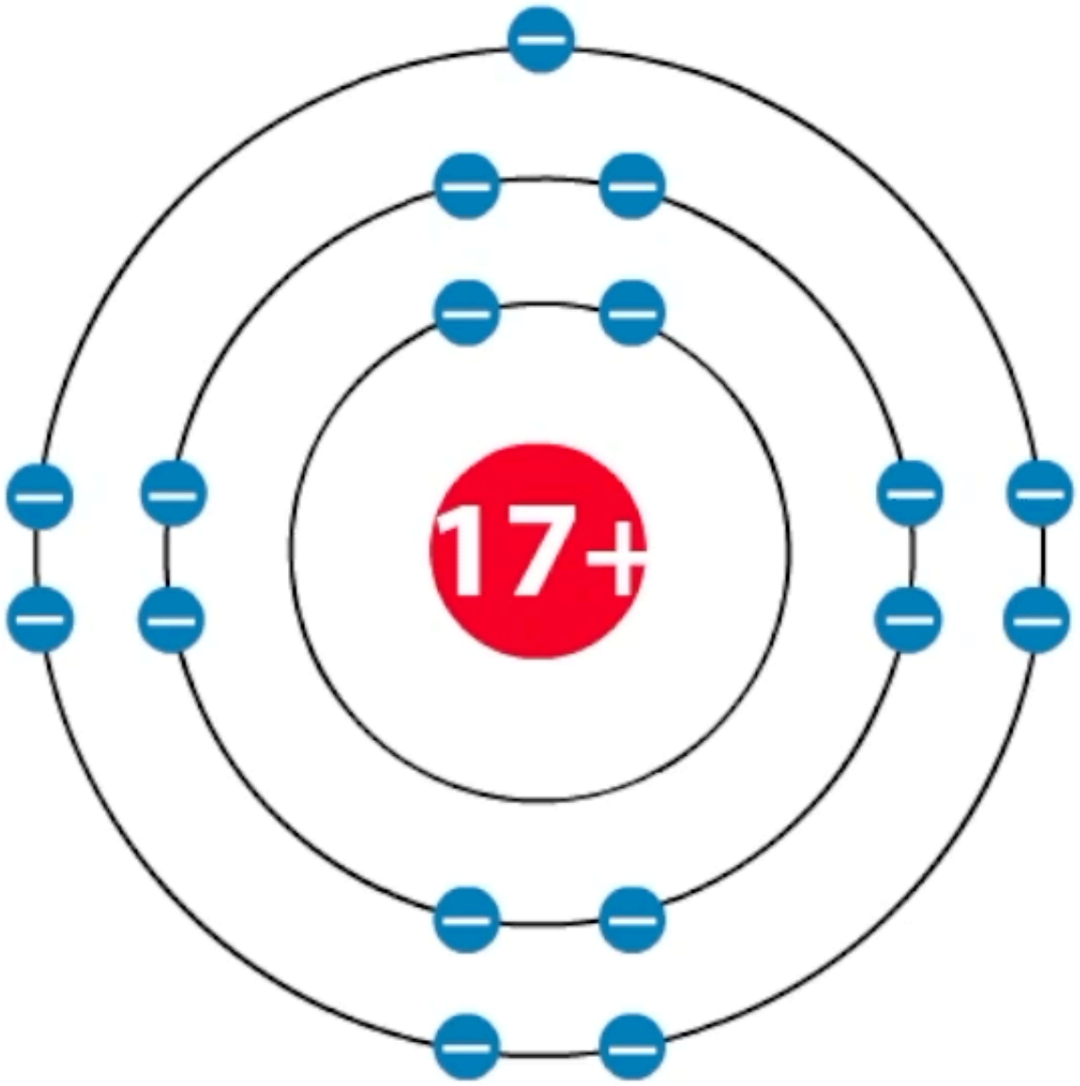
Ionic Bonds





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Molecular weight (or mass): the sum of all the atomic weights in a molecule.

The **molecular weight** of H_2 is **2**

Mole: the amount of a substance whose weight, in grams, is equal to its **molecular weight**.

One **mole** of $\mathbf{H_2}$ weighs **2 g**

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One **mole** of any given compound contains approximately

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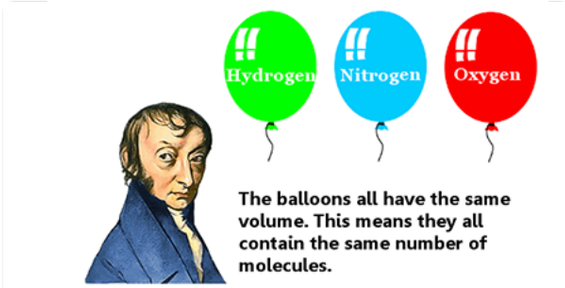
A 1 **molar** (**1 M**) **solution** is **one mole** of a compound dissolved (normally in water) to make up **one litre**.



Amedeo Avogadro

Lorenzo Romano Amedeo Carlo Avogadro, Count of Quaregna and Cerreto was an Italian scientist, most noted for his contribution to molecular theory now known as Avogadro's law, which states that equal volumes of gases under the same conditions of temperature and pressure will contain equal numbers of molecules. Wikipedia

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Died: July 9, 1856, Turin, Italy

Full name: Lorenzo Romano Amedeo Carlo Avogadro

Known for: Avogadro's law; Avogadro constant

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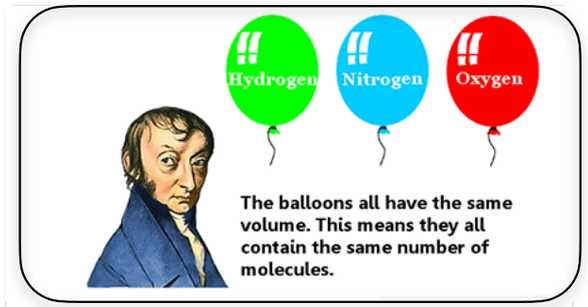

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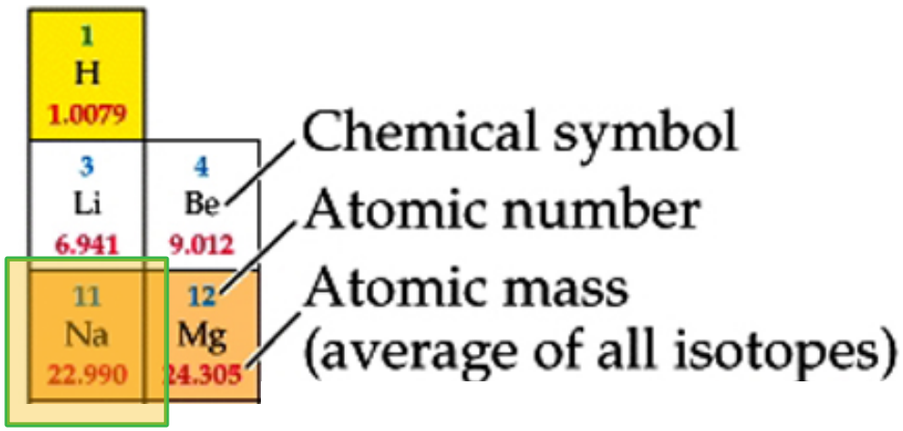

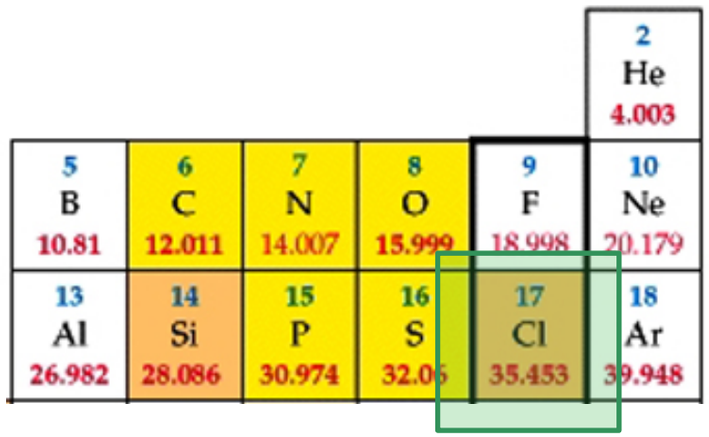

One **mole** of sodium chloride (table salt) is the atomic weight of sodium (**23.0**) plus the **atomic mass (weight)** of chlorine (**35.5**), dissolved in one litre of water.

23.0 + 35.5 = **58.5** (in grams), **58.5 g**

When **58.5 grams** of sodium chloride are dissolved in some amount of water, and then additional water is added to create a **final volume of a litre**,

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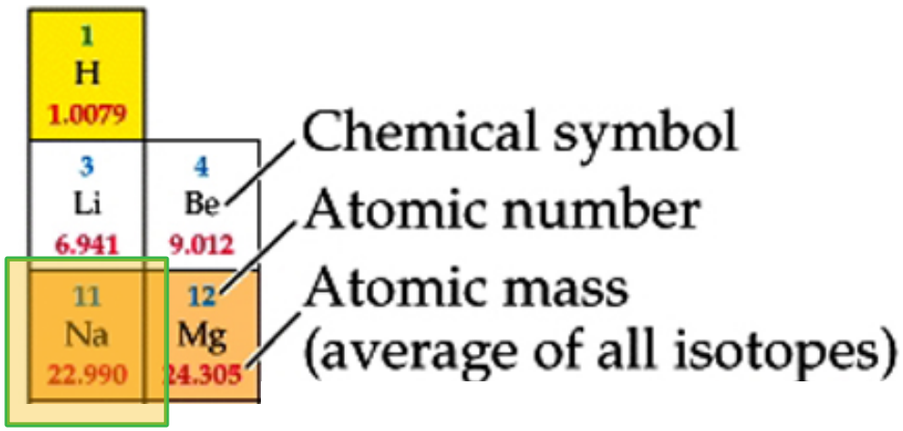

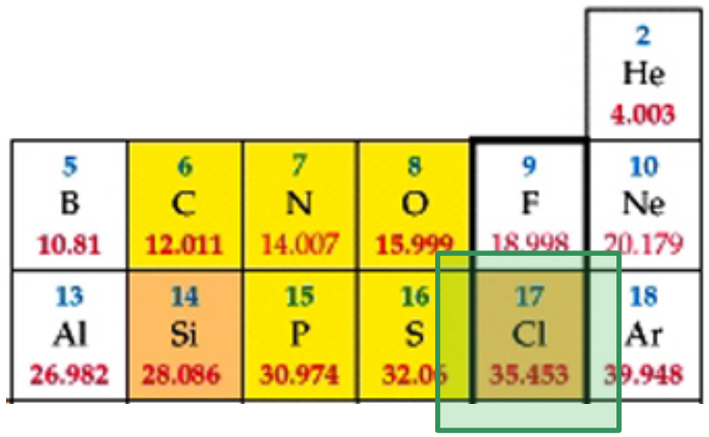

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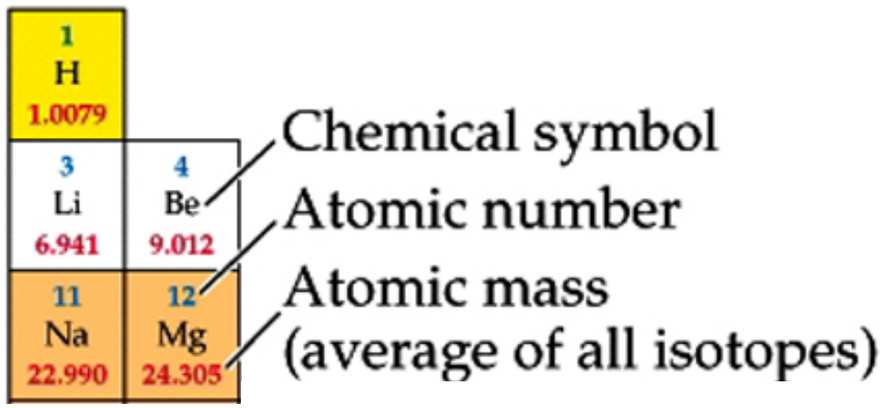

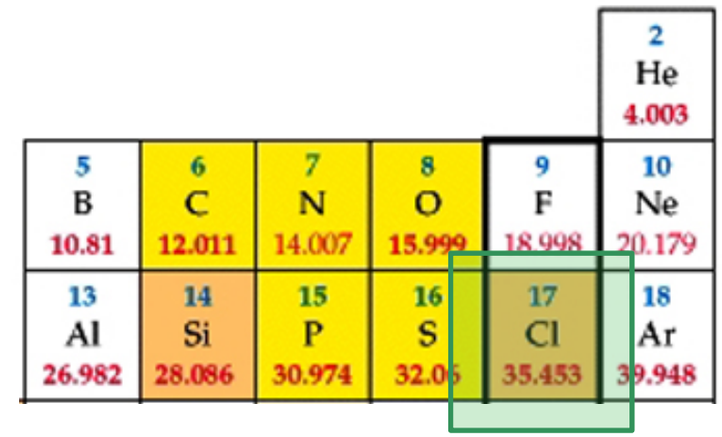

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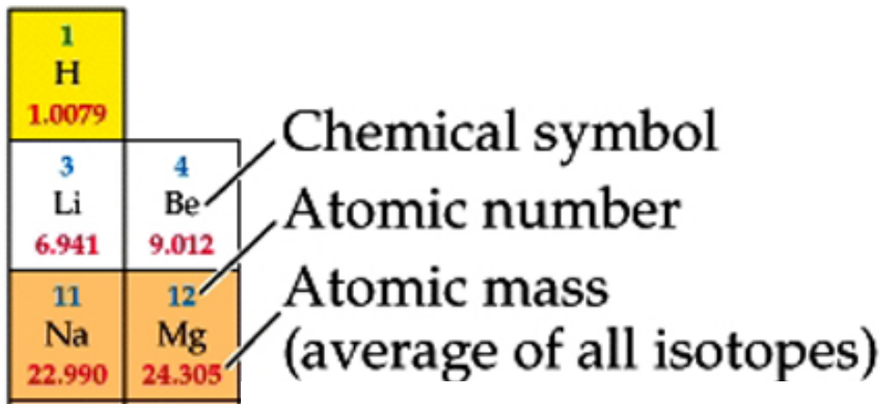

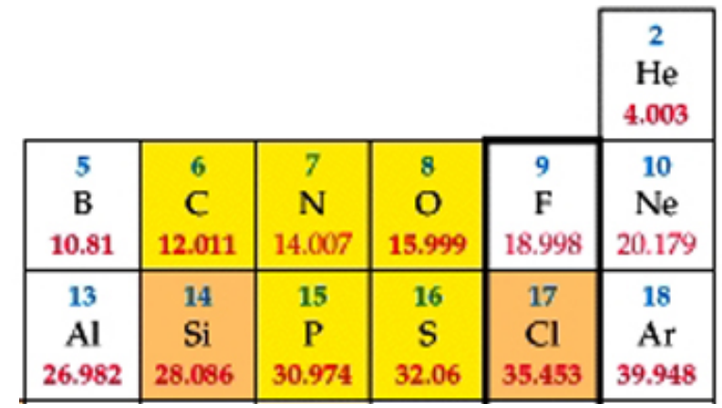

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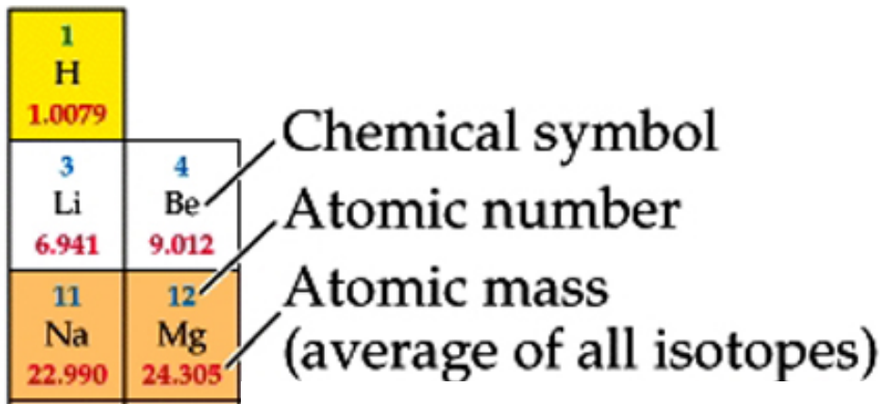

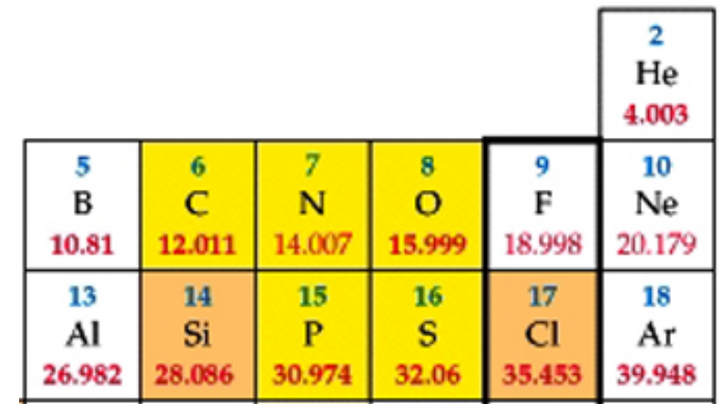

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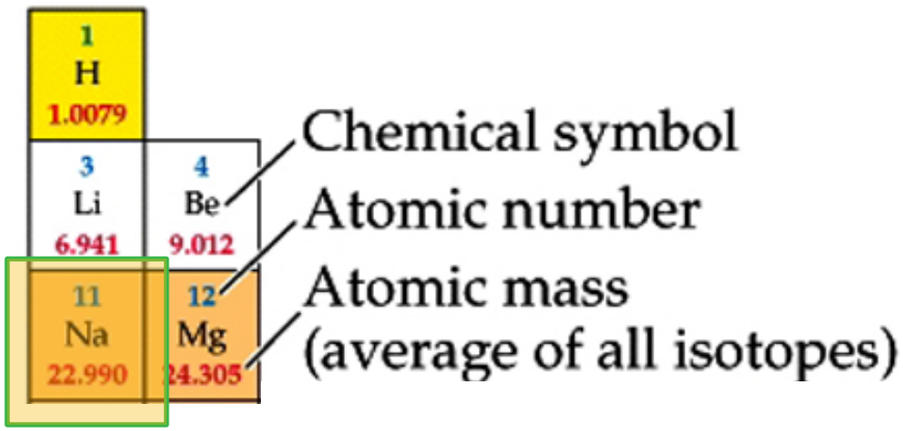
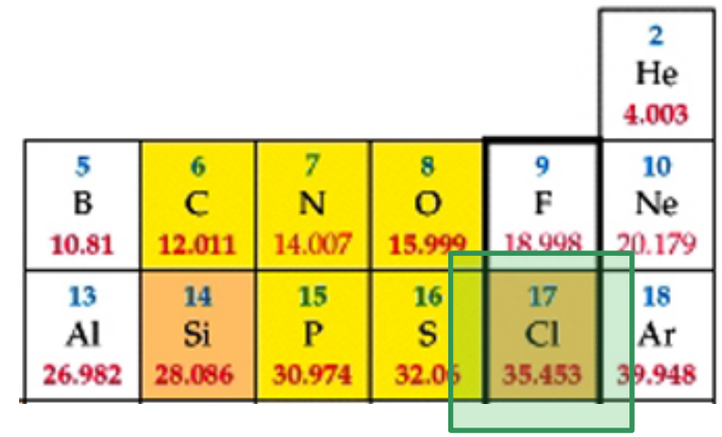




1 M solution or 1 molar solution

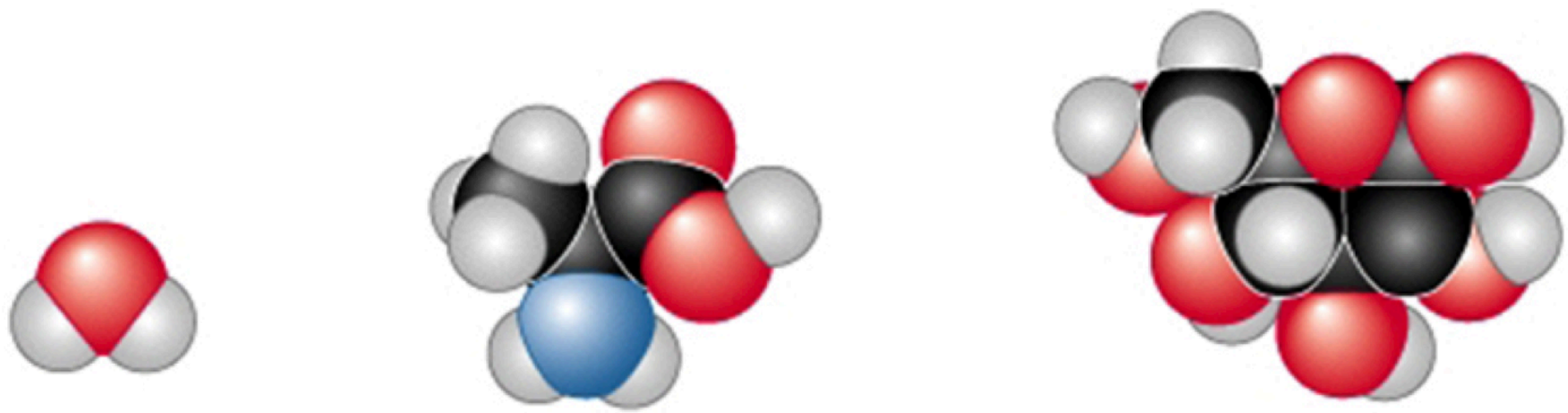
1 mM is **1/1000** of a **molar** solution.

1 µM is **1/1000** of a **mM**…

How many grams of NaCl in a 1 **mM** salt solution?

58.5 mg in 1 ml x 1/1000 = 58.5 μg / ml

	Hydrogen	Carbon	Nitrogen	Oxygen
Atomic weights	1	12	14	16



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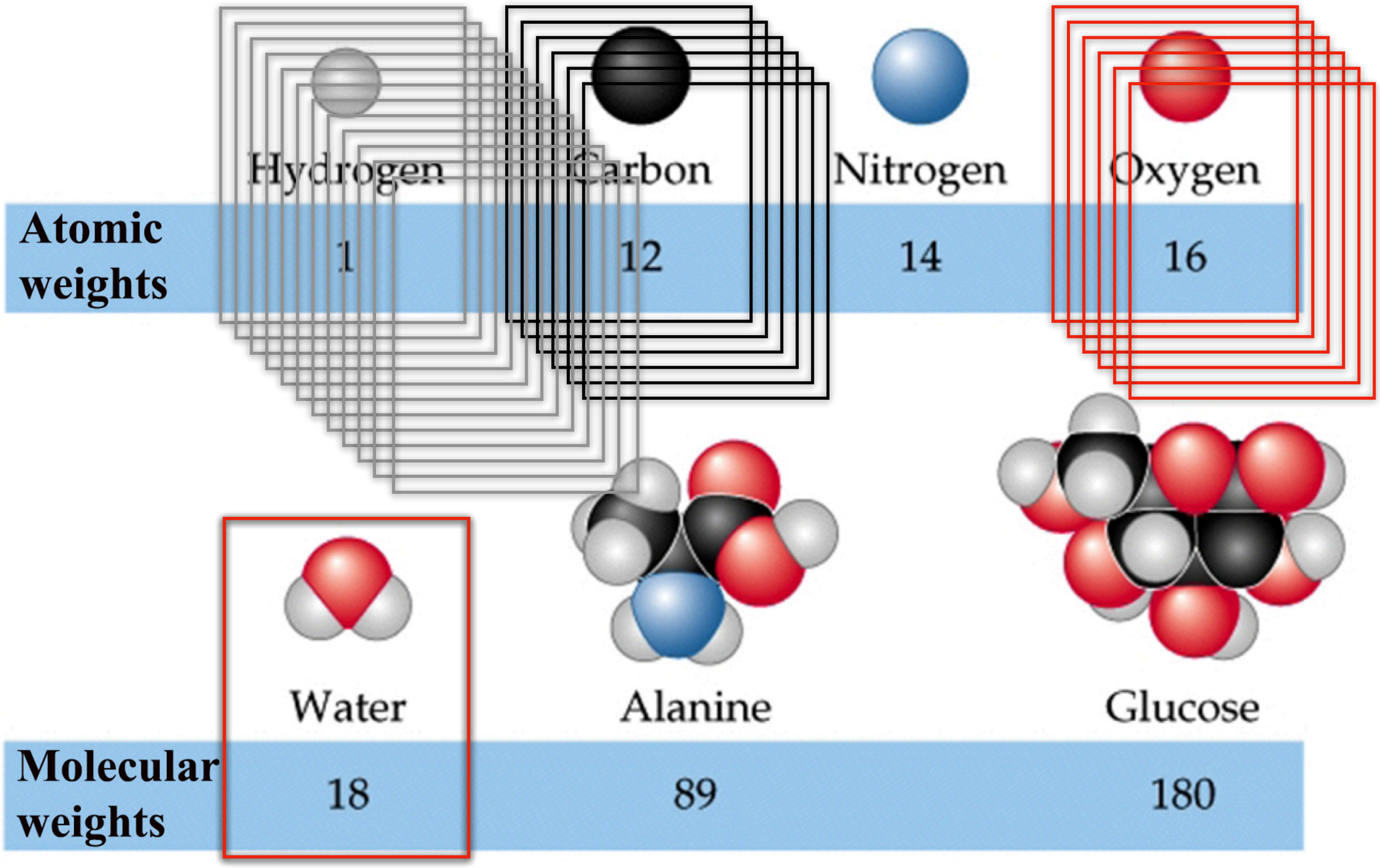
Molecular weights	18	89	180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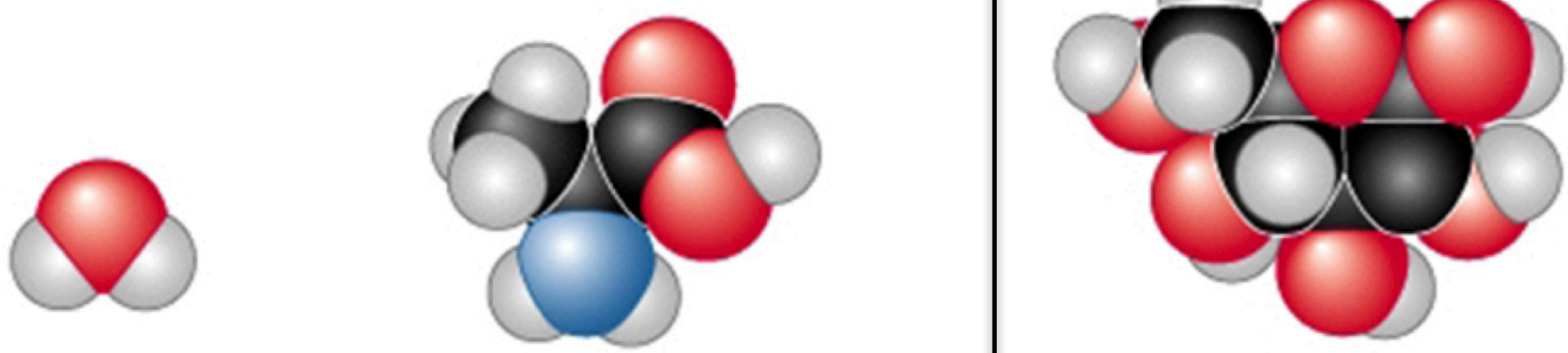

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$C_6 H_{12} O_6$

Acids, Bases, and the pH Scale

Acids donate H^+; bases accept H^+.

If a compound increases the **H^+** ion concentration when added to water, then the compound is **acidic**.

If the reaction is complete:

such as: $HCl \rightarrow H^+ + Cl^-$ it is a **strong acid**.

Not all acids "dissolve" fully into their ionic forms in water.

Acetic acid, for instance, does not completely react and is, therefore, called a **weak acid**.

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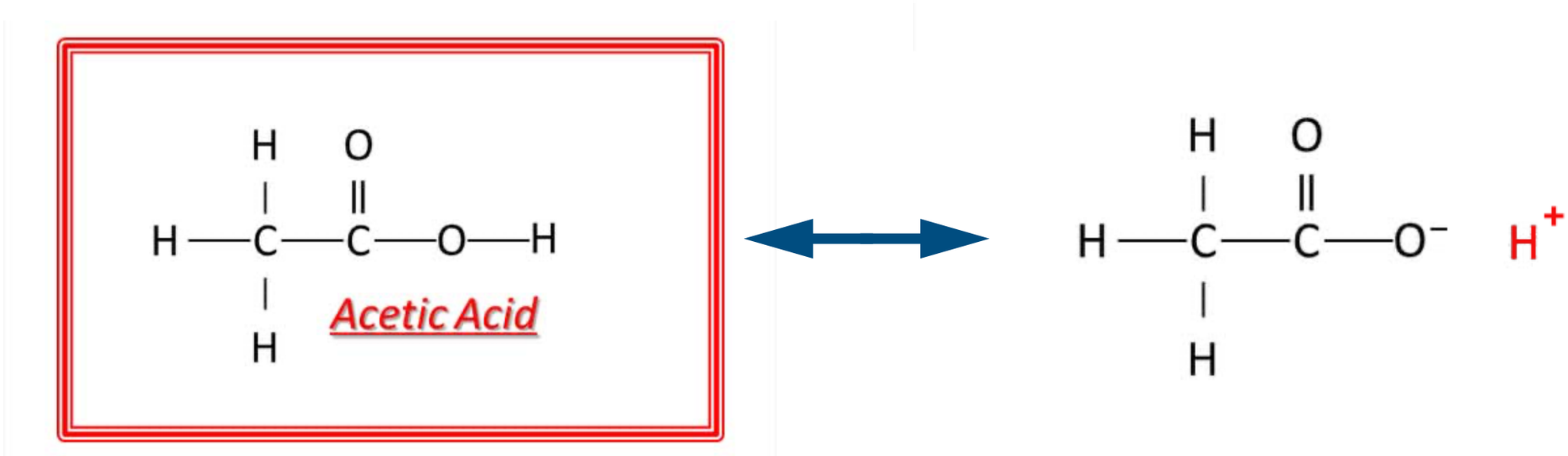

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Acids, Bases, and the pH Scale

Acids donate H^+; **bases accept H^+**

If a compound increases the **OH^-** ion concentration (which in effect will "mop up" available H^+ when added to water, then the compound is **basic**.

Just as with acids, there are strong and weak bases.

A **strong** base completely reacts: **$NaOH \longrightarrow Na^+ + OH^-$**.

A weak base, such as **bicarbonate**, does not completely react, and accepts H^+ ions in several ways, one being the formation of weak carbonic acid.

While water is both an acid and a base… it actually is a very "weak acid", and has a slight tendancy to ionize (break apart) into H^+ and OH^-.

This ionization is very important for living creatures and the chemical reactions they must perform.

Acids, Bases, and the pH Scale

Acids donate H^+; bases accept H^+.

Reversible chemical reactions -in principle- can proceed in either direction, but the extent of reversibility may vary.

$$\boxed{\text{—}NH_2 + H^+ \rightleftarrows \text{—}NH_3^+}$$

A carboxyl group (—COOH) is also common in a number of biological compounds.

As we will discuss further, **carboxyl groups** also function as **both an acid** and a **base,**

because —COOH $\rightleftarrows$ —COO^- + H^+

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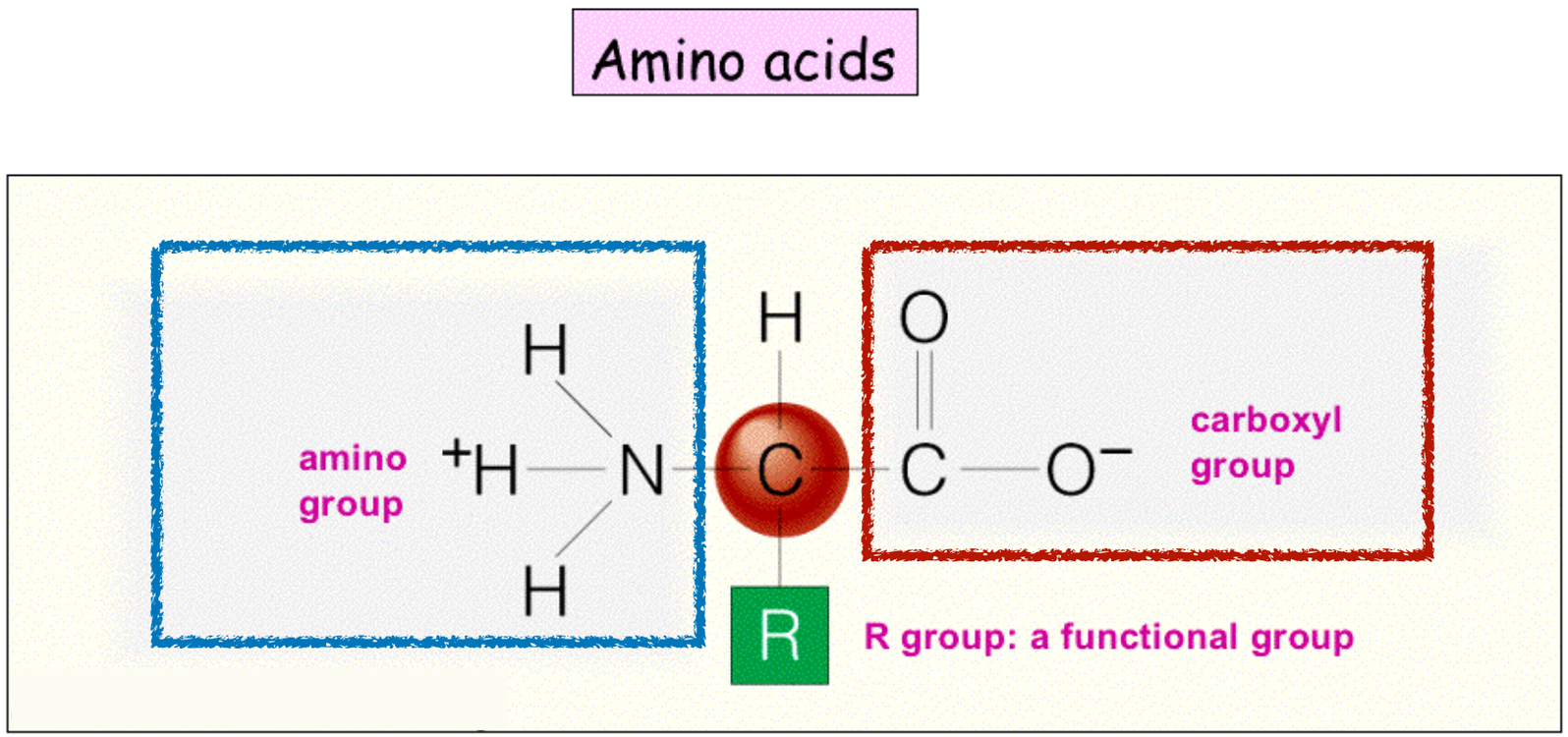
Amino acids: the very building blocks of proteins, contain both **carboxyl groups** and **amino groups**, so they are **simultaneously acids and bases**.



Acids, Bases, and the pH Scale

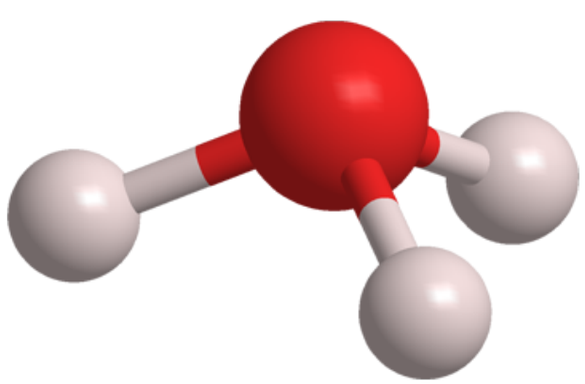
Acids donate H^+; bases accept H^+.

pH is the measure of **hydrogen ion** concentration in a solution,

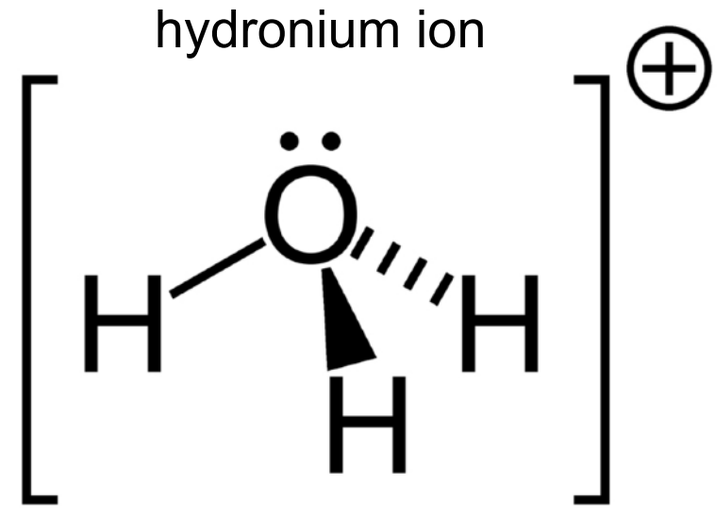
-first introduced in 1909, Soren Sorensen, a Danish biochemist, who proposed what is now known as the **pH scale**.

Sorensen developed a simple equation to express the hydr(ox)onium (hydronium) ion concentrations logarithmically.

hydronium ion



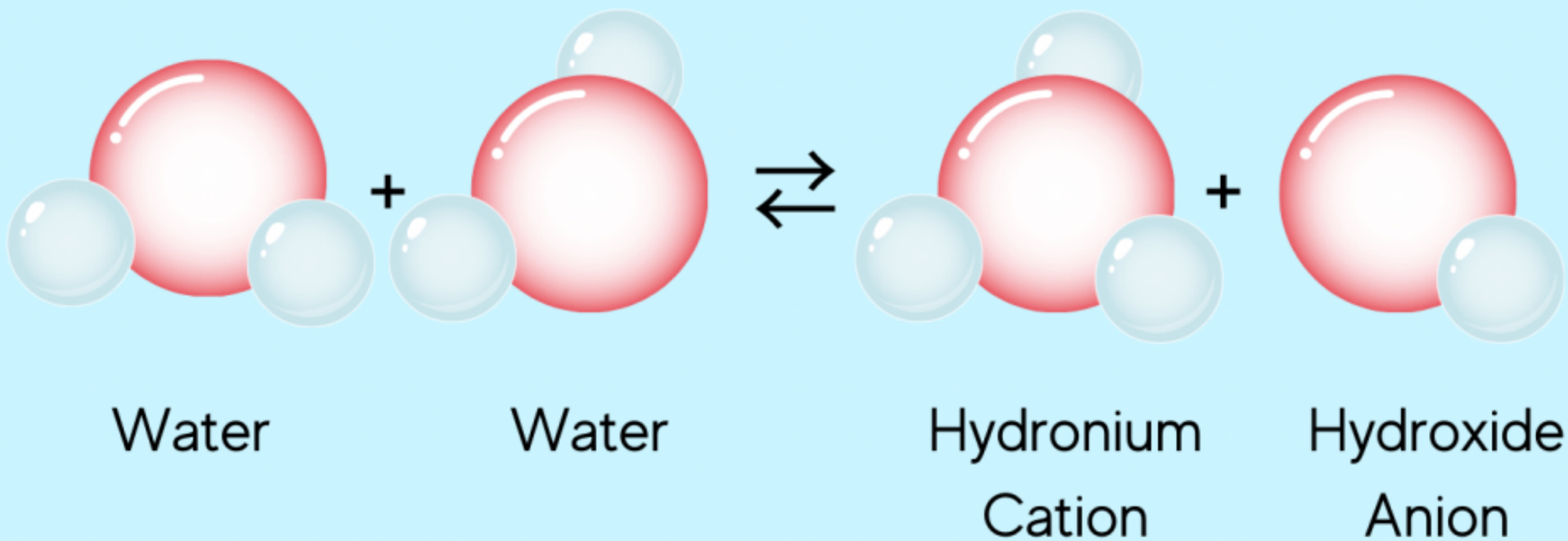
hydronium ion



Hydronium Ion or Oxonium

Hydronium is the ion H_3O^+. It is the simplest oxonium ion.

$$H_2O + H_2O \rightleftarrows H_3O^+ + OH^-$$



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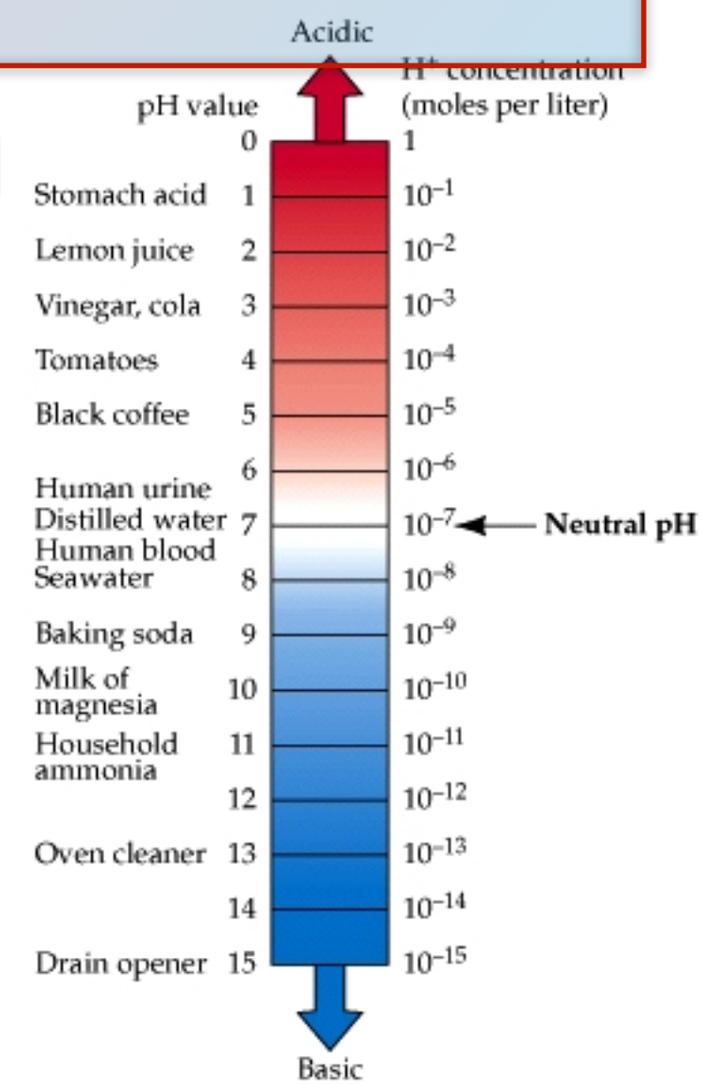
Acids, Bases, and the pH Scale

Acids donate H^+; bases accept H^+.

The **pH** of a solution is the **negative logarithm** (base 10) of the hydronium ion concentration (expressed in moles per liter).

The equation for the pH of a solution is: **pH = - log $[H_3O^+]$**

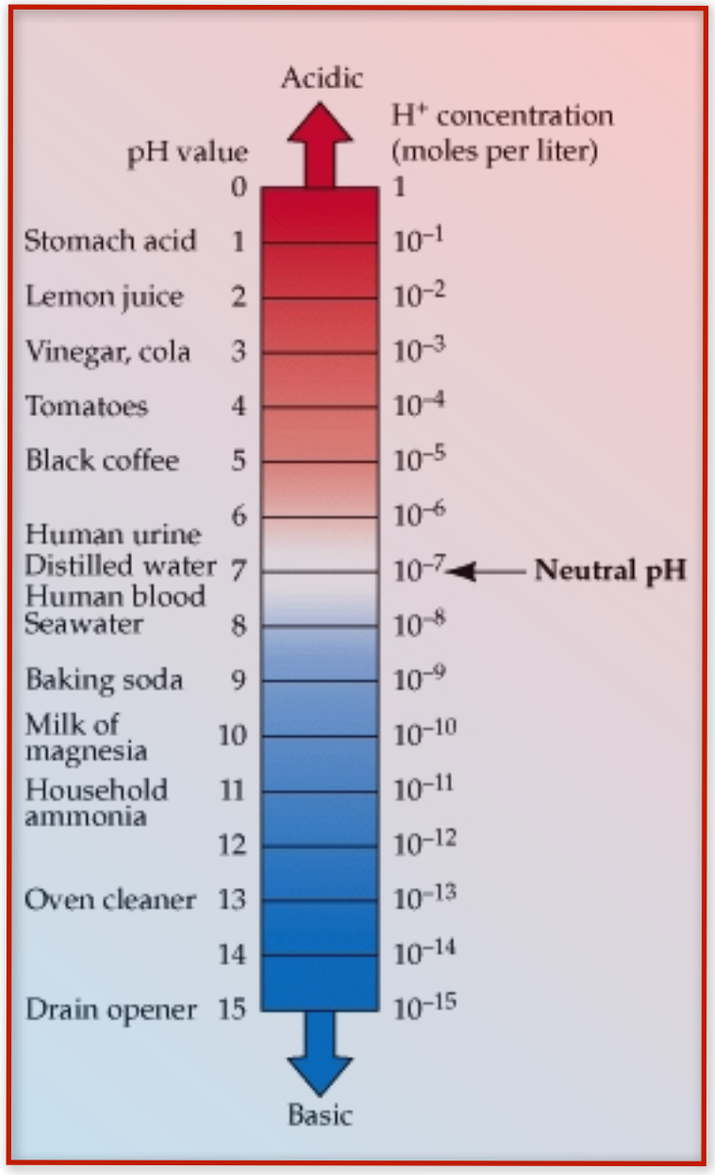


Acids, Bases, and the pH Scale

Acids donate H^+; bases accept H^+.

The **pH** of a solution is the **negative logarithm** (base 10) of the hydronium ion concentration (expressed in moles per liter).

The equation for the pH of a solution is: **$pH = -\log [H_3O^+]$**



A **pH 7** means that the concentration of hydrogen ions (or **more specifically the** concentration of **hydro(xo)nium ions [1 x 10^{-7}]**.

Even strongly acidic solutions have mostly water molecules and not ions.

A solution with **pH 1** has one H^+ for every **556 water molecules**
When water is at **pH 6**, it is 10^{-6} molar for H^+ and 10^{-8} molar for OH^-.
When water is at **pH 9**, it is 10^{-9} molar for H^+ and 10^{-5} molar for OH^-.

A solution at **pH 1** can have a powerfully corrosive effect on a variety of materials including metals, polysaccharides, proteins, nucleic acids, and bone.

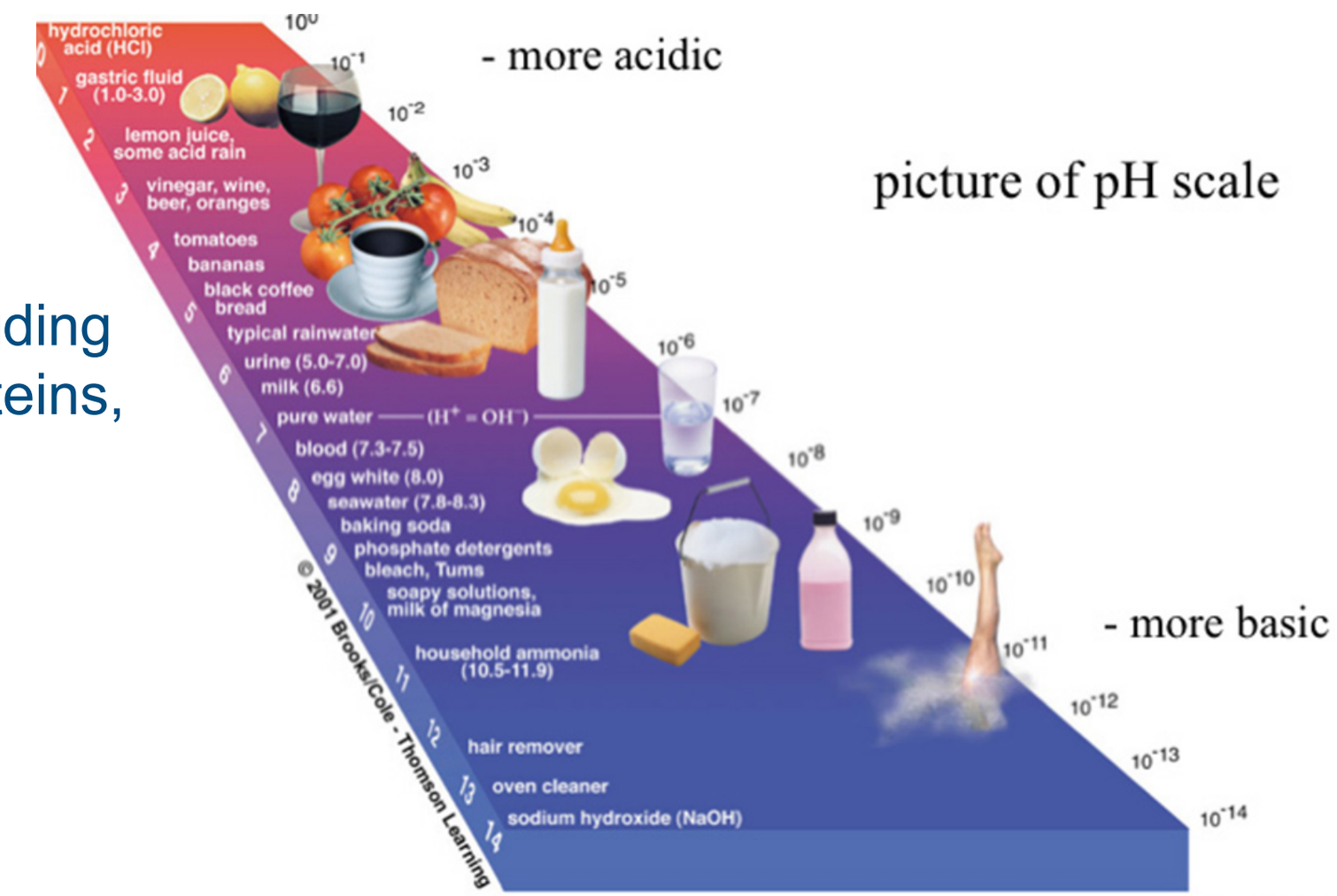


Fig. 2.17, p. 30

Buffers minimize pH change

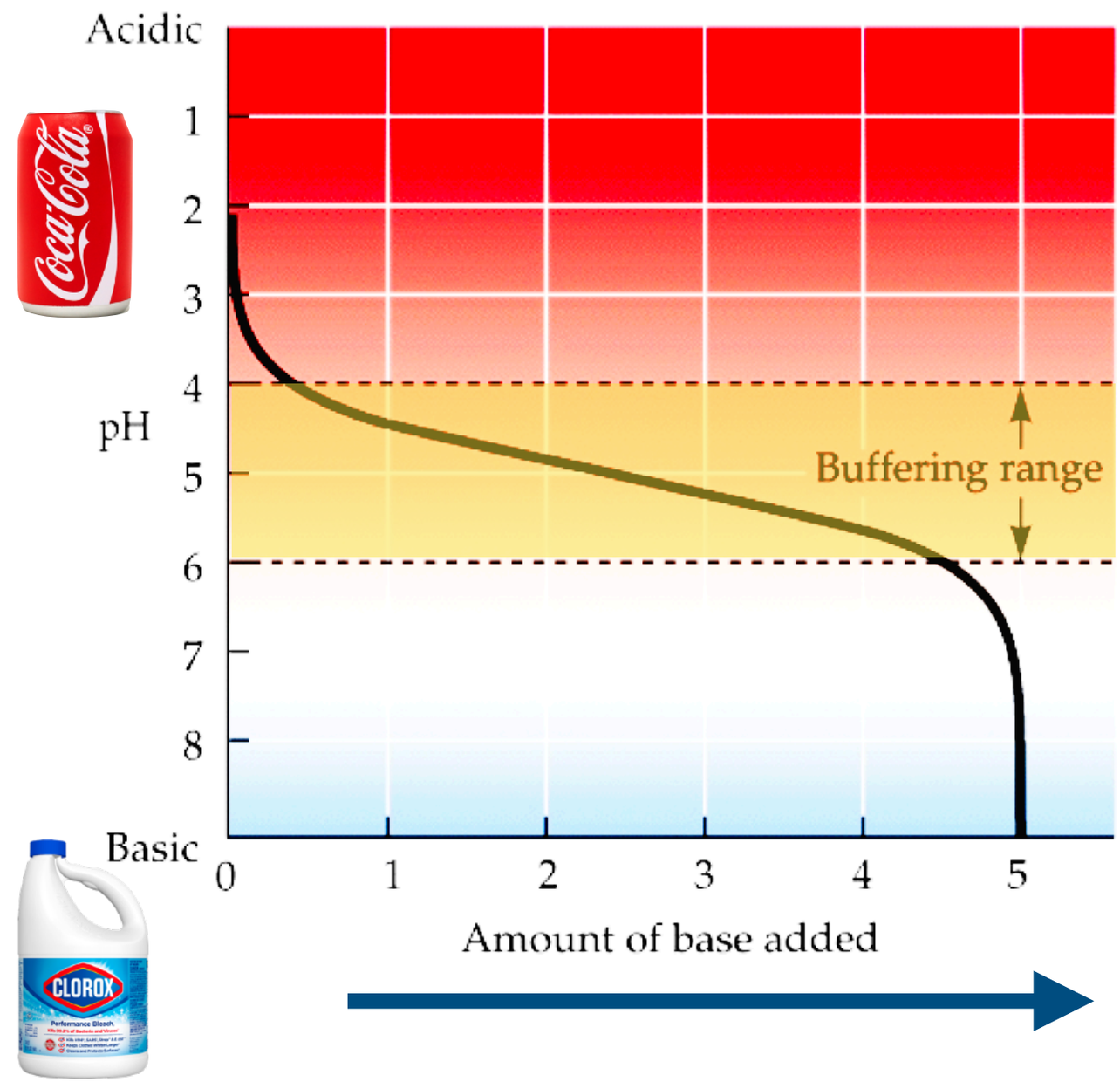
A **Buffer** is a mixture of a weak acid and its corresponding weak base.

Because buffers can react with both added bases and acids, they make the overall solution more resistant to changes in.

Different buffers transition to and from ionic forms at their particular characteristic pH ranges.

Buffers are common in biology and extremely important in the regulation of the internal environments of organisms.

Many important biological buffers transition around **pH 7**, which keeps the pH near neutral.



Buffers minimize pH change

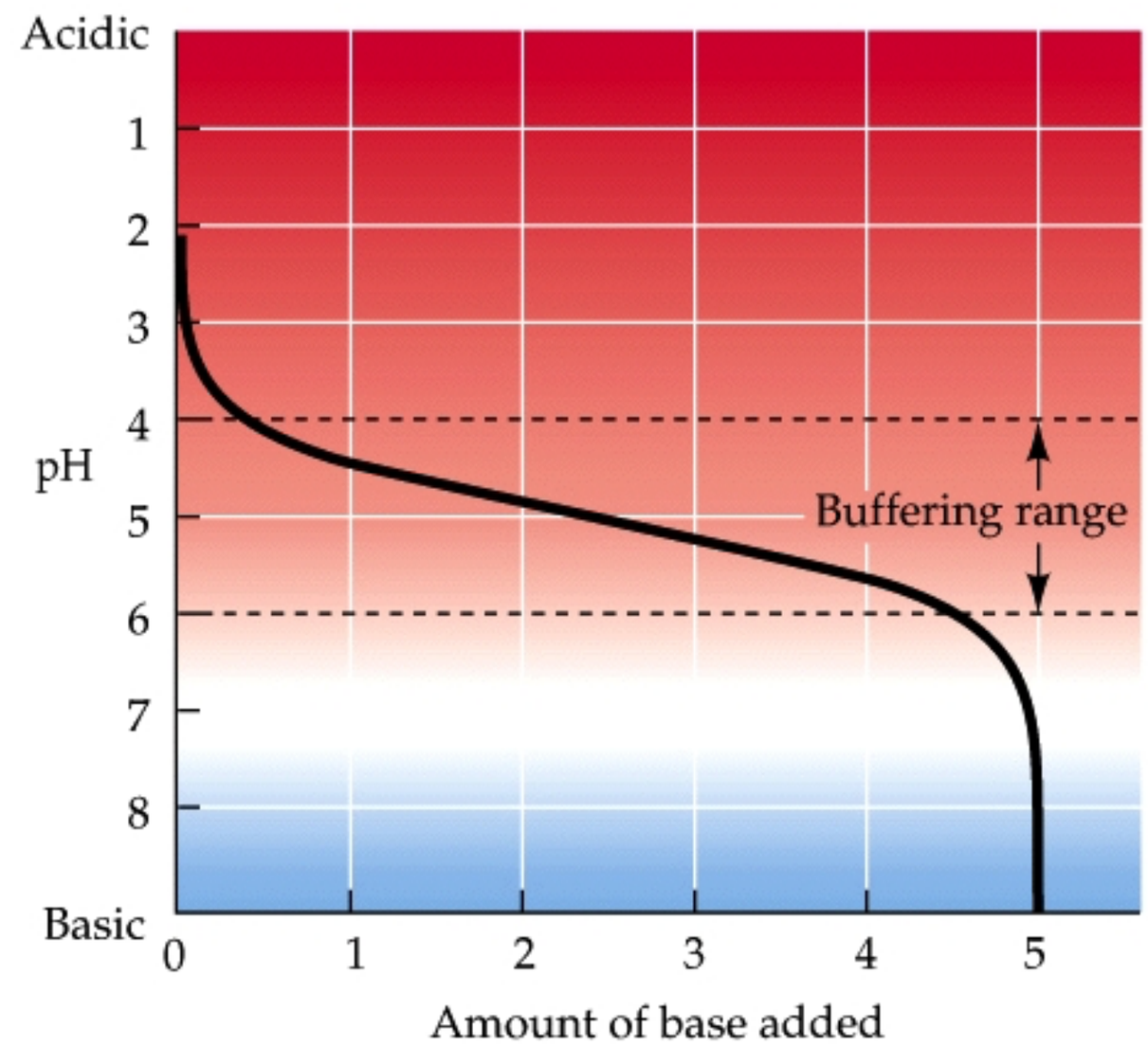
A **Buffer** is a mixture of a weak acid and its corresponding weak base.

Because buffers can react with both added bases and acids, they make the overall solution more resistant to changes in.

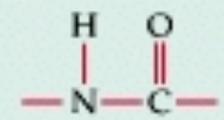
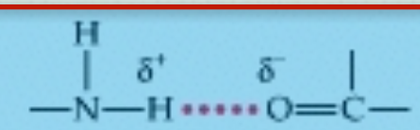
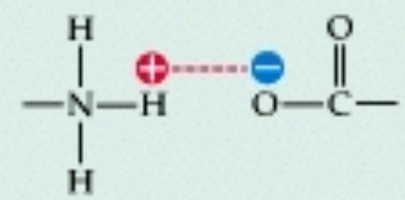
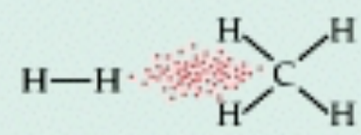
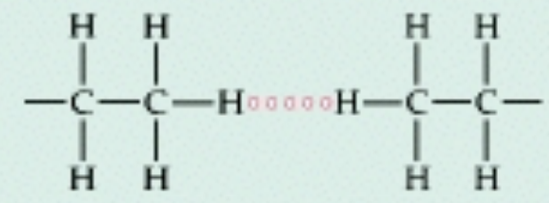
Buffers illustrate the law of **mass action:**

The addition of components to one side of a reaction drives the reaction in the direction that uses that component.

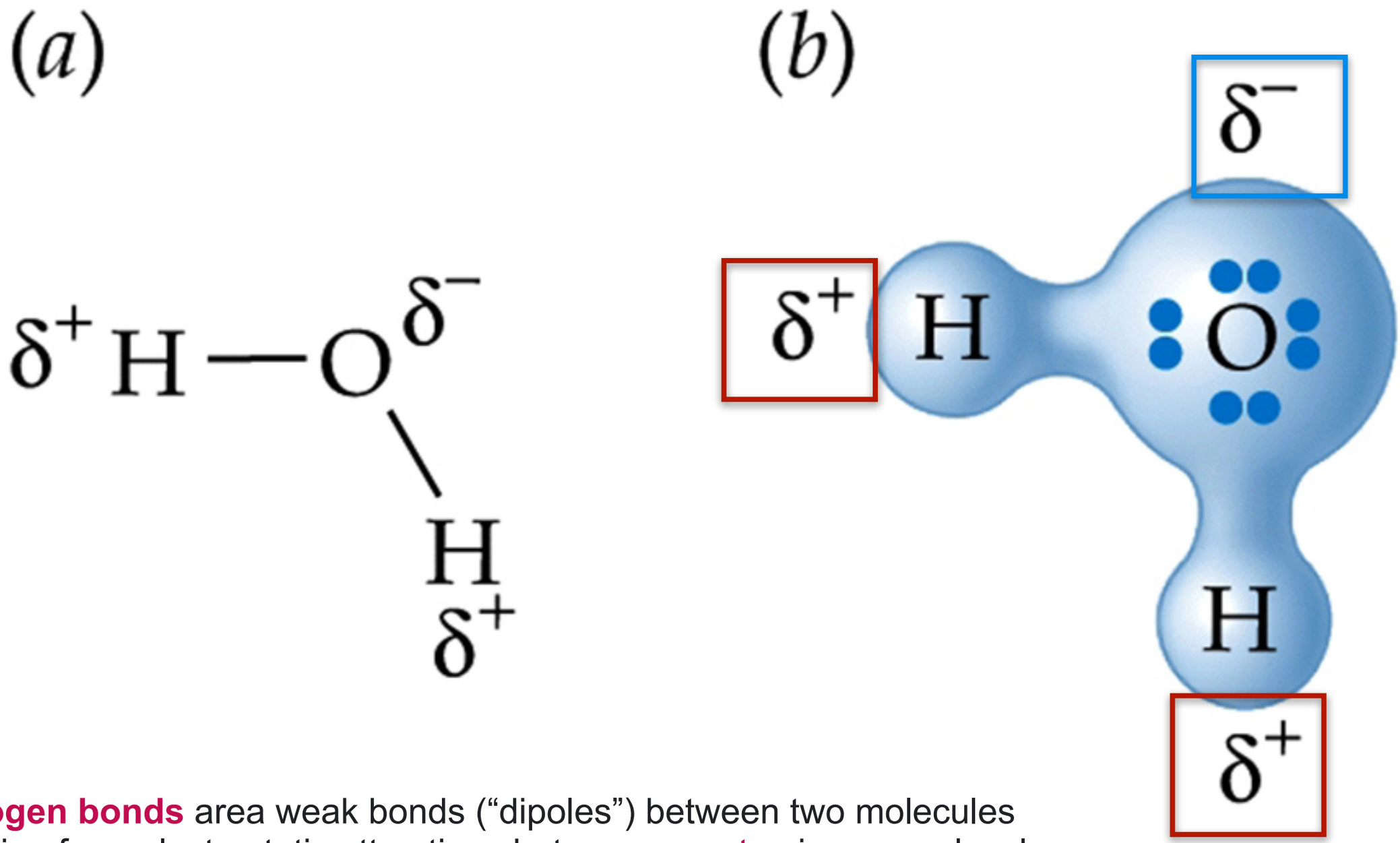
As an acid or a base is added to a solution, the buffer will change form, transitioning between ionic and non-ionic bonds



2.1 Chemical Bonds and Interactions

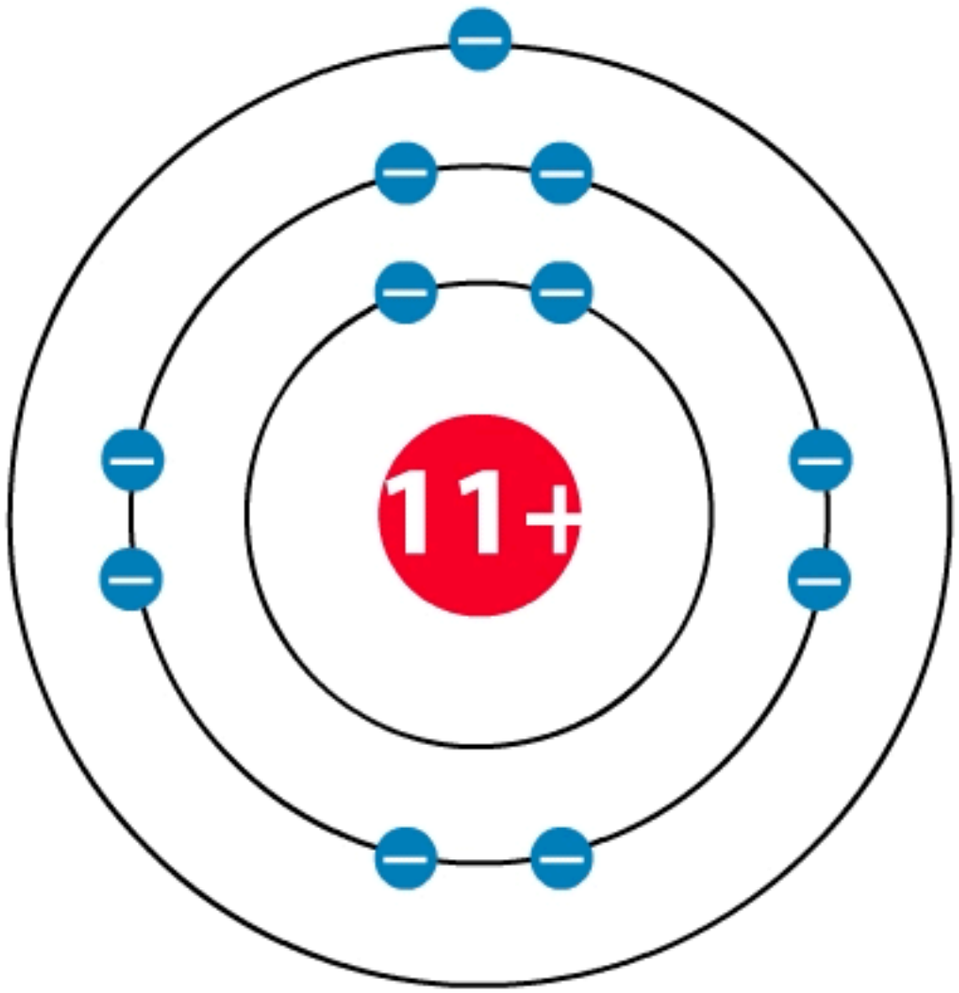
NAME	BASIS OF INTERACTION	STRUCTURE	BOND ENERGY[a] (KCAL/MOL)
Covalent bond	Sharing of electron pairs		50–110
Hydrogen bond	Weak electrostatic interactions		3–7
Ionic interaction	Attraction of opposite charges		3–7
van der Waals interaction	Interaction of electron clouds		1
Hydrophobic interaction	Interaction of nonpolar substances		1–2

[a]*Bond energy* is the amount of energy needed to separate two bonded or interacting atoms under physiological conditions.

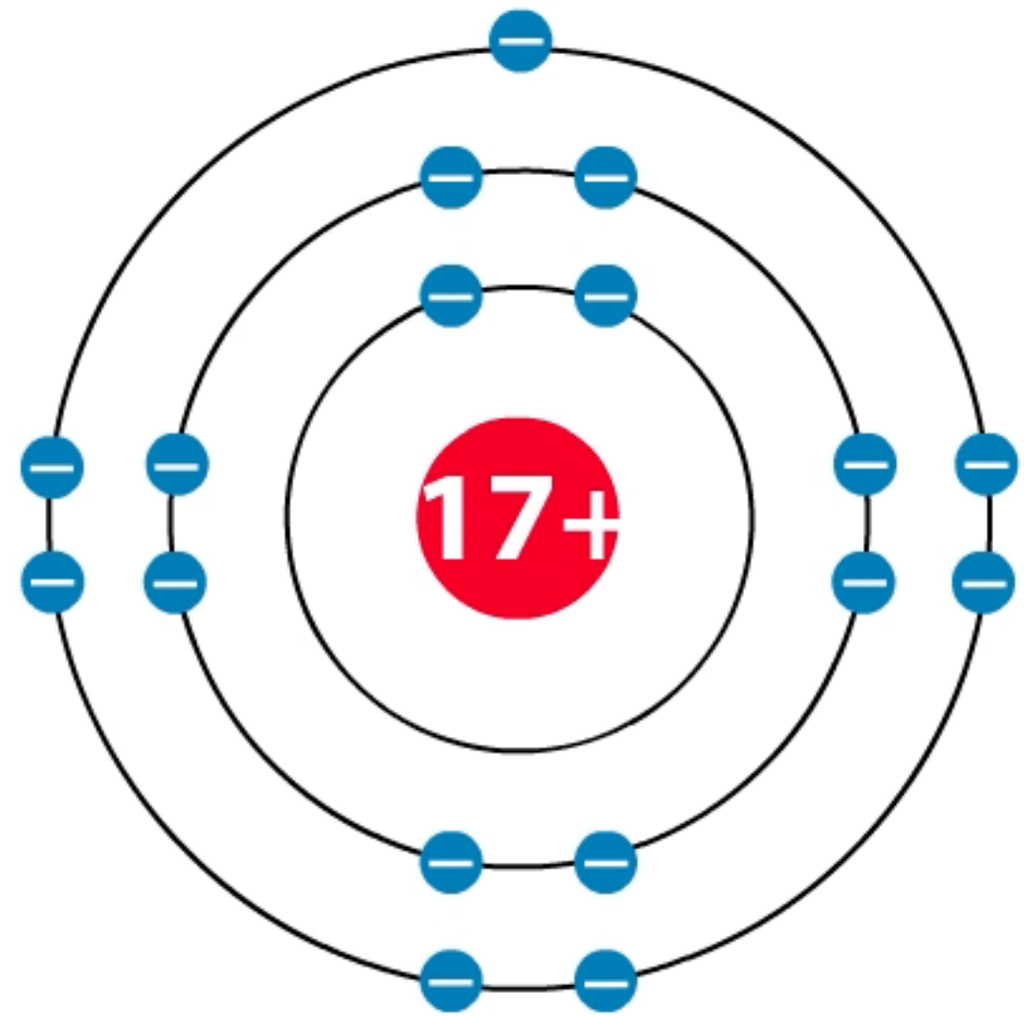


Hydrogen bonds area weak bonds ("dipoles") between two molecules -resulting from electrostatic attractions between a proton in one molecule and an electronegative region of a molecule in the other.

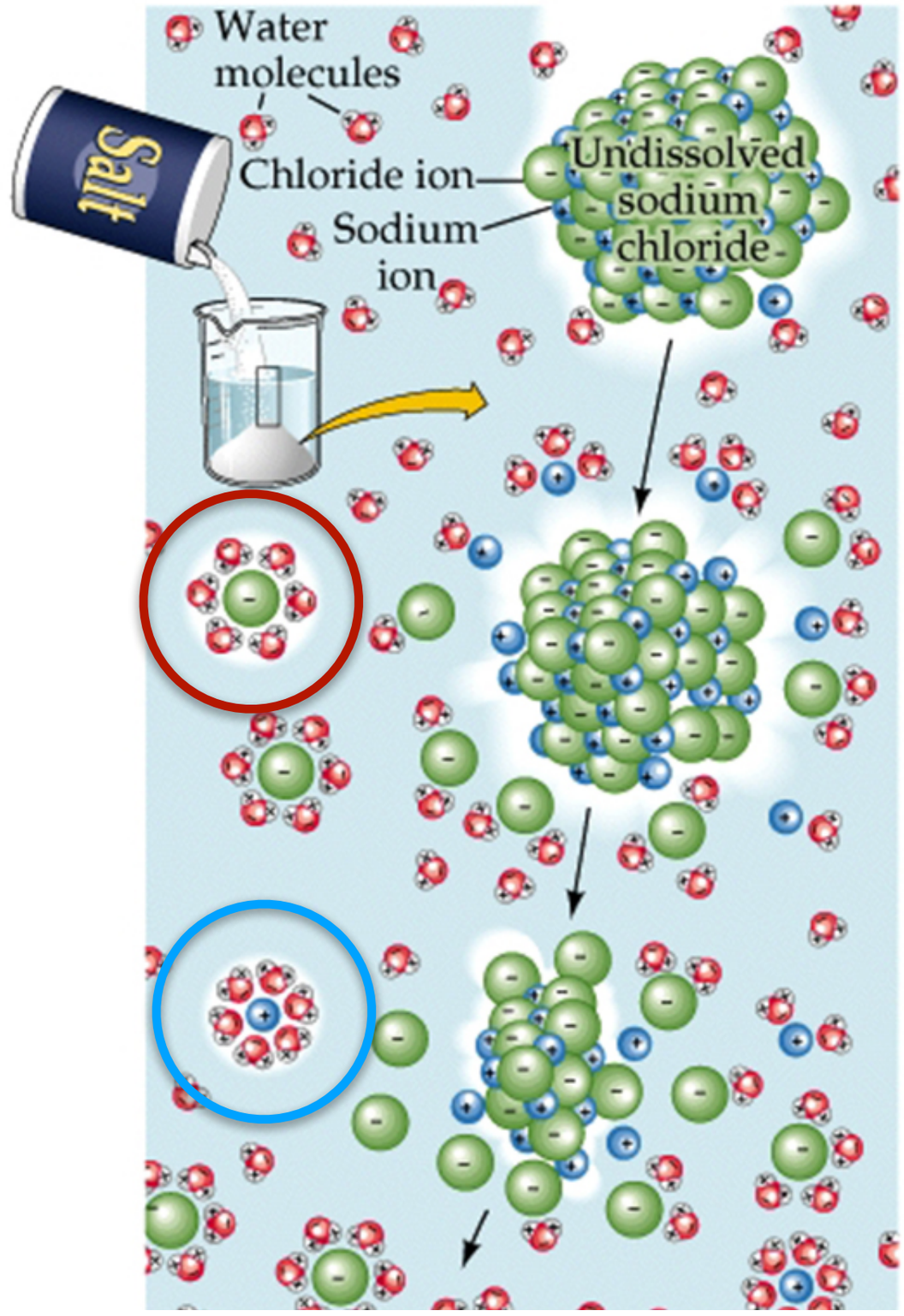
Ionic Bonds



sodium atom

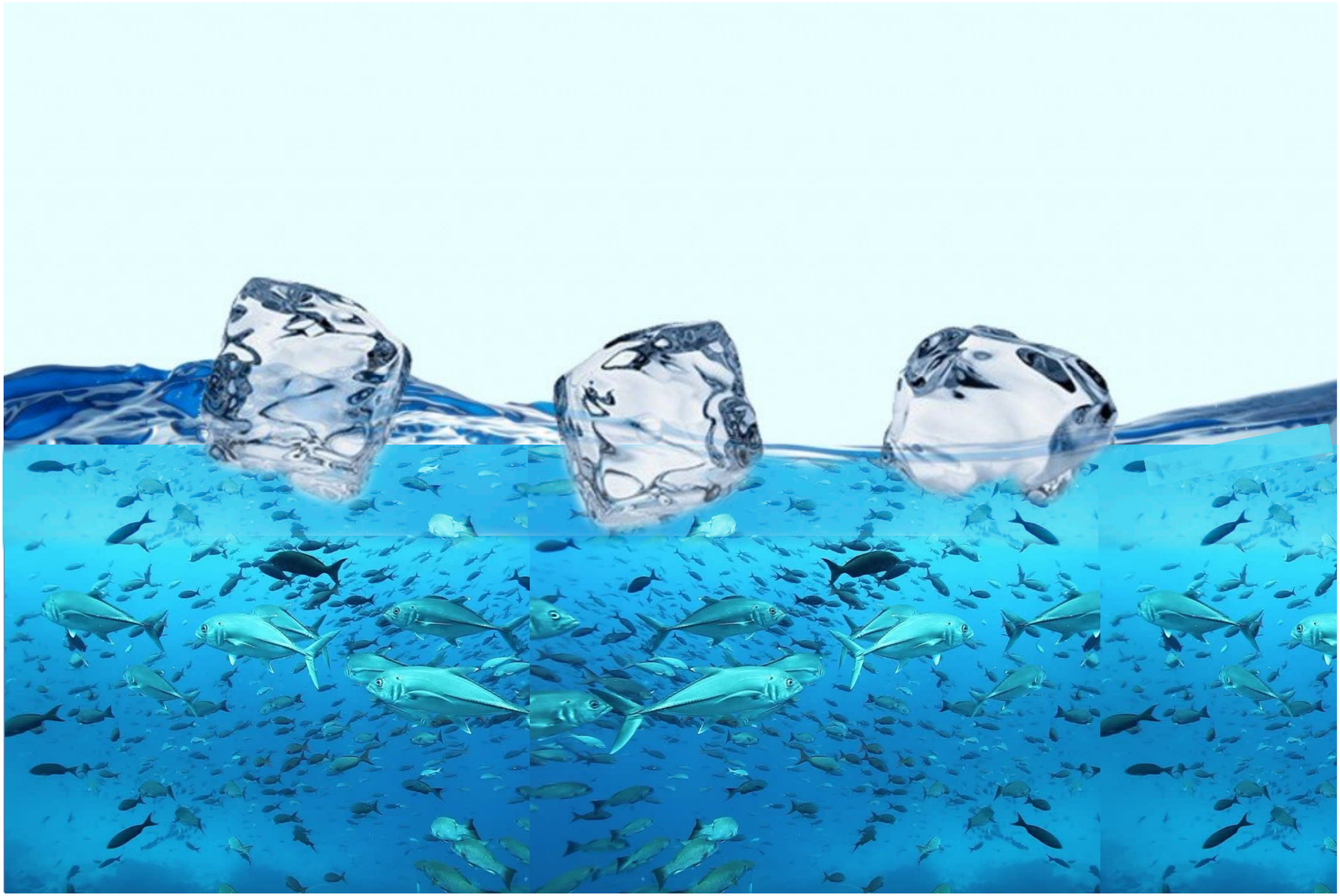


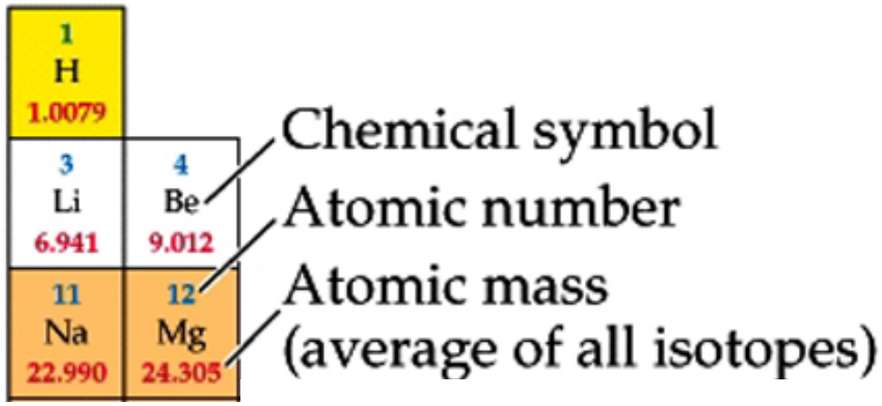
chlorine atom

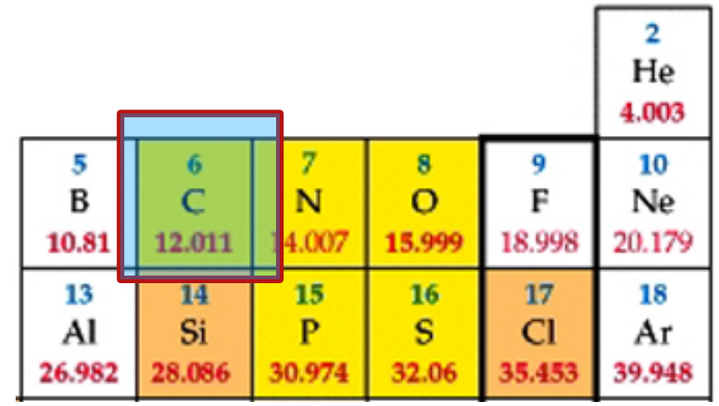

Water molecules
Salt
Chloride ion
Sodium ion
Undissolved sodium chloride

Hydrogen Bonds and the Structure of Water and Ice

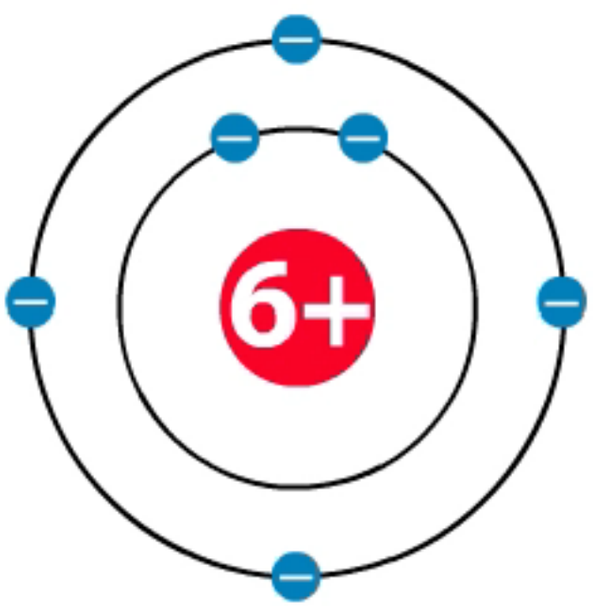
A hydrogen bond is a type of chemical bond. Extensive networks of hydrogen bonds largely define the physical properties of water.



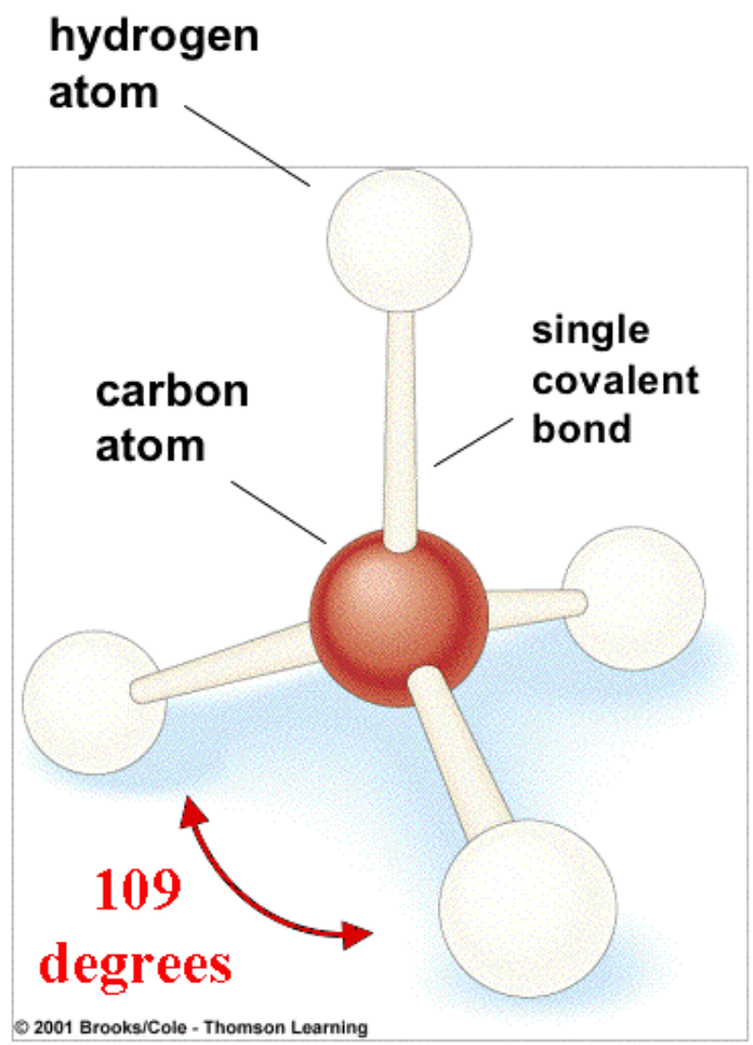




A closer look at carbon



Carbon



methane(CH_4)

-atomic number of 6 (six protons)

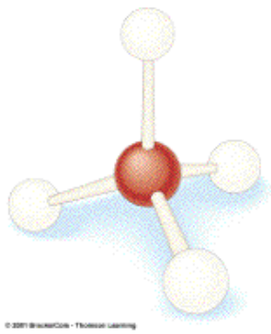
- 2 inner shell electrons

- +4 in its outer shell

- needs to share four electrons with partner atoms

- tetrahedral geometry

Building larger molecules with carbon



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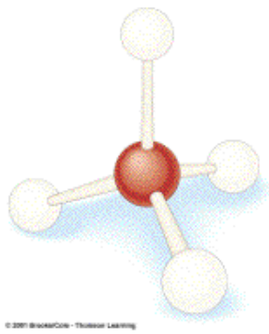
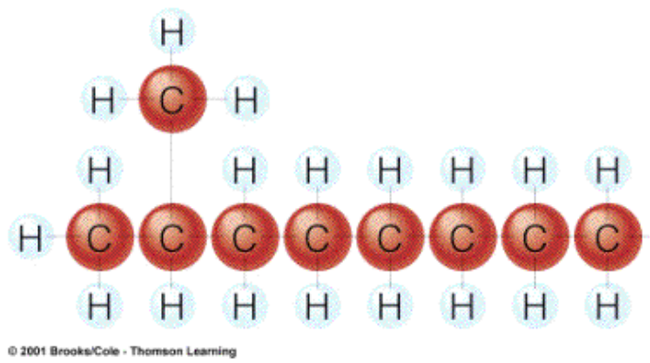


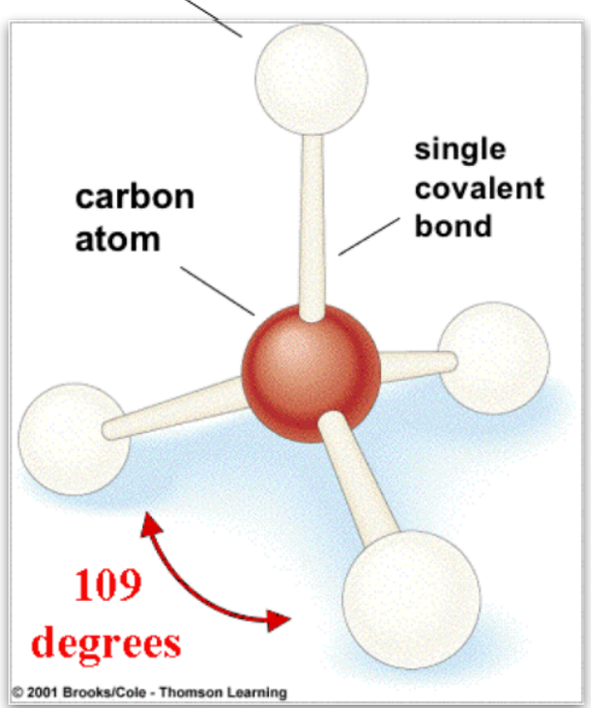
etc.... =

carbon "backbone"



- a carbon chain

A closer look at carbon



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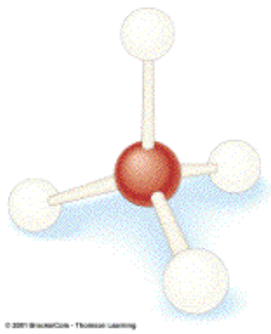

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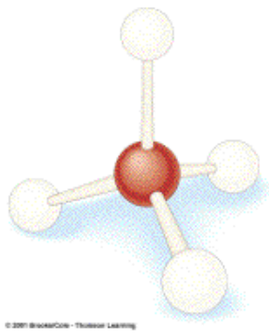
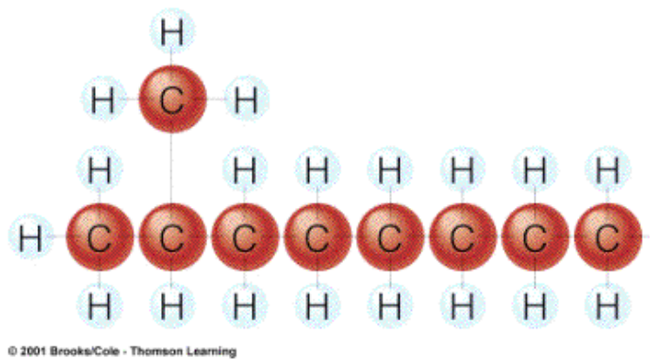


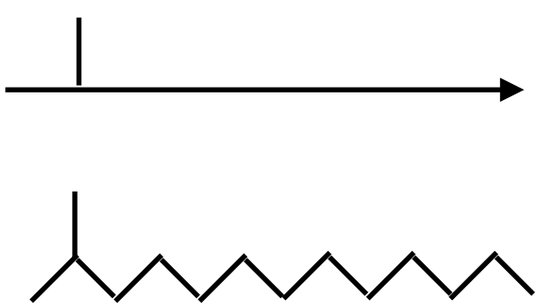
etc....

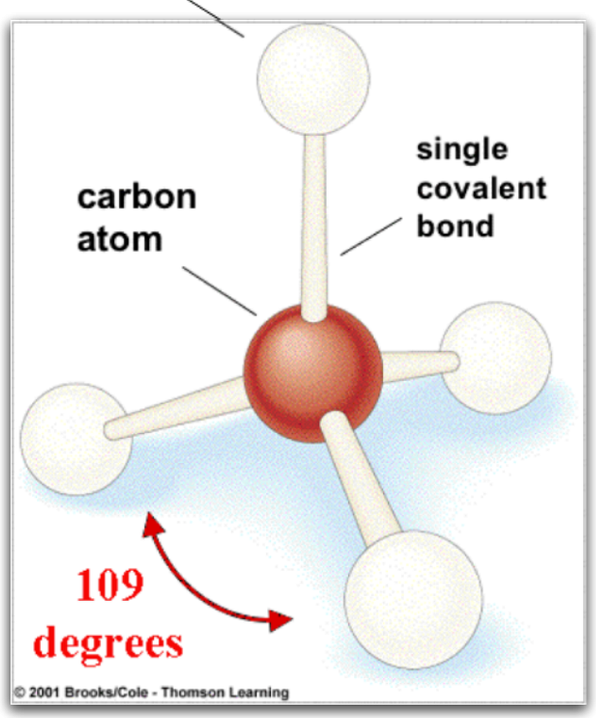
=

carbon "backbone"



- a carbon chain





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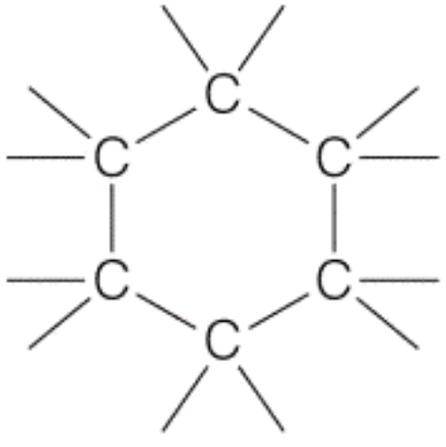
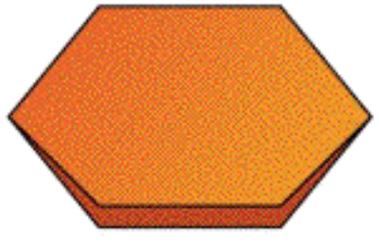
- tetrahedral geometry

Building stable ring structures with C



or



carbon rings

benzene

- electrons are shared among all the C atoms, or delocalized, and make rings very stable

- molecules that have a benzene ring backbone are called aromatic

Macromolecules: Giant Polymers

There are four major types of biological macromolecules:

Proteins, Carbohydrates, Lipids (?), and **Nucleic acids.**

These macromolecules are made the same way in all living things, and they are present in all organisms in roughly the same proportions.

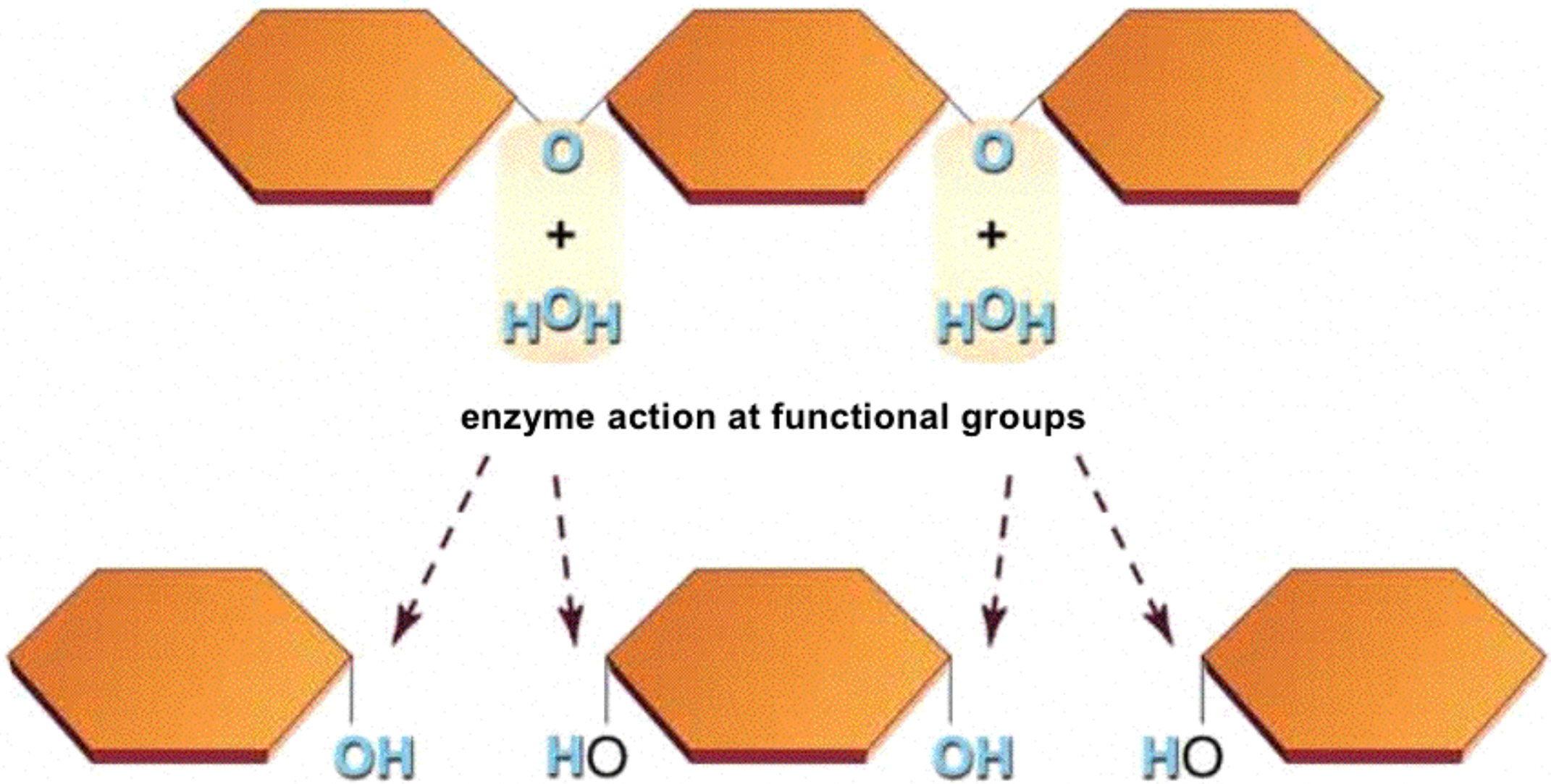
Macromolecules are essentially GIANT polymers, which are formed by **covalent linkages** of smaller units called monomers.

Molecules with molecular weights greater than **1,000 Daltons** (atomic mass units) are usually classified as "**macromolecules**".

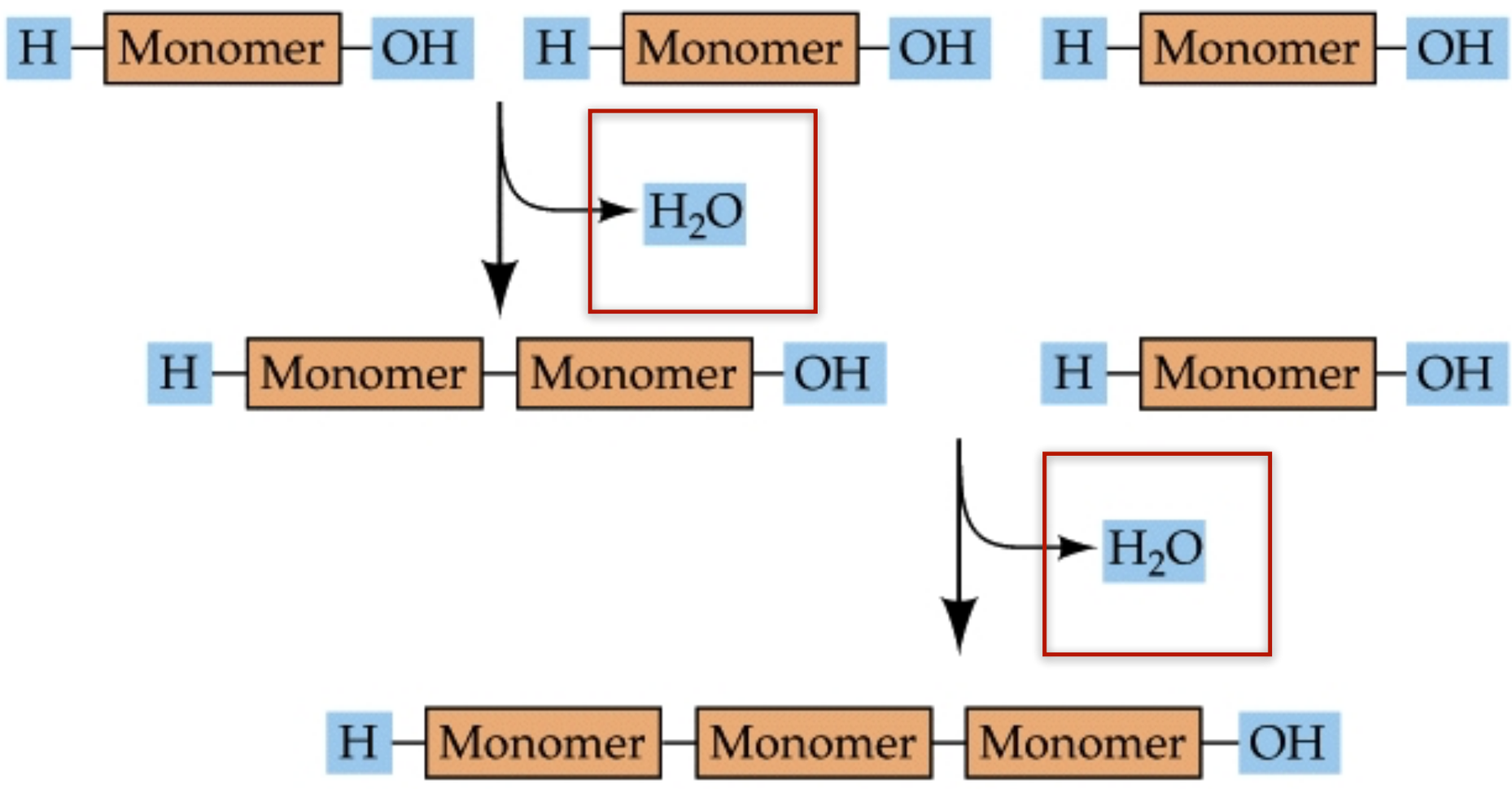
Some of the many roles of **macromolecules** include:

Energy source
Energy storage
Structural support
Catalysis
Transport
Protection and defense
Regulation of metabolic activities
Maintenance of homeostasis
Means for movement, growth, and development
Heredity

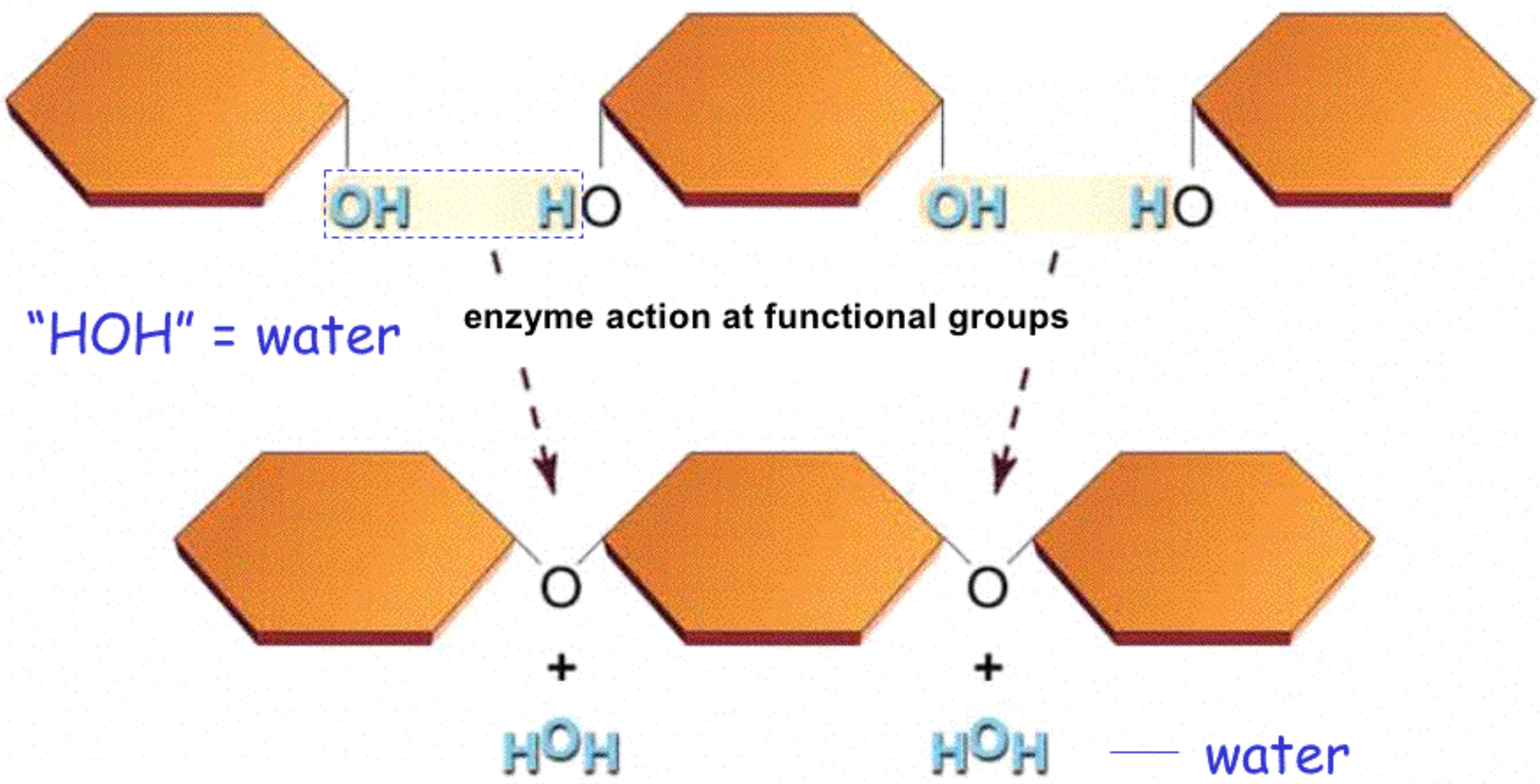
Hydrolysis



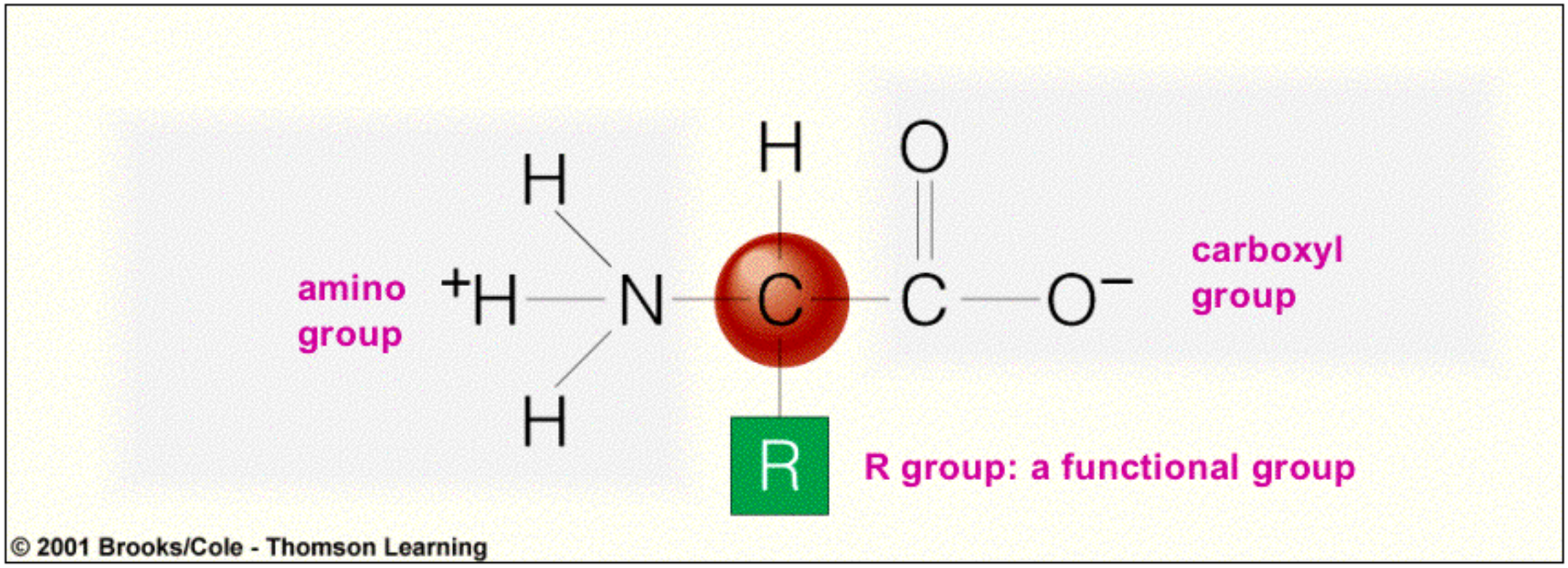
(*a*) **Condensation**

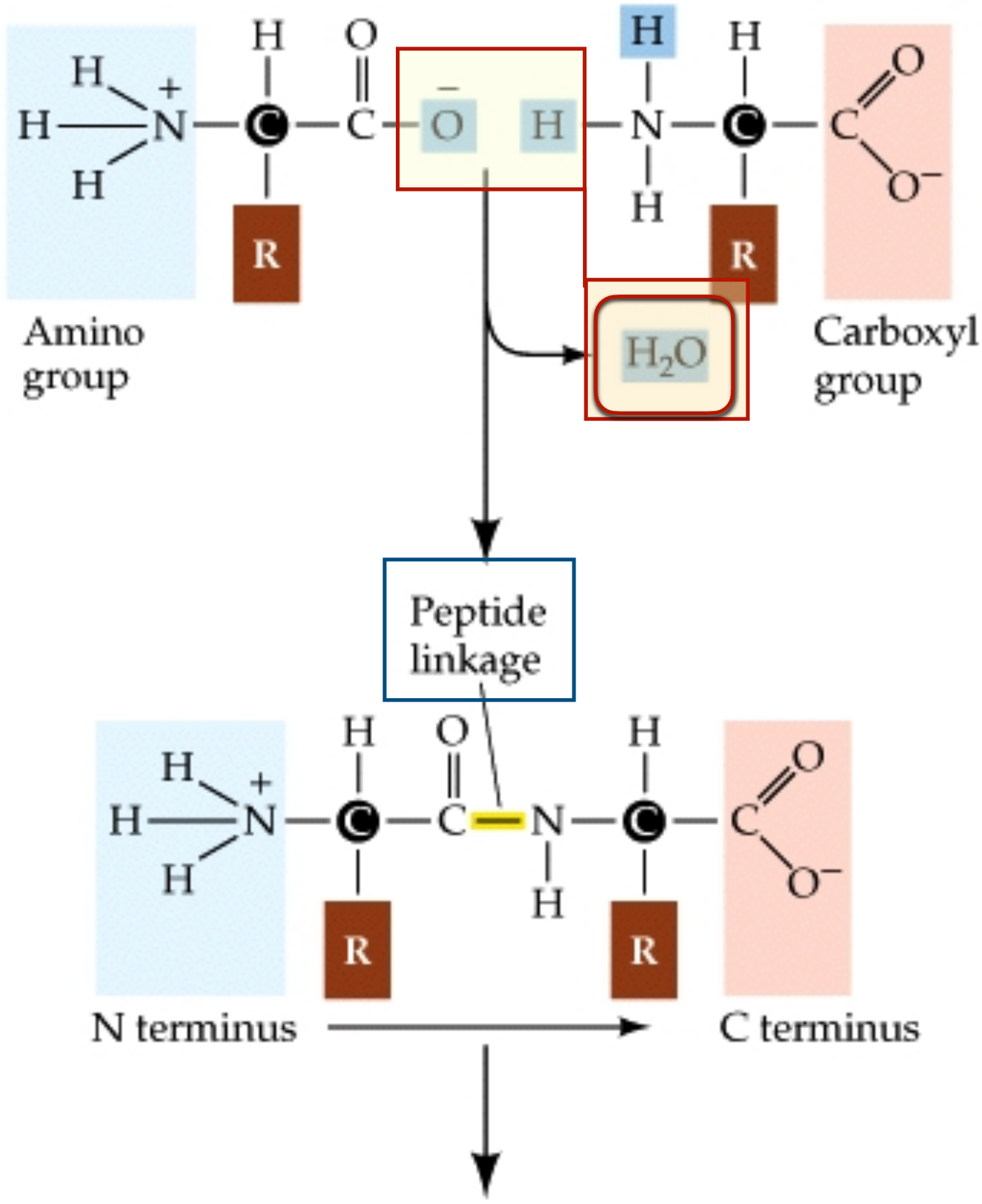


Condensation

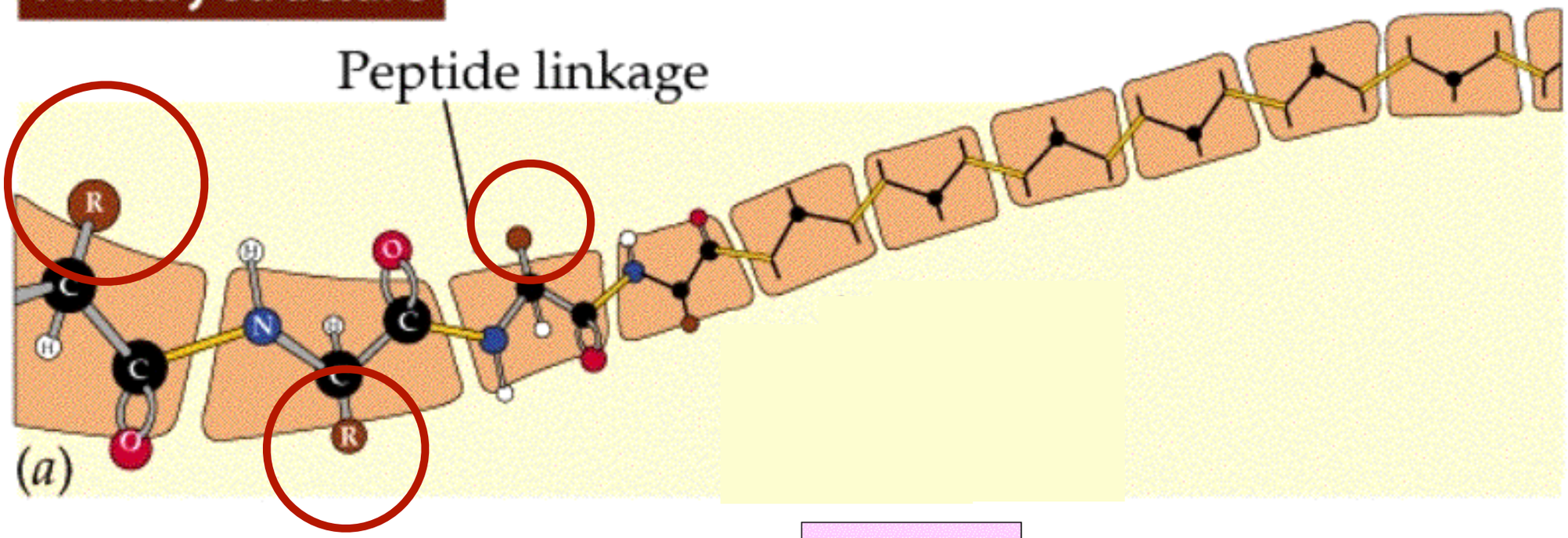


Amino acids

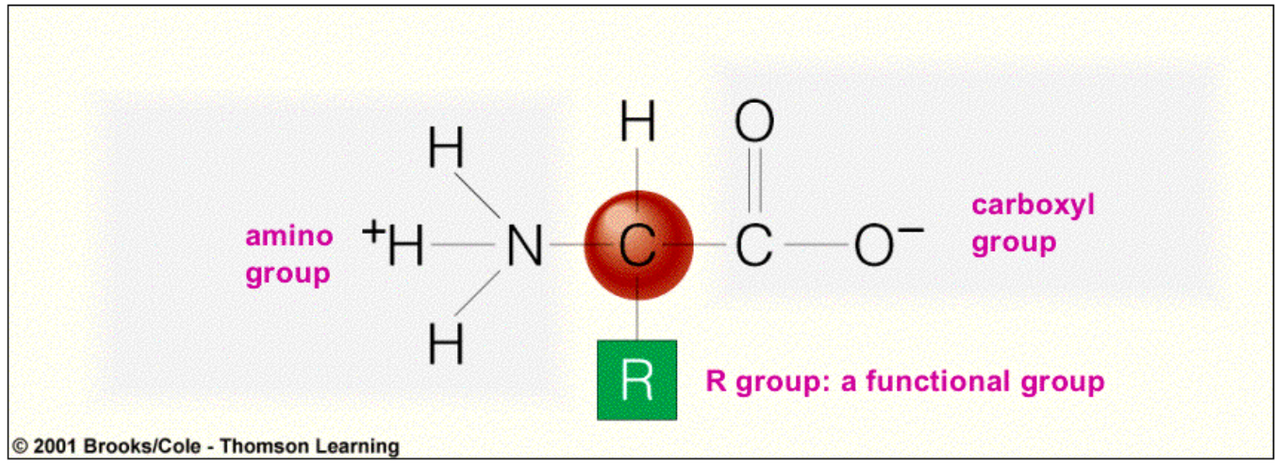

H
H
O
amino group
+H
N
C
C
O−
carboxyl group
H
R
R group: a functional group
© 2001 Brooks/Cole - Thomson Learning


Amino group
Carboxyl group
H_2O
Peptide linkage
N terminus
C terminus

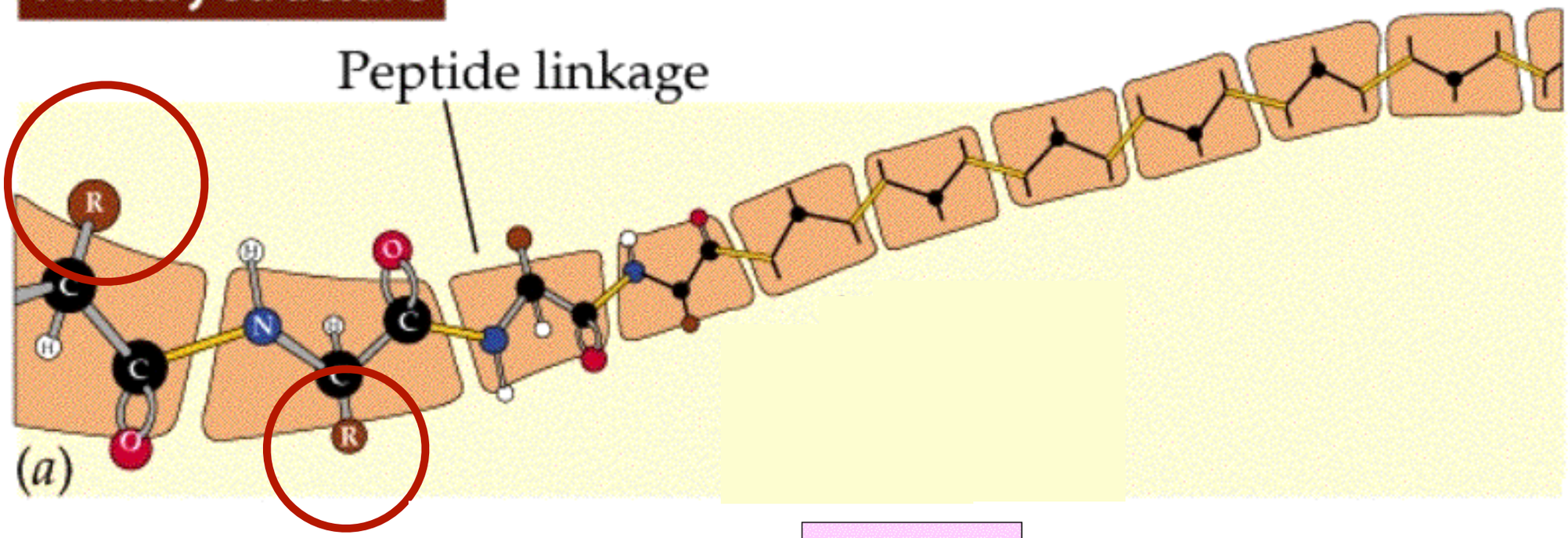
Primary structure



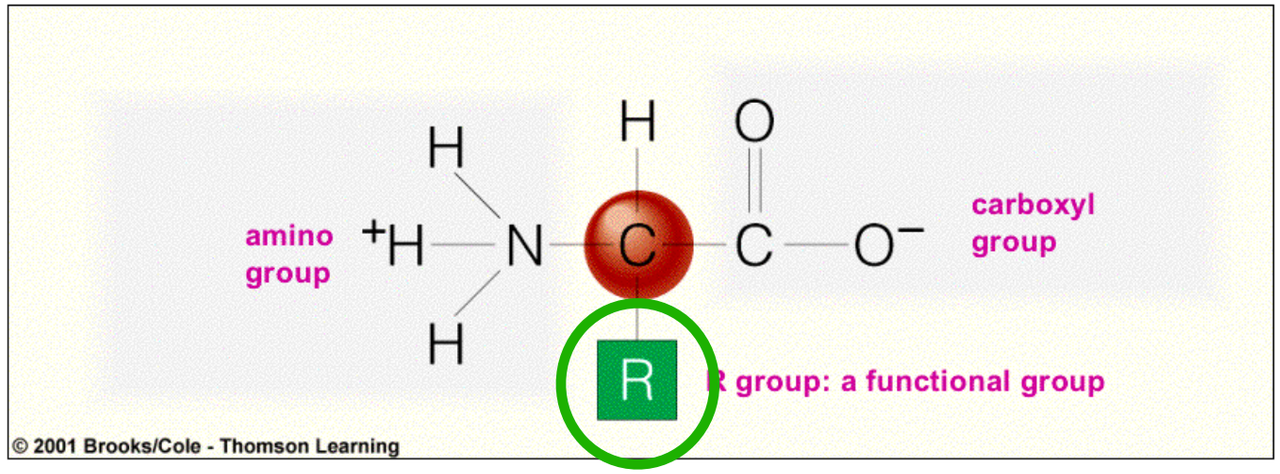
Amino acids



Primary structure

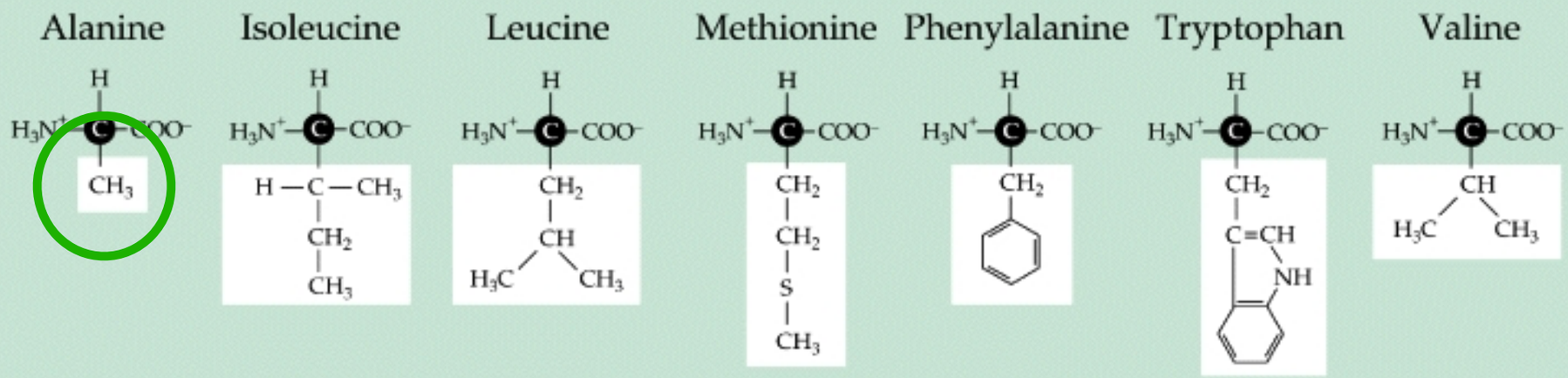


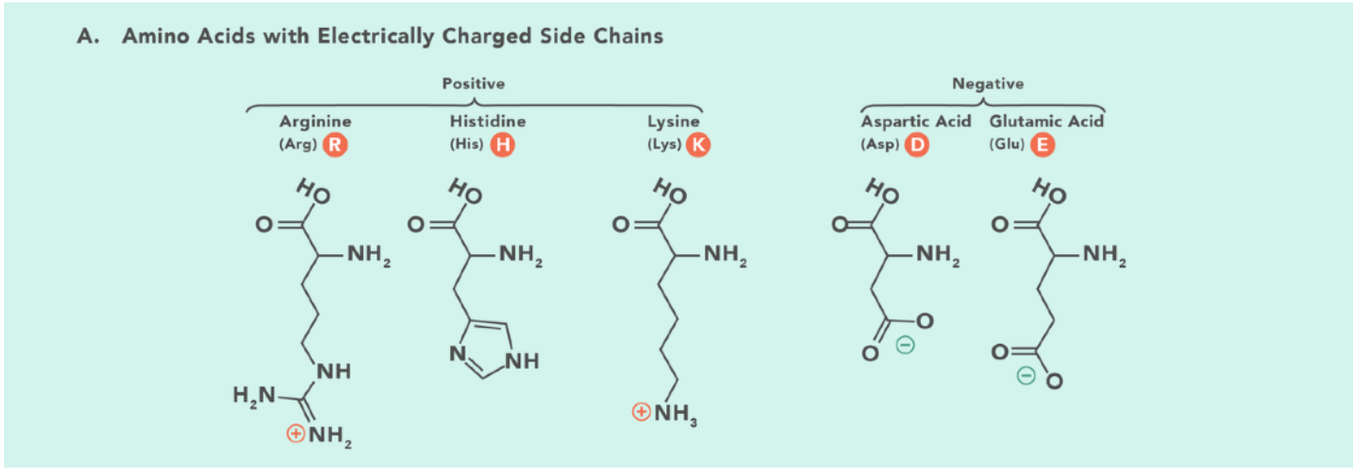
Amino acids

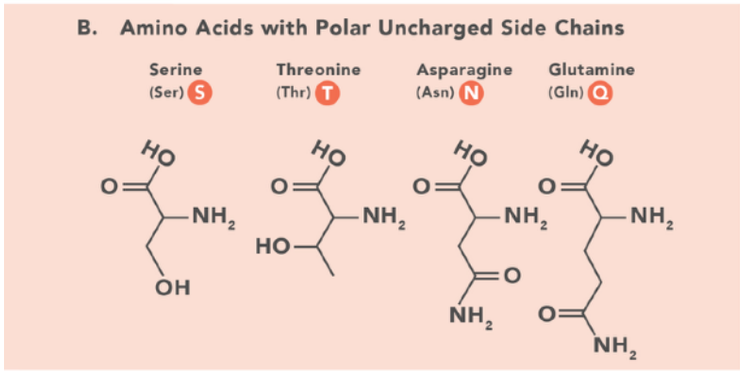


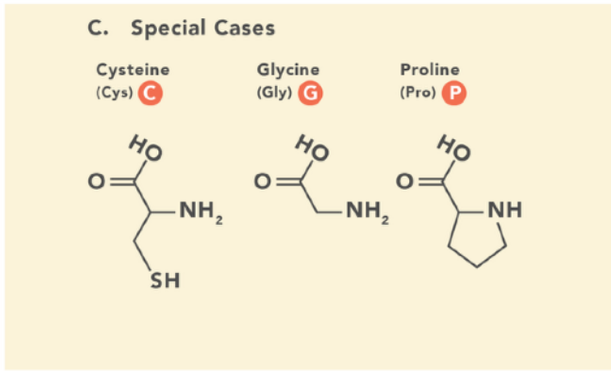
3.2 Twenty Amino Acids Found in Proteins

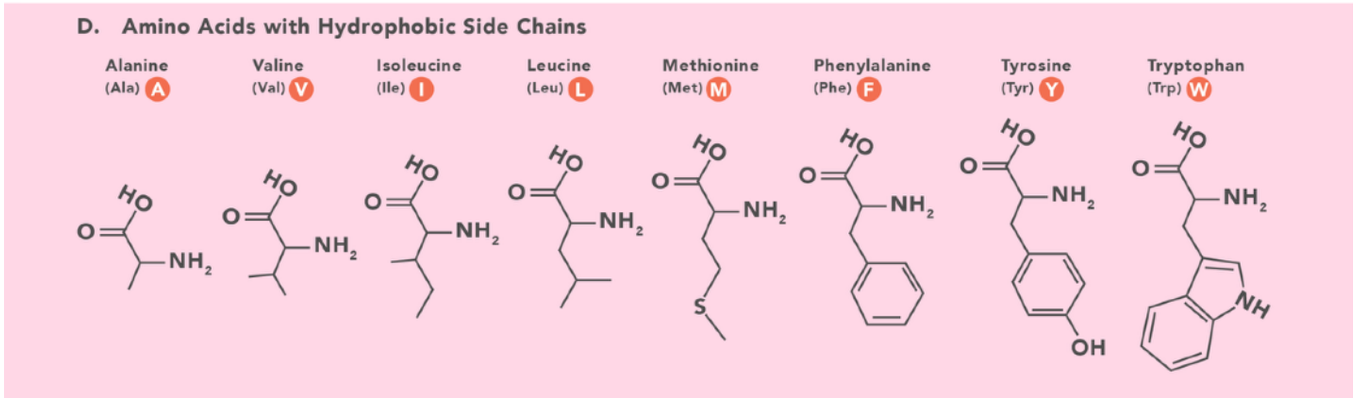
D. *Amino acids with hydrophobic side chains*





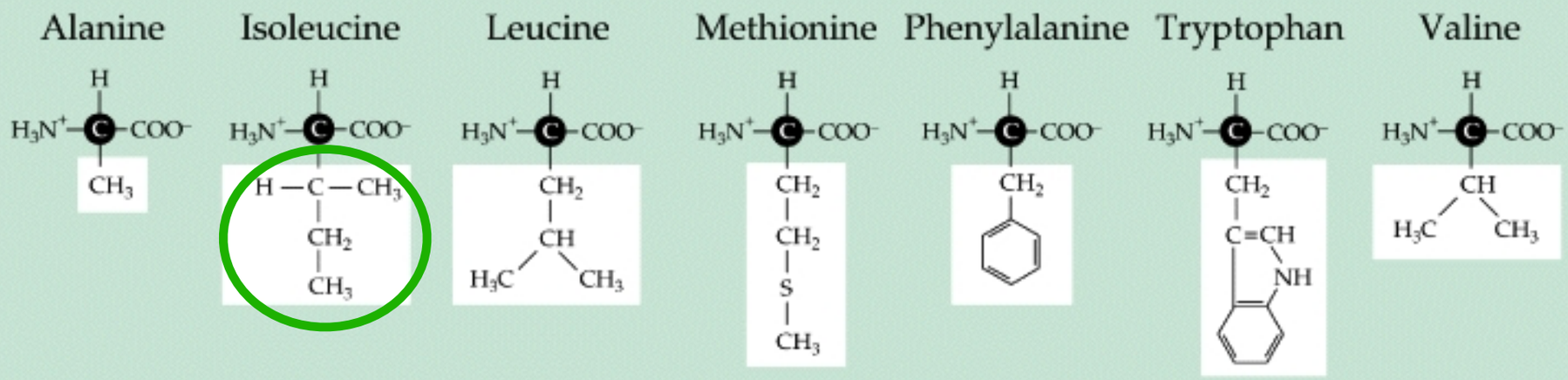


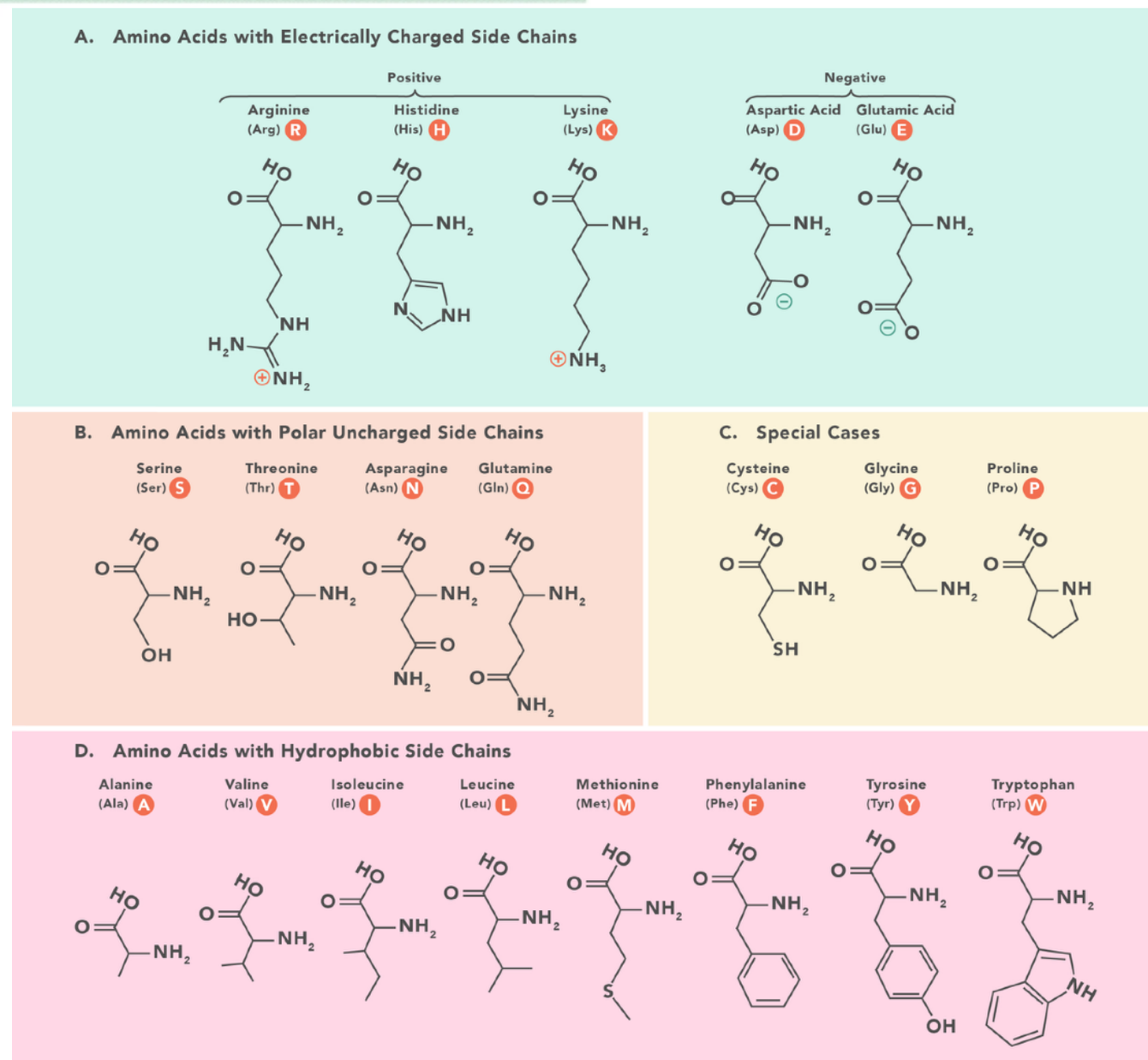




3.2 Twenty Amino Acids Found in Proteins

D. *Amino acids with hydrophobic side chains*





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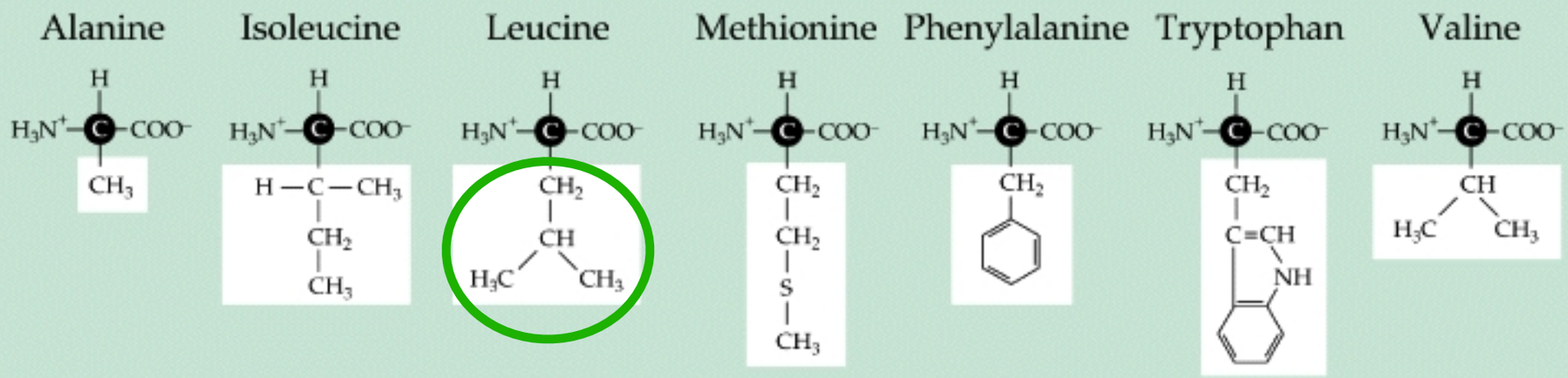
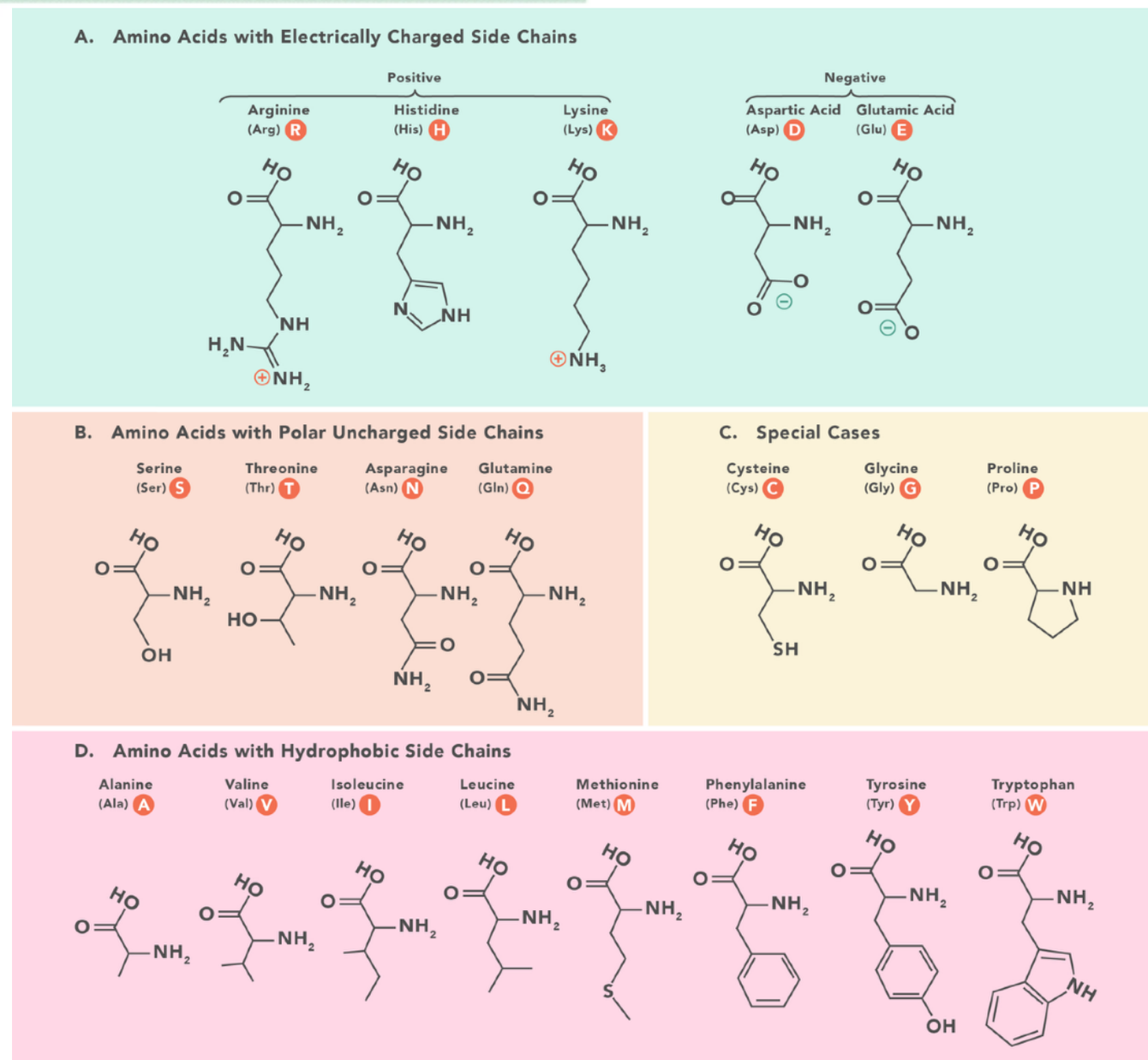




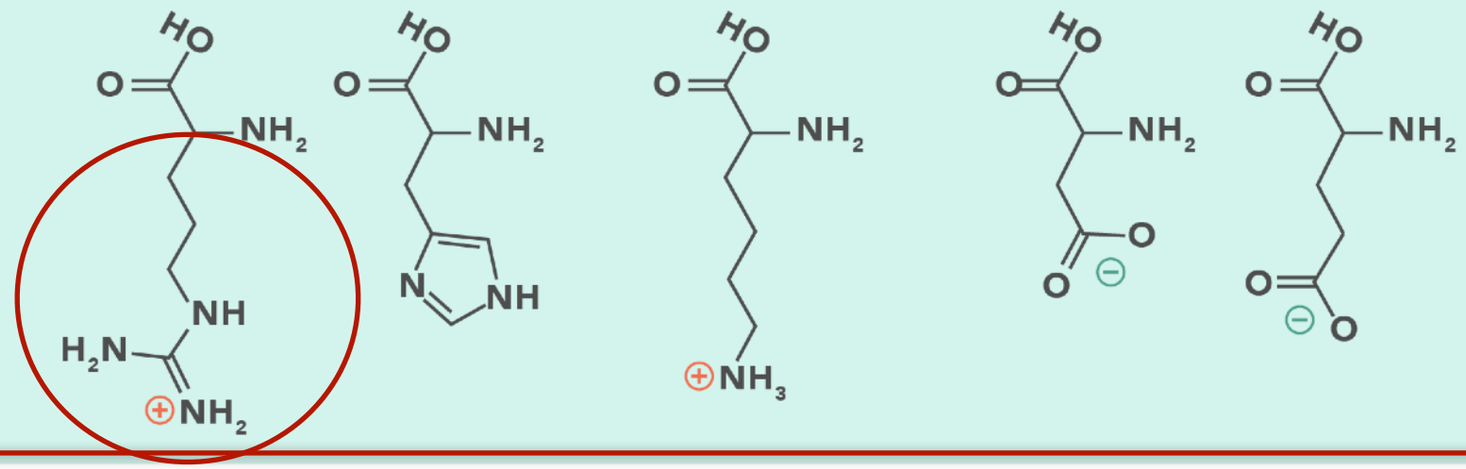
A. Amino Acids with Electrically Charged Side Chains

Positive

- Arginine (Arg) R
- Histidine (His) H
- Lysine (Lys) K

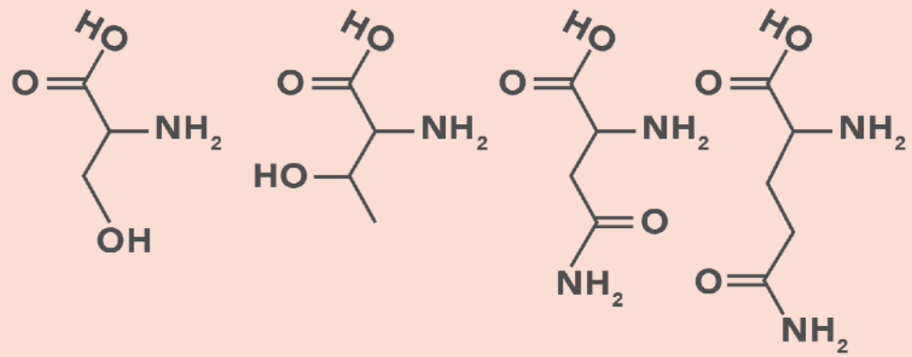
Negative

- Aspartic Acid (Asp) D
- Glutamic Acid (Glu) E



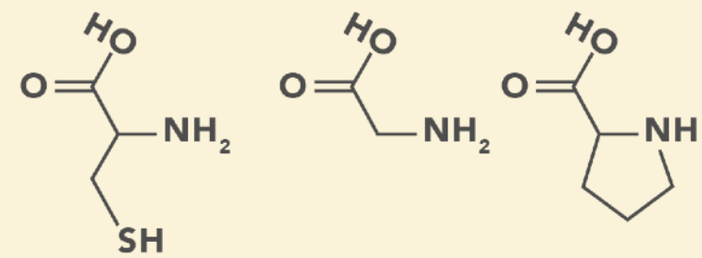
B. Amino Acids with Polar Uncharged Side Chains

- Serine (Ser) S
- Threonine (Thr) T
- Asparagine (Asn) N
- Glutamine (Gln) Q



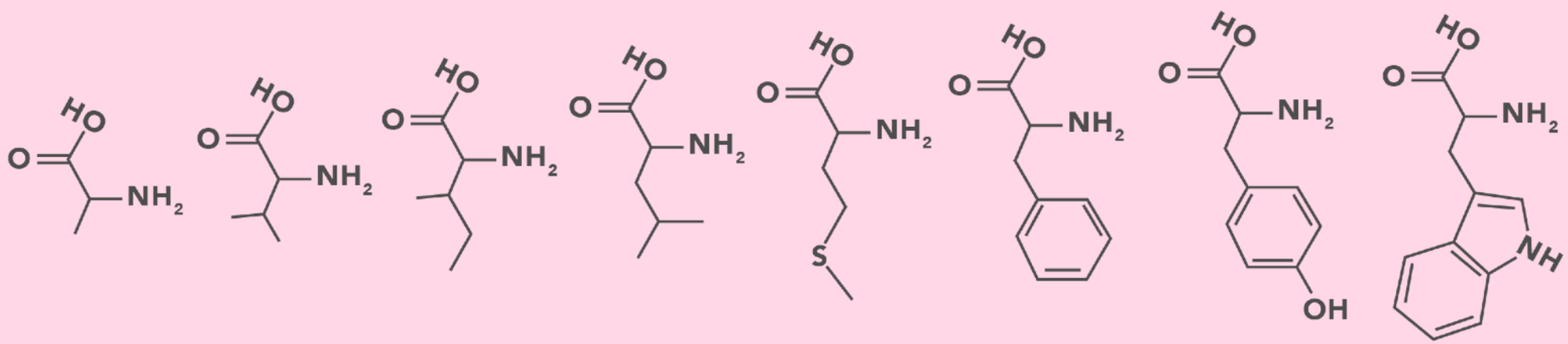
C. Special Cases

- Cysteine (Cys) C
- Glycine (Gly) G
- Proline (Pro) P

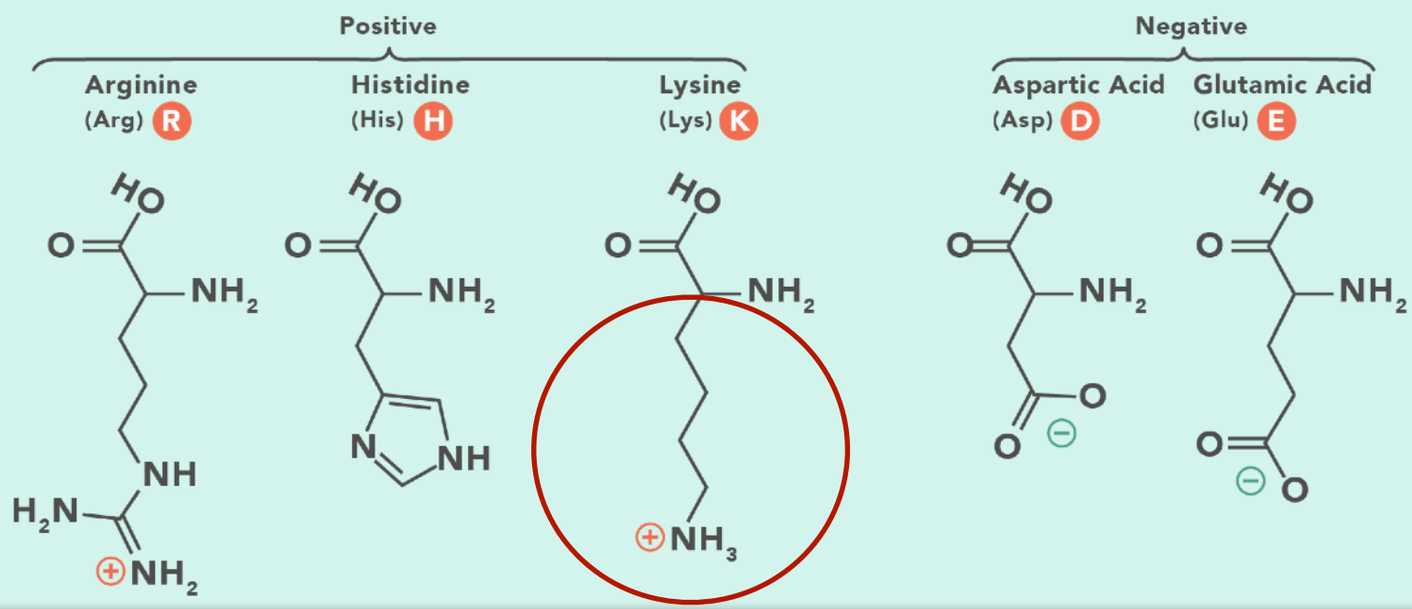


D. Amino Acids with Hydrophobic Side Chains

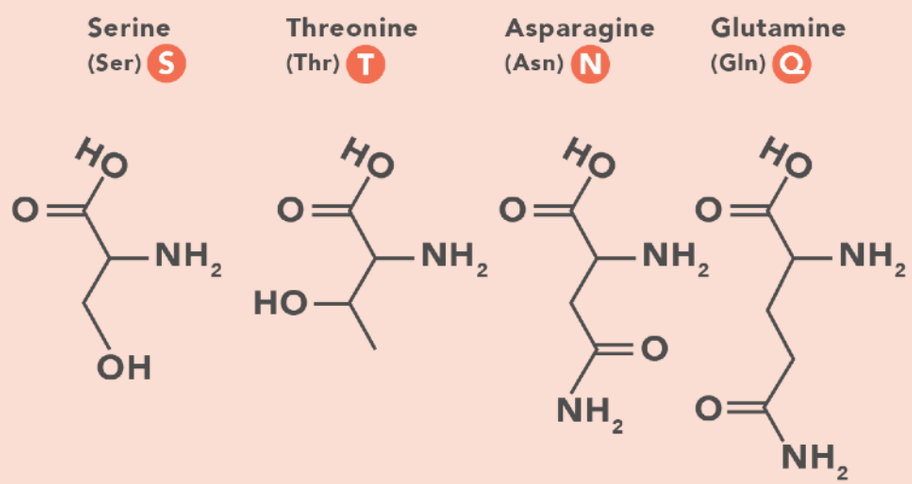
- Alanine (Ala) A
- Valine (Val) V
- Isoleucine (Ile) I
- Leucine (Leu) L
- Methionine (Met) M
- Phenylalanine (Phe) F
- Tyrosine (Tyr) Y
- Tryptophan (Trp) W



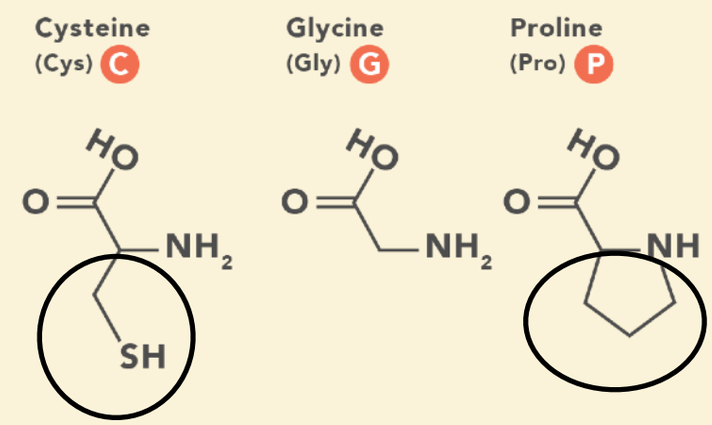
A. Amino Acids with Electrically Charged Side Chains



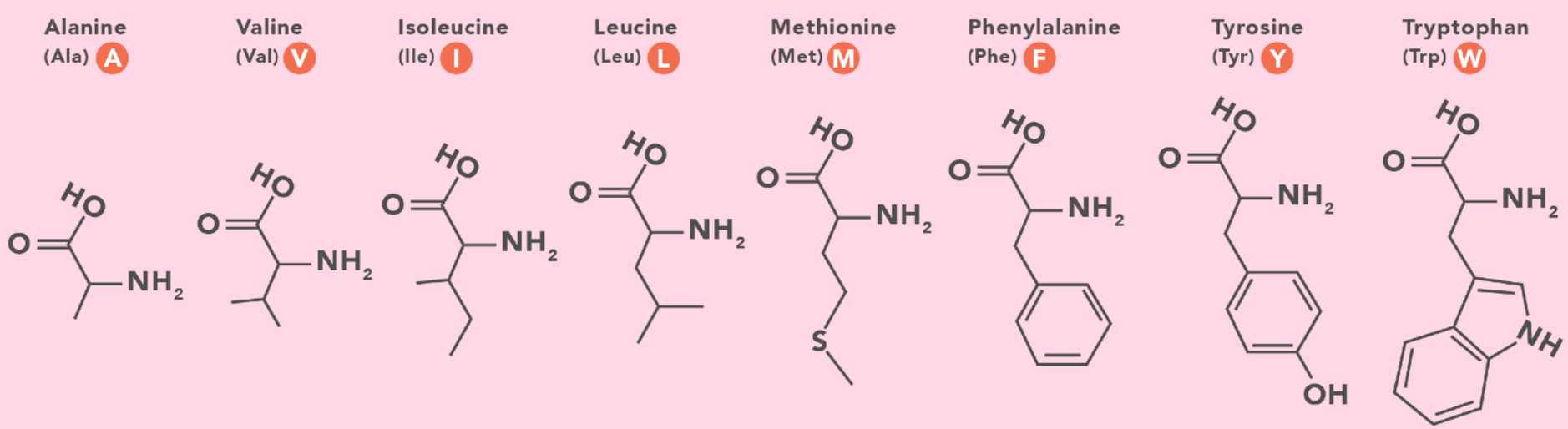
B. Amino Acids with Polar Uncharged Side Chains

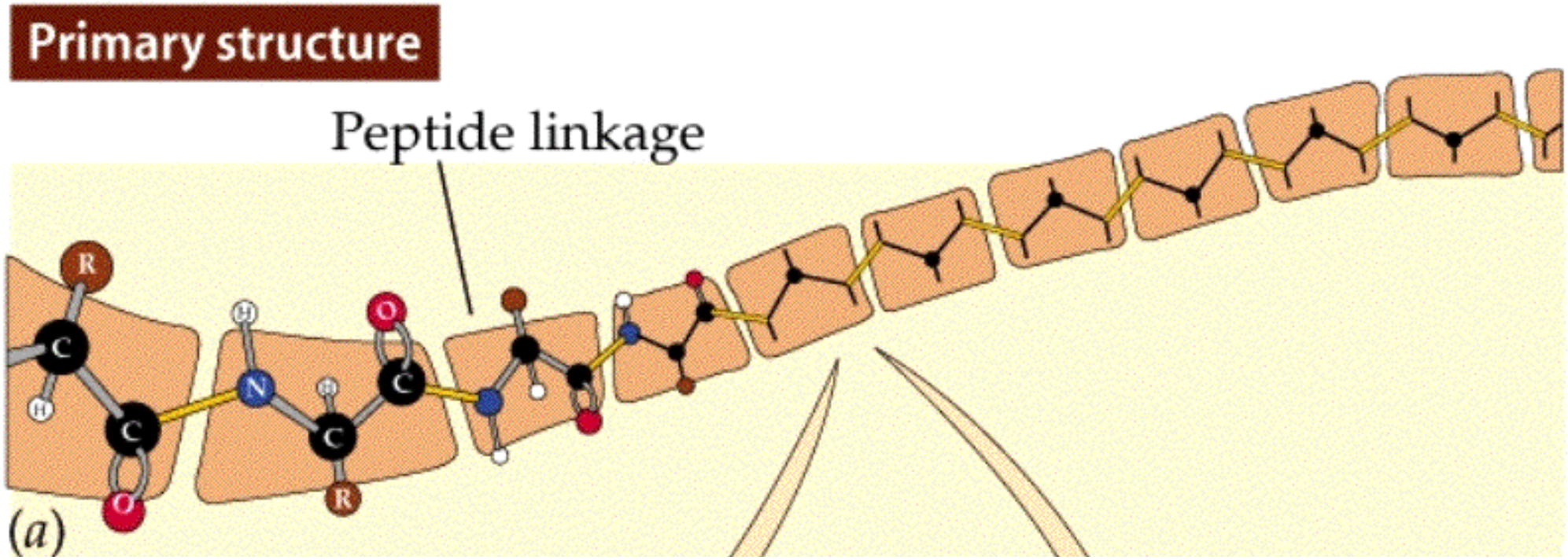


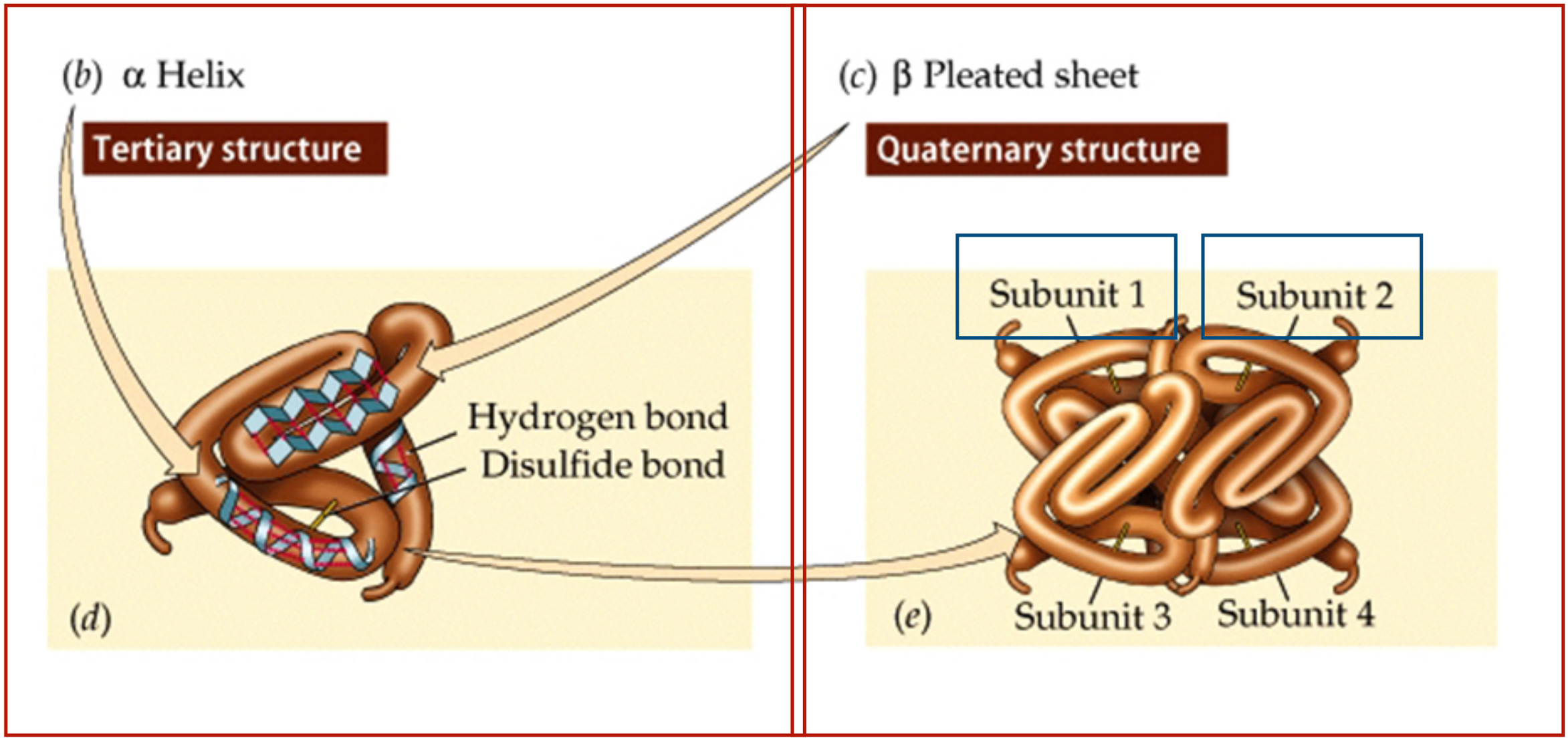
C. Special Cases

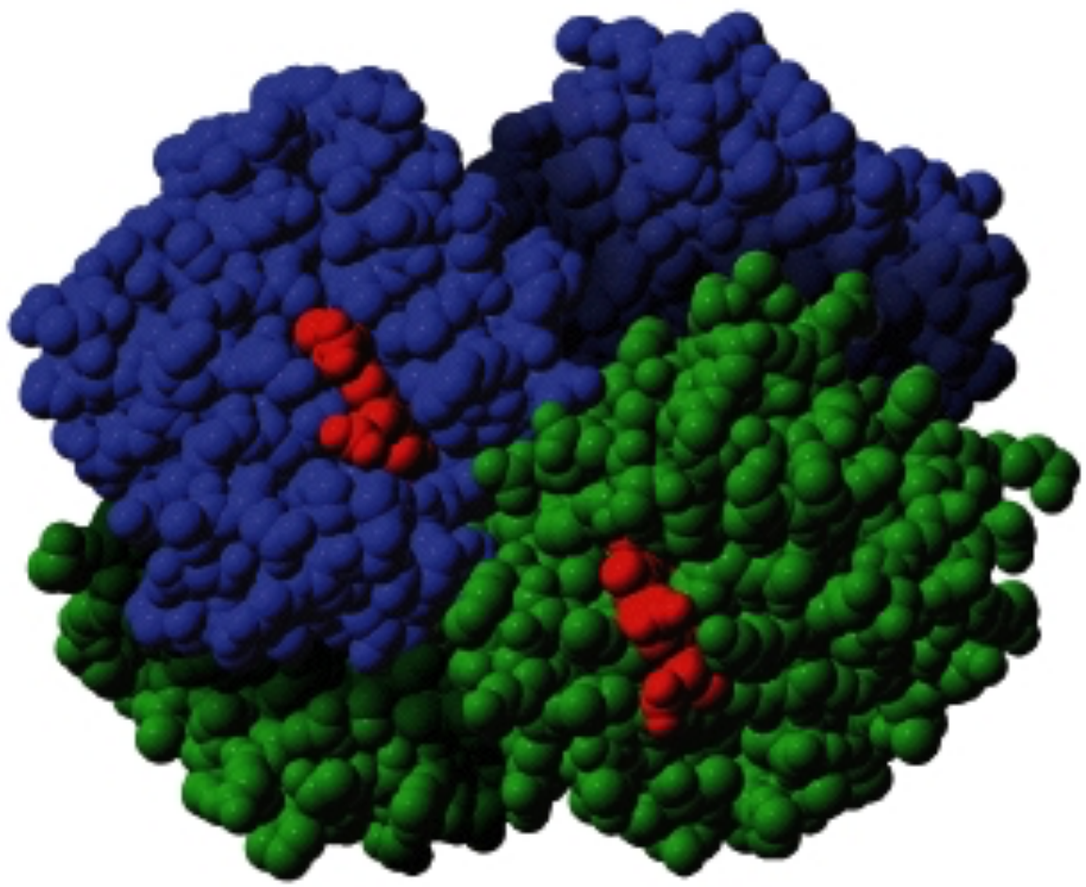


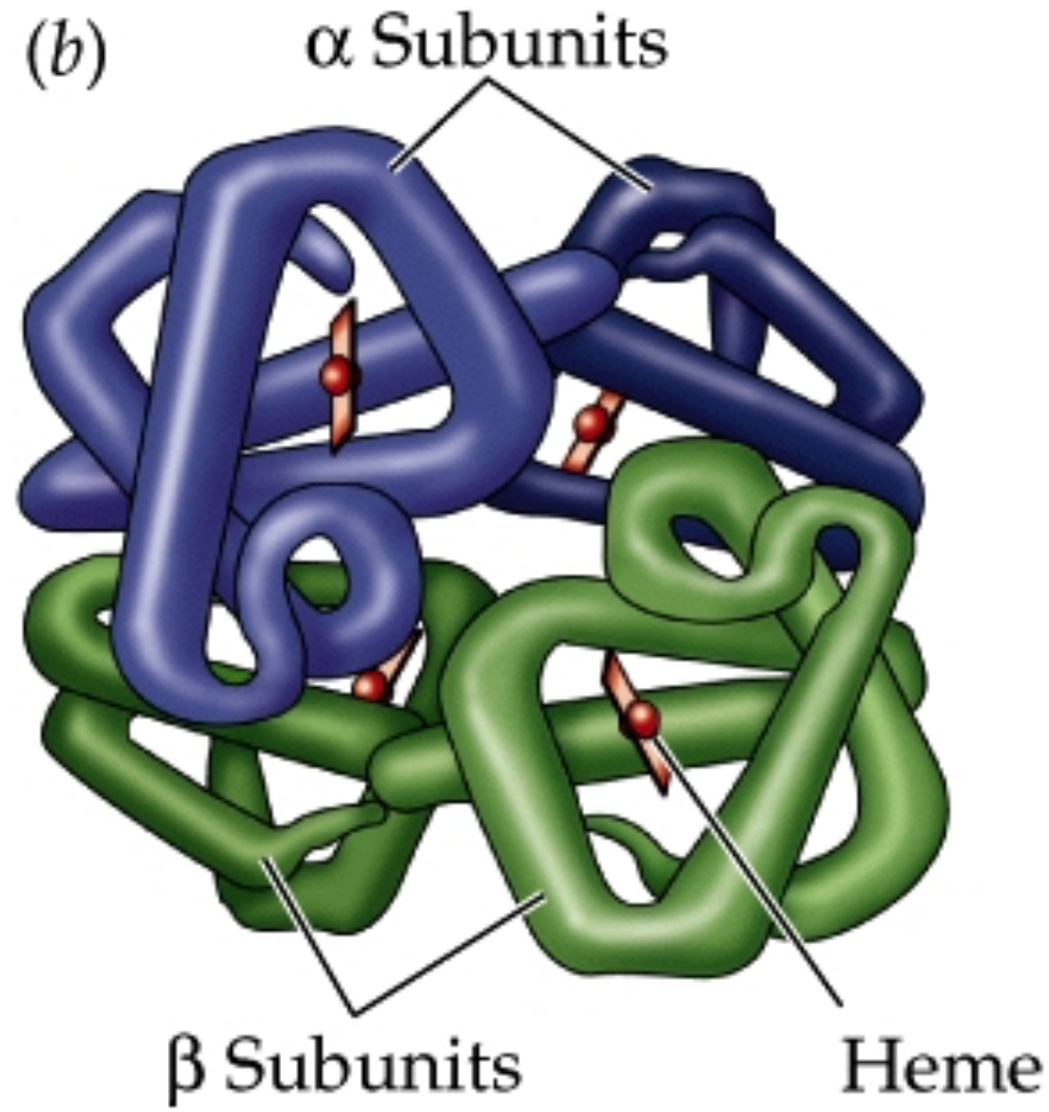
D. Amino Acids with Hydrophobic Side Chains

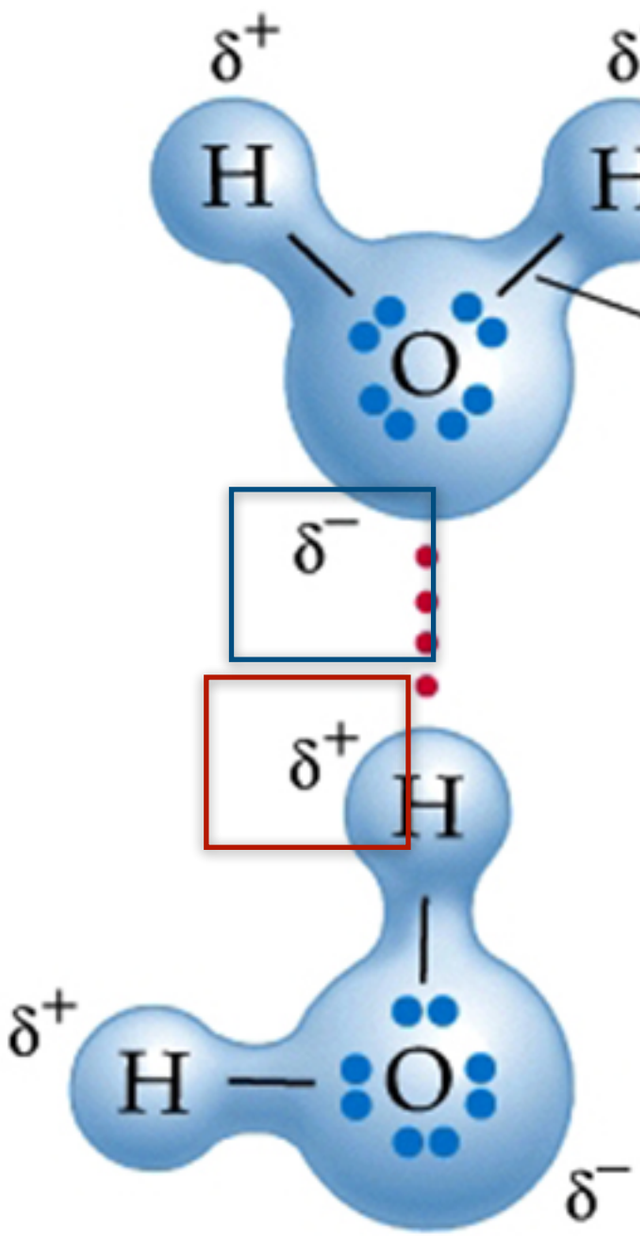



Primary structure
Peptide linkage
(a)


(b) α Helix
Tertiary structure
Hydrogen bond
Disulfide bond
(d)
(c) β Pleated sheet
Quaternary structure
Subunit 1
Subunit 2
(e)
Subunit 3
Subunit 4

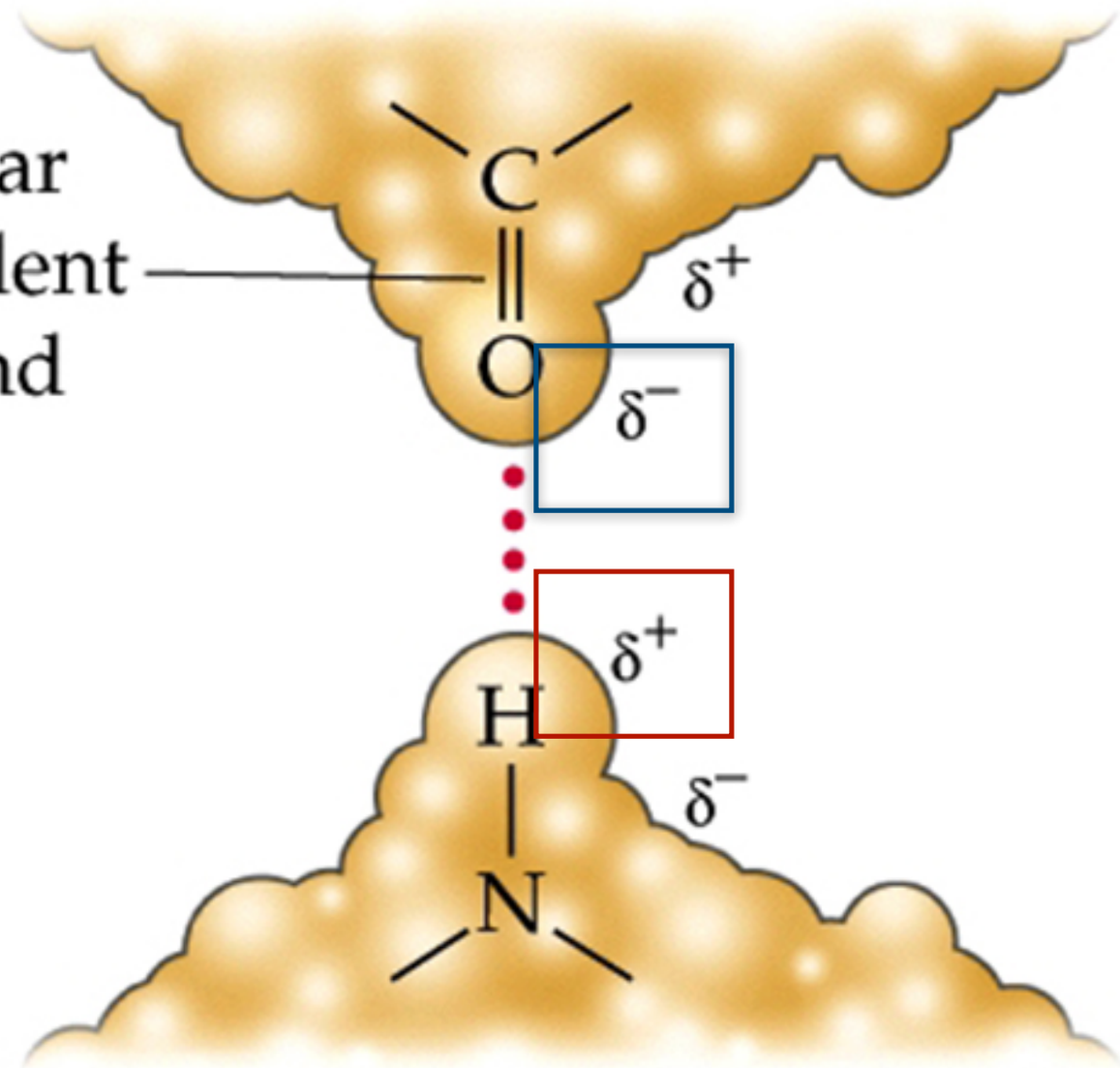

(a)


(b)
α Subunits
β Subunits
Heme



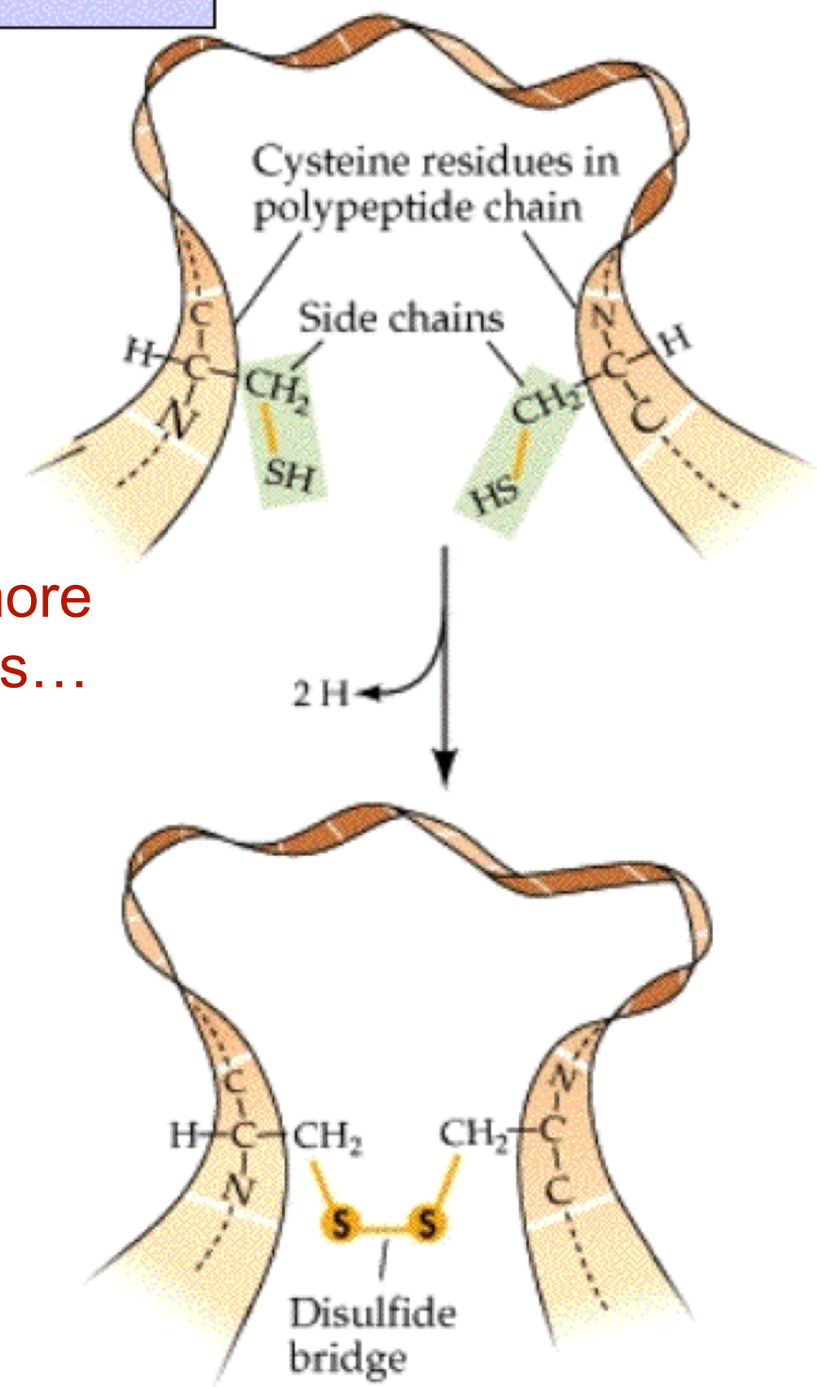
Two water molecules

Polar covalent bond



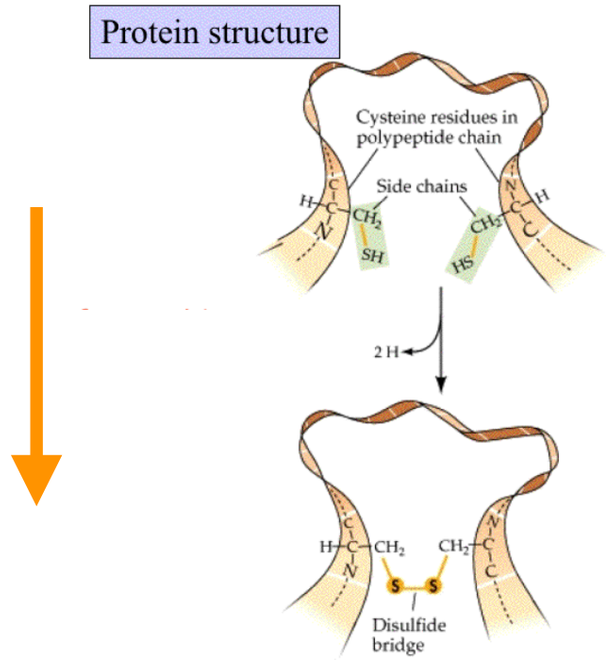
Two parts of one large molecule

Protein structure

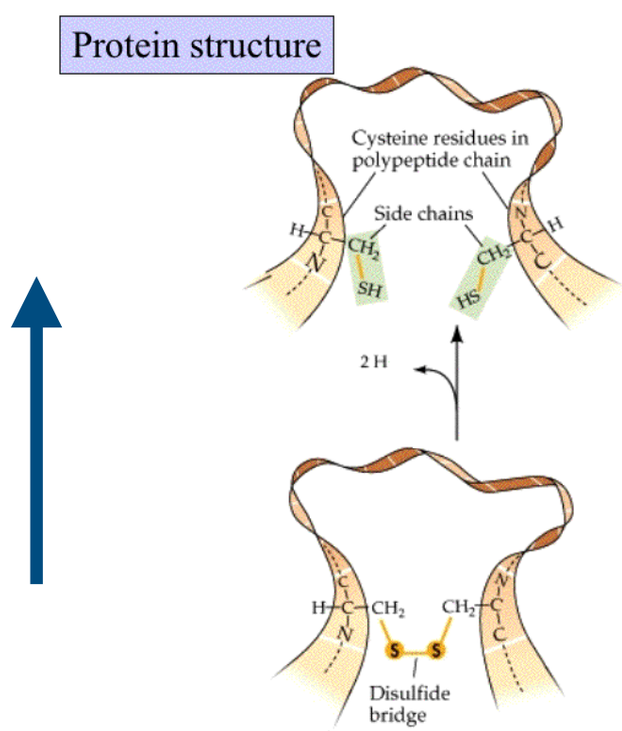


-curls in “curly” hair are formed from making more permanent **covalent bonds** between cysteines…

removing hydrogen



formaldehyde and formaldehyde-releasing chemicals



Carbohydrates: Sugars and Sugar Polymers

Carbohydrate monomers have molecular weights that approximates **100 Daltons.**

Polymers composed of monomers can have molecular weights of up to hundreds of thousands of Daltons.
There are four major categories of carbohydrates:

Monosaccharides,

Disaccharides, which consist of 2 x **monosaccharides** and

Oligosaccharides, which consist of between **3 and 20 monosaccharides**.

Finally there are
Polysaccharides, which are composed of hundreds to thousands of monosaccharides.

The general formula for a **carbohydrate monomer** is multiples of CH_2O, maintaining a ratio of 1 carbon to every 2 hydrogens and 1 oxygen.