

# Summary: Chapter 2-Chemistry Review

## I. Bonding

***A. How many bonds between C, O, N, and H***

***B. Geometry***

1. Tetrahedral
2. Planar - e.g. C forms double bond with C or O

***C. Electronegativity***

1. (N & O) > (C & H)
2. Bonds between C or H and O or N are polar; bonds between C & H are not

***D. H<sub>2</sub>O***

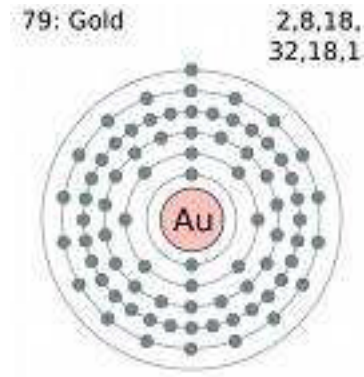
1. is more electronegative → Polar Bonds
2. Hydrogen Bonds attract molecules
3. dissociation of H<sub>2</sub>O = H<sup>+</sup> + OH<sup>-</sup>

***E. Ionic bonds -- e.g. Na<sup>+</sup> and Cl<sup>-</sup>***

***F. van der Waals Interactions***

# Elements & Compounds

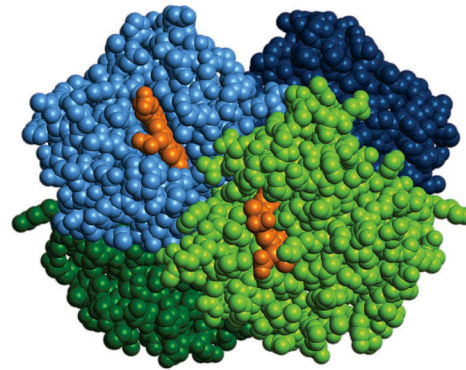
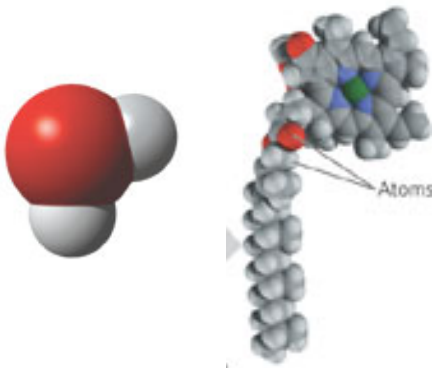
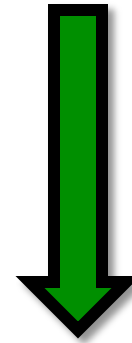
- An **Element** is a substance that cannot be broken down to other substances by chemical means.
- A **Compound** is a substance consisting of two or more elements in **fixed ratios**.
- A compound has characteristics different from those of its elements.



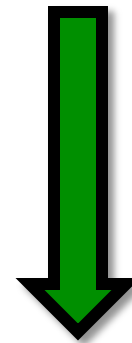
# Elements & Compounds



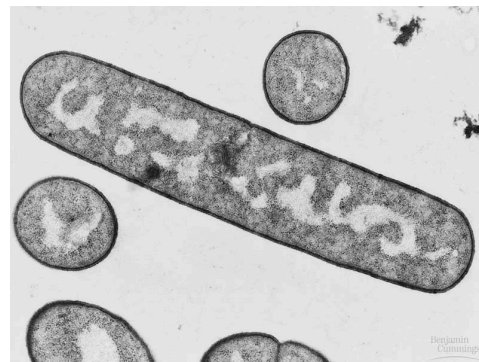
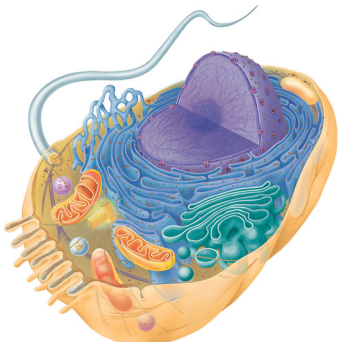
**Atoms (Elements)**



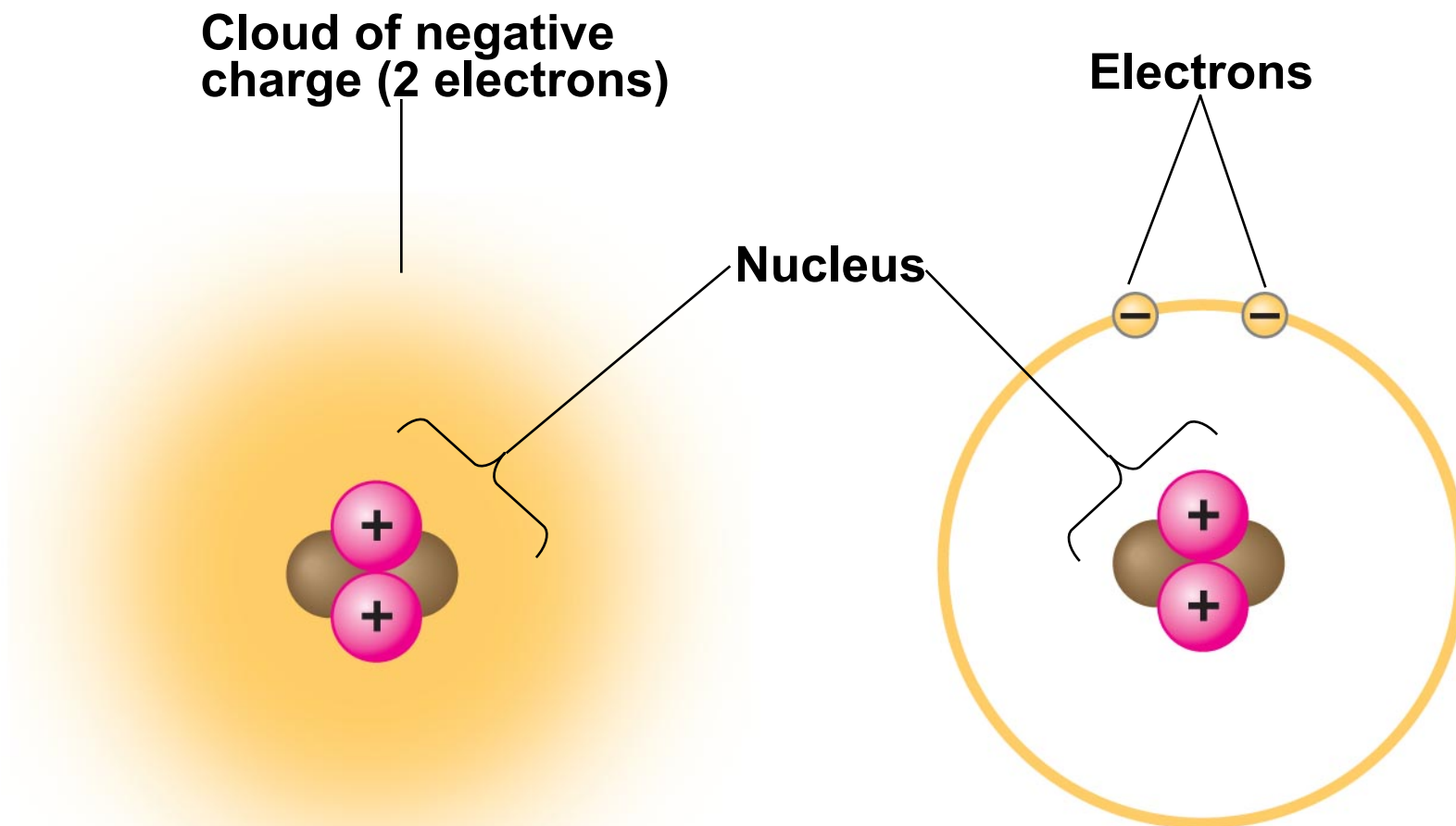
**Molecules (Compounds)**



**Cells**



**Fig. 2.5: Simplified model of a Helium (He) Atom**



**Atomic number** →  
= number of protons

**Mass Number** (~atomic mass)  
= number of **Neutrons** + **Protons**  
= 4 for Helium

**Atomic Mass** →

2
<b>He</b>
Helium
4.002602

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# The Periodic Table of the Elements

**These Elements make up ~97% of living organisms**

1 IA New Original	2 IIA											13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H 1.0079																	2 He 4.0026
3 Li 6.941	4 Be 9.0121											5 B 10.811	6 C 12.010	7 N 14.006	8 O 15.999	9 F 18.998	10 Ne 20.179
11 Na 22.989	12 Mg 24.305	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 —	9 VIIIB	10 —	11 IB	12 IIB	13 Al 26.981	14 Si 28.085	15 P 30.973	16 S 32.065	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.955	22 Ti 47.867	23 V 50.941	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.409	31 Ga 69.723	32 Ge 72.64	33 As 74.921	34 Se 78.96	35 Br 79.904	36 Kr 83.798
37 Rb 85.467	38 Sr 87.62	39 Y 88.905	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (97.907)	44 Ru 101.07	45 Rh 102.90	46 Pd 106.42	47 Ag 107.86	48 Cd 112.41	49 In 114.81	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.90	56 Ba 137.32	57–71	72 Hf 178.49	73 Ta 180.94	74 W 183.84	75 Re 186.20	76 Os 190.23	77 Ir 192.21	78 Pt 195.08	79 Au 196.96	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (208.98)	85 At (209.98)	86 Rn (222.01)
87 Fr (223)	88 Ra (226)	89–103	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (271)	111 Rg (272)	112 Uub (285)	113 Uut (284)	114 Uuq (289)	115 Uup (288)	116 Uuh (292)	117 Uus	118 Uuo (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

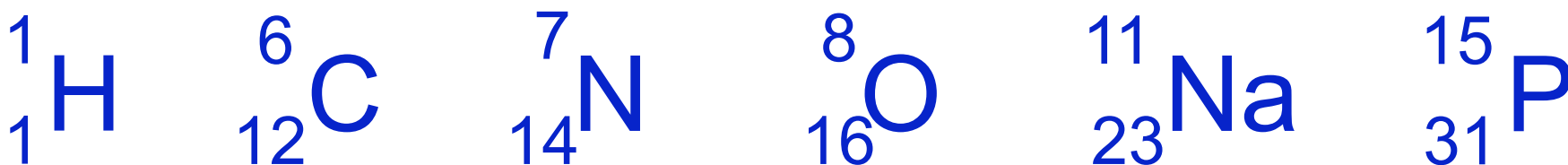
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The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

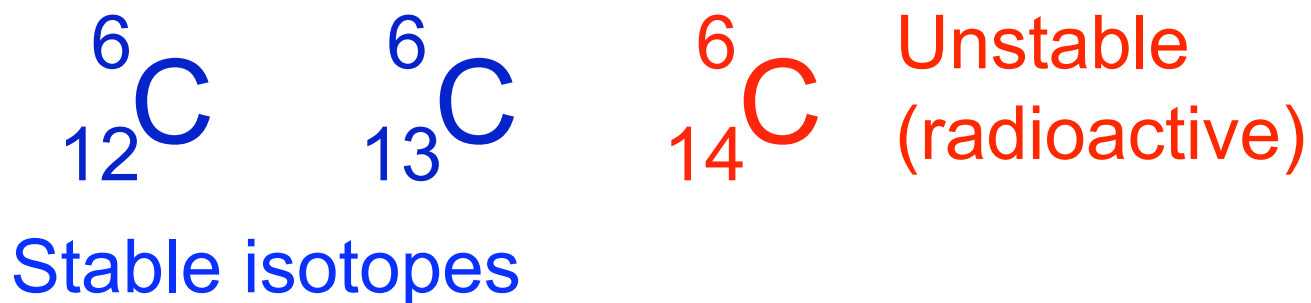
57 La 138.90	58 Ce 140.11	59 Pr 140.90	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.25	69 Tm 168.93	70 Yb 173.04	71 Lu 174.96
89 Ac (227)	90 Th 232.03	91 Pa 231.03	92 U 238.02	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

## Properties of Elements Depends Upon Atomic Structure

Atoms of different elements differ in their number of subatomic particles:











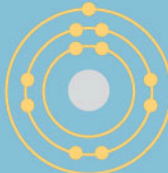
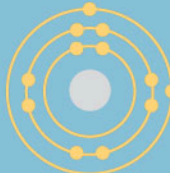
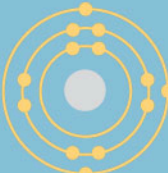
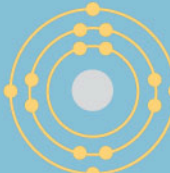
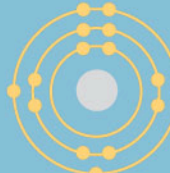
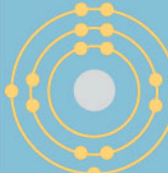
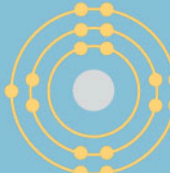
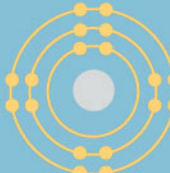


**Isotopes** of an element have same number of **protons** but different number of **neutrons**:





**Fig. 2.9: Electrons are distributed in shells of orbitals. Each orbital contains a maximum of two electrons.**

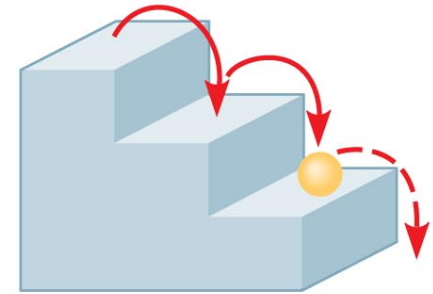
First shell	<div><div><div>Hydrogen <math>{}_1\text{H}</math></div></div><div><div><div>2</div><div>He</div><div>4.00</div></div><div>Atomic number</div><div>Element symbol</div><div>Mass number</div></div><div><div>Helium <math>{}_2\text{He}</math></div><div>Electron distribution diagram</div></div></div>							
	Lithium ${}_3\text{Li}$	Beryllium ${}_4\text{Be}$	Boron ${}_5\text{B}$	Carbon ${}_6\text{C}$	Nitrogen ${}_7\text{N}$	Oxygen ${}_8\text{O}$	Fluorine ${}_9\text{F}$	Neon ${}_{10}\text{Ne}$
Second shell								
Third shell	Sodium ${}_{11}\text{Na}$	Magnesium ${}_{12}\text{Mg}$	Aluminum ${}_{13}\text{Al}$	Silicon ${}_{14}\text{Si}$	Phosphorus ${}_{15}\text{P}$	Sulfur ${}_{16}\text{S}$	Chlorine ${}_{17}\text{Cl}$	Argon ${}_{18}\text{Ar}$
								

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Chemical behavior of an atom depends mostly on number of electrons in **outermost shell** called **Valence Electrons**

## Fig. 2.8: Energy Levels of Electrons / Electron Shells

(a) A ball bouncing down a flight of stairs provides an analogy for energy levels of electrons

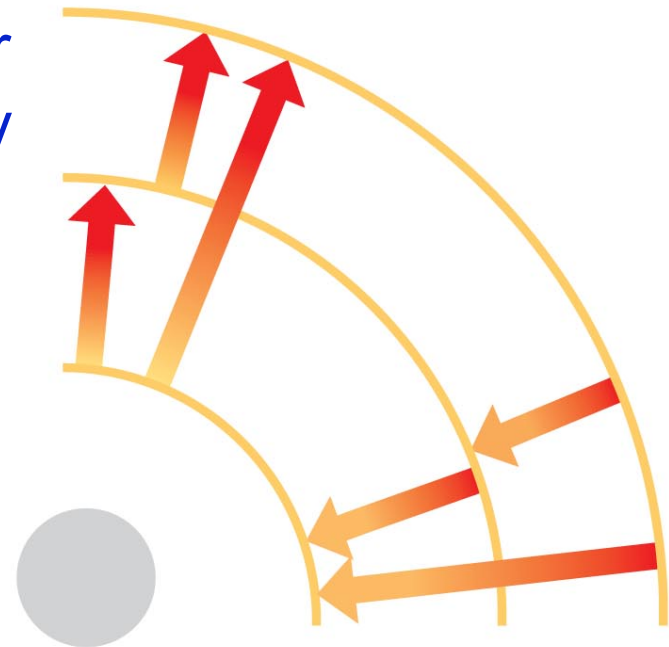


Electrons in an atom vary in the amount of **potential energy** they possess (**fixed, discrete amounts**)

Different discrete energy levels correlate with average distance of electron from nucleus (**electron shells**)

Higher energy

Lower energy





# We Are Carbon-Based Lifeforms

**Table 2.1 Naturally Occurring Elements in the Human Body**

Symbol	Element	Atomic Number (see p. 33)	Percentage of Human Body Weight
<b>Elements making up about 96% of human body weight</b>			
O	Oxygen	8	65.0
C	Carbon	6	18.5
H	Hydrogen	1	9.5
N	Nitrogen	7	3.3
<b>Elements making up about 4% of human body weight</b>			
Ca	Calcium	20	1.5
P	Phosphorus	15	1.0
K	Potassium	19	0.4
S	Sulfur	16	0.3
Na	Sodium	11	0.2
Cl	Chlorine	17	0.2
Mg	Magnesium	12	0.1

**Elements making up less than 0.01% of human body weight (trace elements)**

Boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), zinc (Zn)

**~96 % of the Human Body is:**

**Oxygen (O)**

**Carbon (C)**

**Hydrogen (H)**

**Nitrogen (N)**

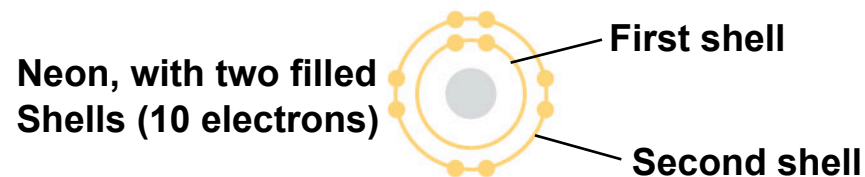
**~4 %: Ca, P, K, S, Na, Cl, Mg**

**Trace elements (< 0.01%):**

B, Cr, Co, Cu, F, I, Fe, Mn, Mo, Se, Si, Sn, V, Zn

**Composition of other organisms on Earth is similar**

**Fig. 2.10:** Electrons are arranged in orbitals that have characteristic shapes and energies

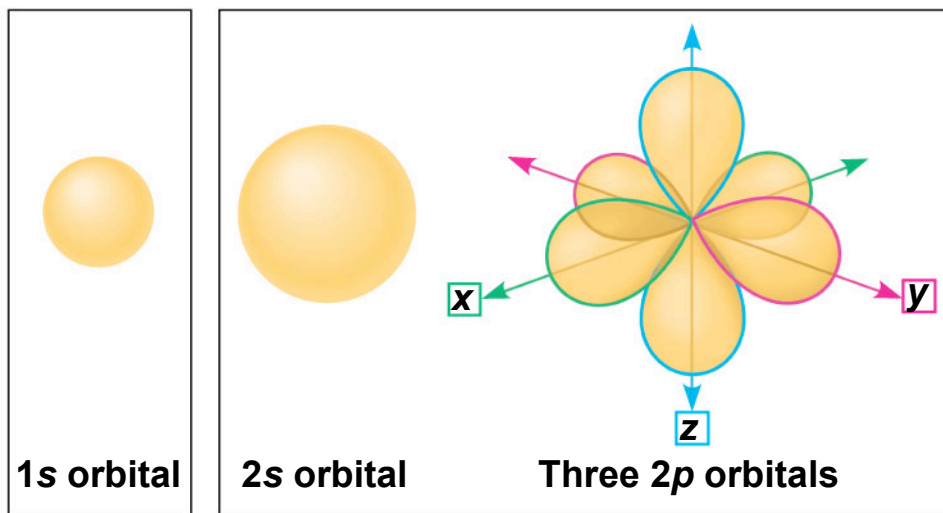


(a) Electron distribution diagram

- The first shell has only an **s orbital** that is **spherical** in shape.
- The second shell has another **spherical s orbital** and **3 p orbitals** that are each shaped somewhat like dumbbells aligned along 3 orthogonal axes.
- Each orbital** can hold a maximum of **2 electrons**.

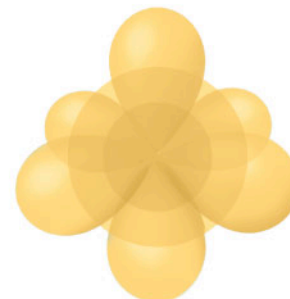
First shell

Second shell



(b) Separate electron orbitals

1s, 2s, and  
2p orbitals



(c) Superimposed electron orbitals

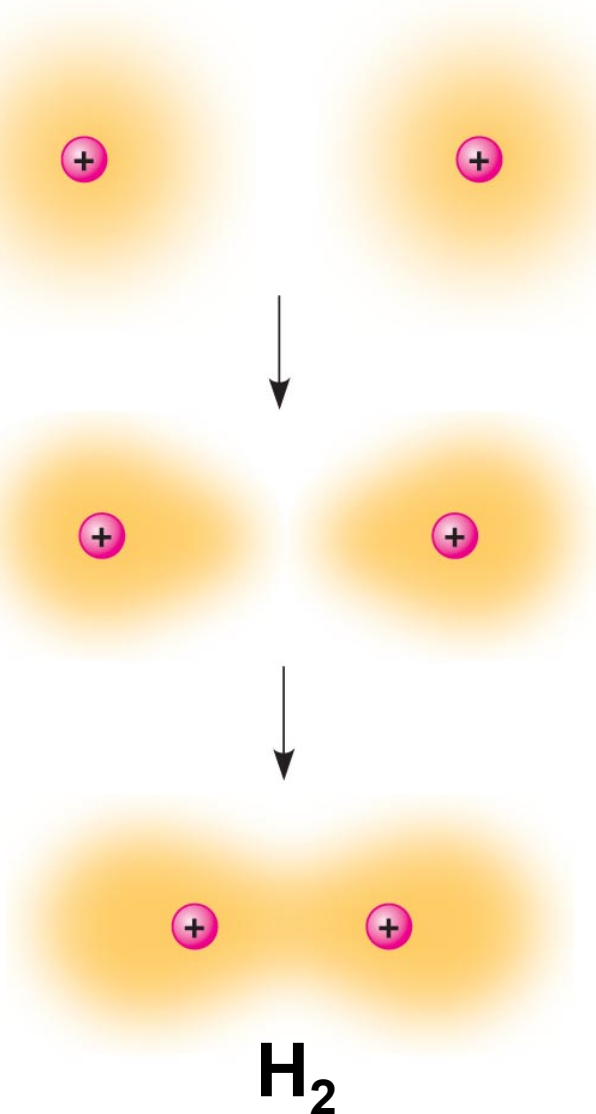
**Fig. 2.11: Chemical Bonds Link Atoms Together**

${}^1\text{H}_1$

${}^1\text{H}_1$

## Covalent bonds

- Form when two atomic nuclei share one or more pairs of electrons filling their **orbitals**.
- The **orbitals** have orientations in space that give molecules three-dimensional shapes.
- In  $\text{H}_2$  – Each **H** atom is able to fill its 1s orbital by sharing its single electron with the other **H** atom.



# Bonding properties of the most common elements in biological molecules

**H:** Atomic No. 1 → **1 electron:**  $1s^1$   
1st shell needs 1 electron → Forms **1 covalent bond**

**C:** Atomic No. 6 → **6 electrons:**  $1s^2 2s^2 2p_x^1 2p_y^1 2p_z^0$   
2nd shell needs 4 electrons → Forms **4 covalent bonds**

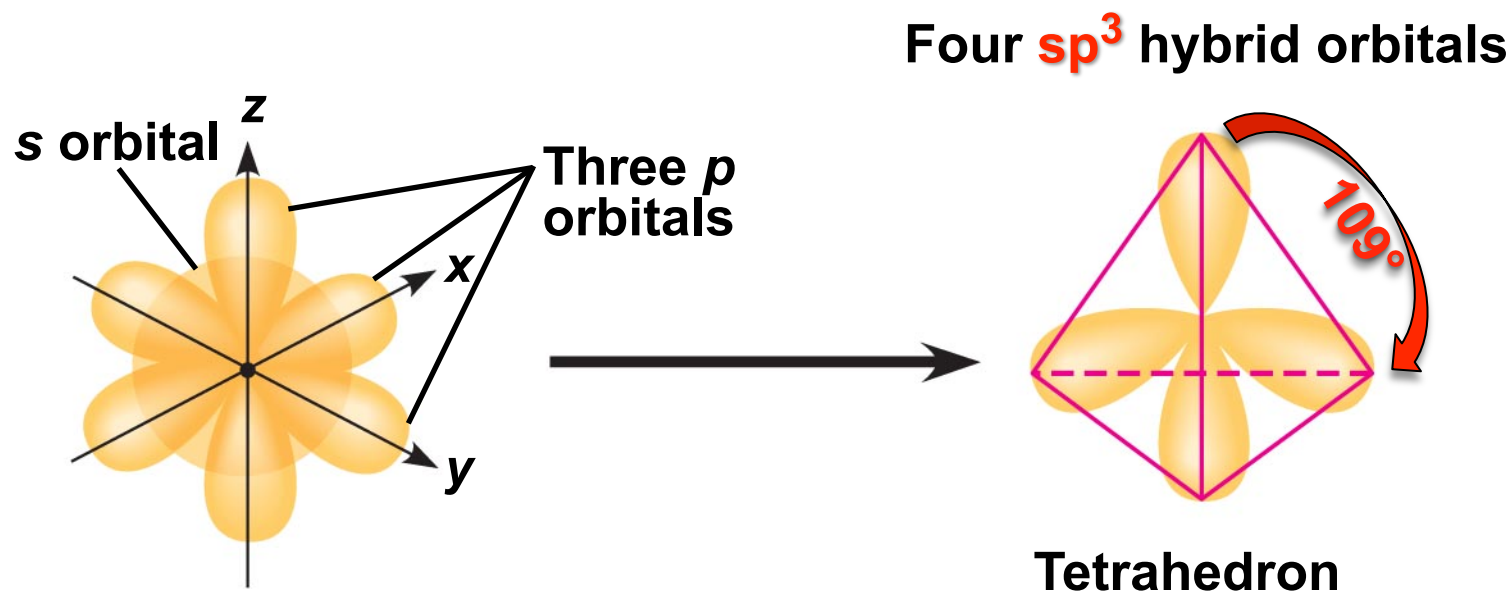
**N:** Atomic No. 7 → **7 electrons:**  $1s^2 2s^2 2p_x^1 2p_y^1 2p_z^1$   
2nd shell needs 3 electrons → Forms **3 covalent bonds**

**O:** Atomic No. 8 → **8 electrons:**  $1s^2 2s^2 2p_x^2 2p_y^1 2p_z^1$   
2nd shell needs 2 electrons → Forms **2 covalent bonds**

## Fig. 2.17a: Hybrid Atomic Orbitals

The orbitals used by **C** to form **4 bonds** to **4 different atoms** are  **$sp^3$  hybrid atomic orbitals**, a combination of the  **$2s$ ,  $2p_x$ ,  $2p_y$ , and  $2p_z$  orbitals**.  
 **$sp^3$**  orbitals point to the corners of a **Tetrahedron**.

This is called “**Tetrahedral Geometry**” characterized by bond angles of  **$109^\circ$** .



**(a) Hybridization of orbitals**

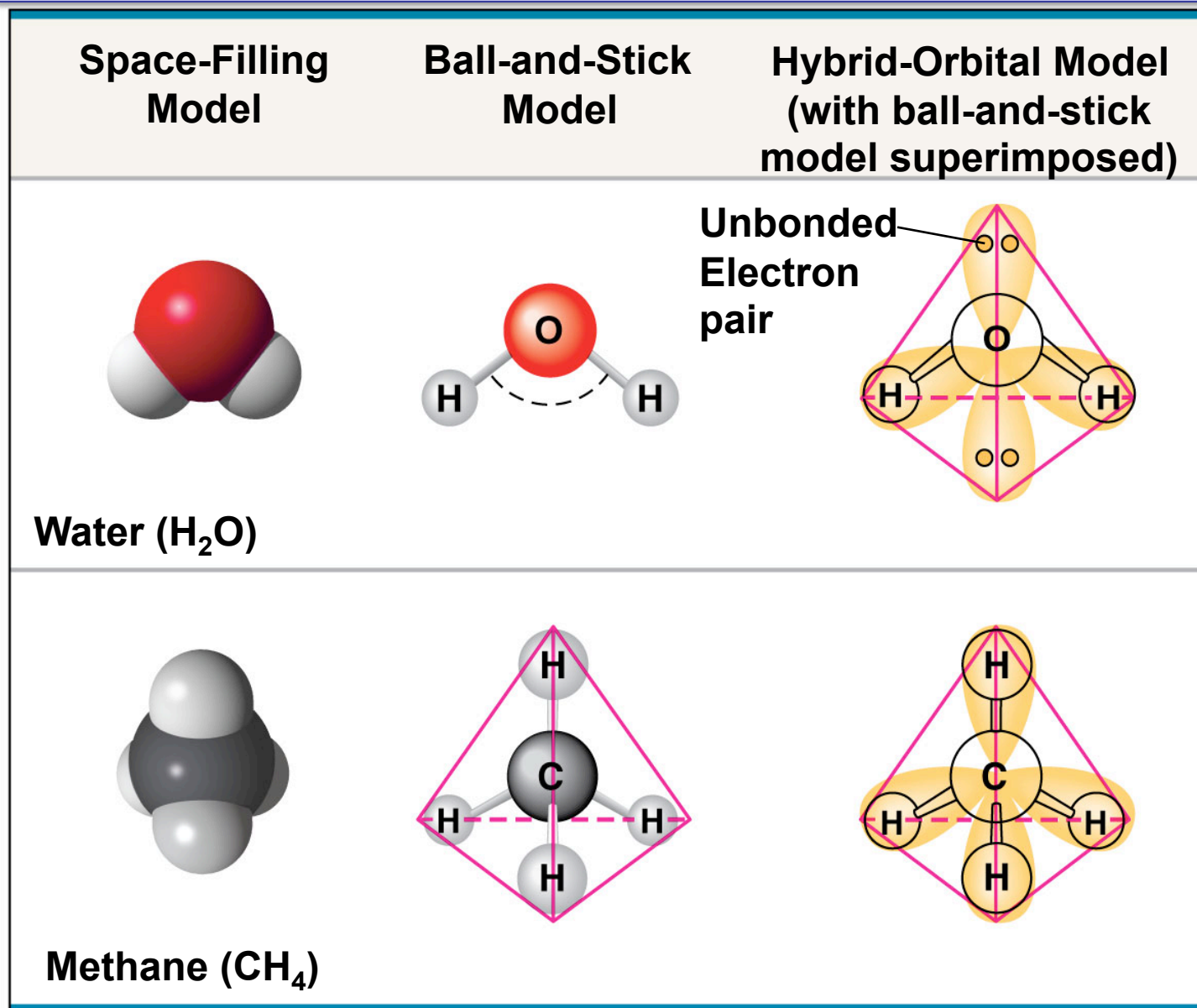
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**Fig. 2.17b: Molecular Shape Models**

A covalent bond that has electron density from shared electrons between the atoms is called a

**$\sigma$  bond**

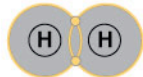

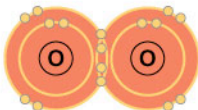

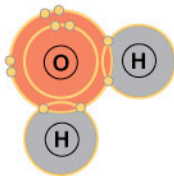

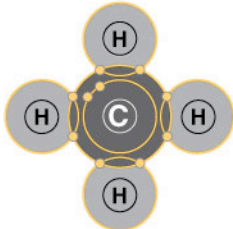

The atoms in water and methane are connected by  **$\sigma$  bonds**.



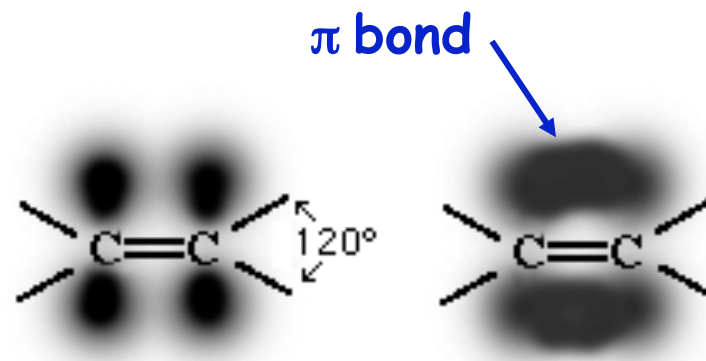
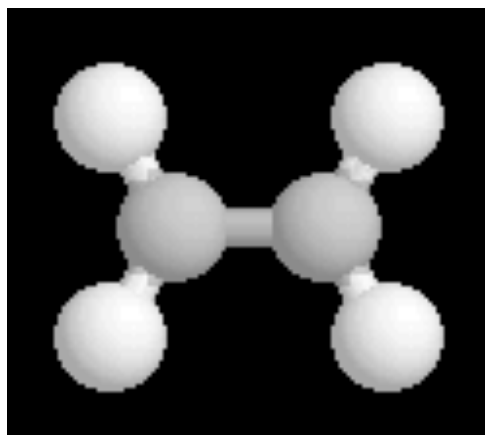
**(b) Molecular-shape models**



**Fig. 2.12: Covalent Bonding in Four Molecules**

Name and Molecular Formula	Electron Distribution Diagram	Lewis Dot Structure and Structural Formula	Space-Filling Model
(a) Hydrogen ( $H_2$ )		$H:H$ $H-H$	
(b) Oxygen ( $O_2$ )		$\ddot{O}::\ddot{O}$ $O=O$	
(c) Water ( $H_2O$ )		$\begin{array}{c} \ddot{O}:H \\   \\ H \end{array}$ $\begin{array}{c} O-H \\   \\ H \end{array}$	
(d) Methane ( $CH_4$ )		$\begin{array}{c} H \\   \\ H:C:H \\   \\ H \end{array}$ $\begin{array}{c} H \\   \\ H-C-H \\   \\ H \end{array}$	

When carbon forms bonds to three different atoms, it uses  **$sp^2$  hybrid orbitals** by combining the **2s orbital** and **two of the 2p orbitals**.



- The two C atoms in **Ethene** form a second or **double bond** between themselves using their third unhybridized **2p** orbitals.
- The second bond is called a  **$\pi$  bond** and prevents the C atoms from rotating around the bonds connecting them.
- Note: the  **$\pi$  bond** does not place electron density between the atoms.

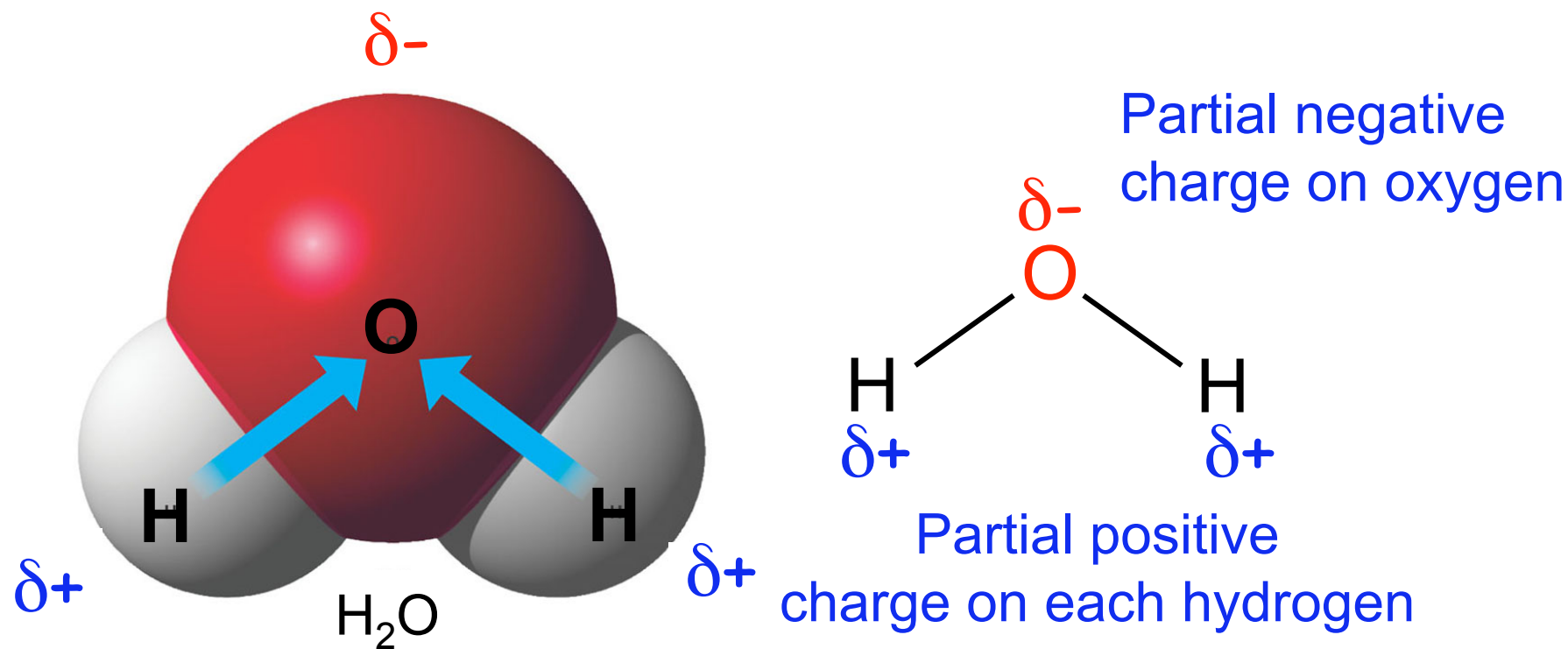
# Chemical Bonds: Linking Atoms Together

**Electronegativity** is a measure of how strongly an atom attracts electrons

<i>Element</i>	<i>Symbol</i>	<i>Electronegativity</i>	
<i>Oxygen</i>	O	3.5	← High
<i>Chlorine</i>	Cl	3.1	
<i>Nitrogen</i>	N	3.0	← High
<i>Carbon</i>	C	2.5	←
<i>Phosphorous</i>	P	2.1	
<i>Hydrogen</i>	H	2.1	←
<i>Sodium</i>	Na	0.9	
<i>Potassium</i>	K	0.9	

- **Nonpolar** covalent bonds form when the **Electronegativities** of two atoms are approximately equal.
- **Polar** covalent bonds form between atoms with strong electronegativity (such as **oxygen**) bonded to atoms with weaker electronegativity (such as **hydrogen**).
- In a **polar covalent bond** one atom has a partial **positive** charge or  $\delta^+$  and the other atom has a partial **negative** charge or  $\delta^-$ .

**Fig. 2.13: Polar Covalent Bonds Are Formed Between Atoms With Unequal Electronegativity**



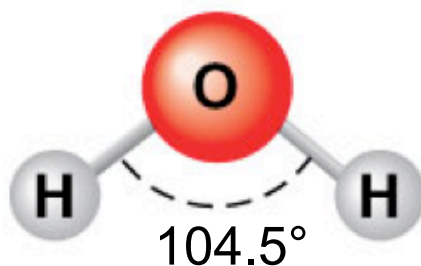
**Fig. 2.17b:  $sp^3$  Hybrid Orbitals in Water,  $H_2O$**

**Space-Filling  
Model**

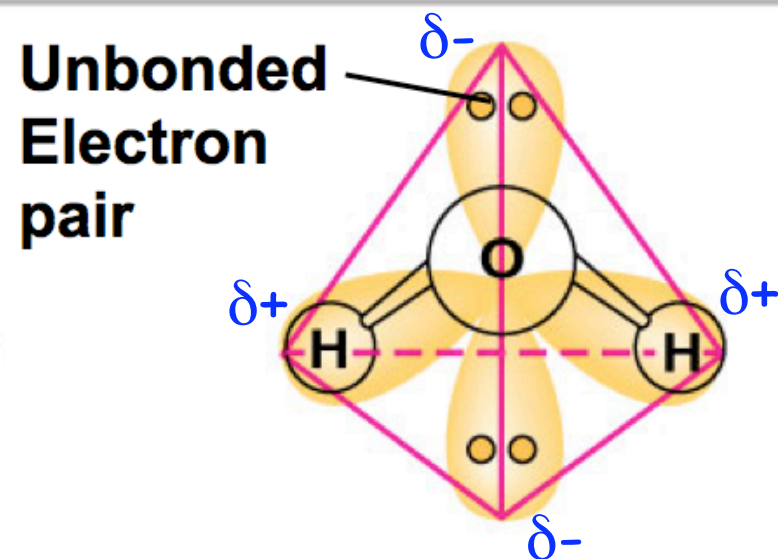


**Water ( $H_2O$ )**

**Ball-and-Stick  
Model**

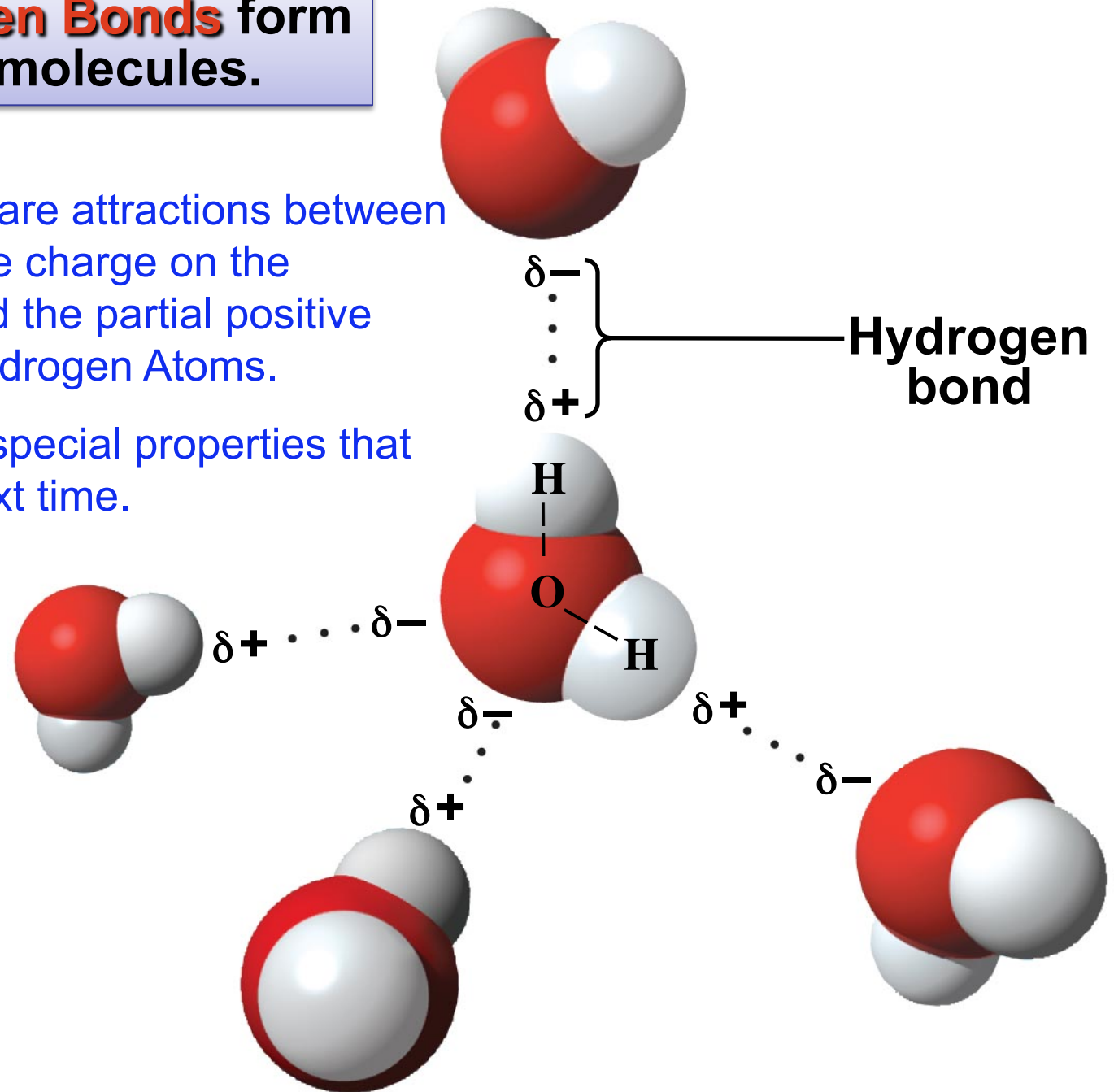


**Hybrid-Orbital Model  
(with ball-and-stick  
model superimposed)**



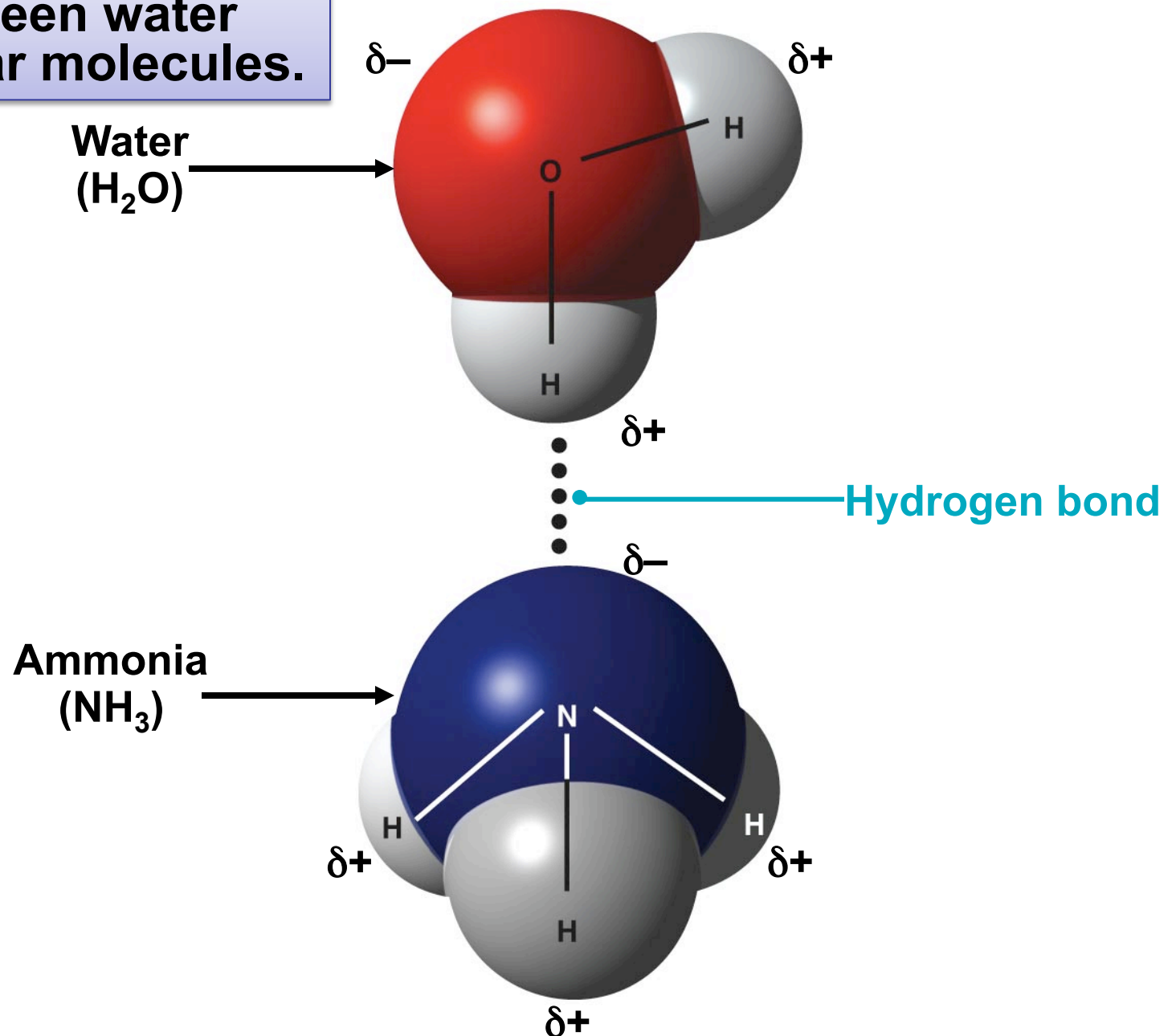
**Fig. 3-2: Hydrogen Bonds** form between water molecules.

- Hydrogen Bonds are attractions between the partial negative charge on the Oxygen atoms and the partial positive charges on the Hydrogen Atoms.
- This gives water special properties that we will discuss next time.

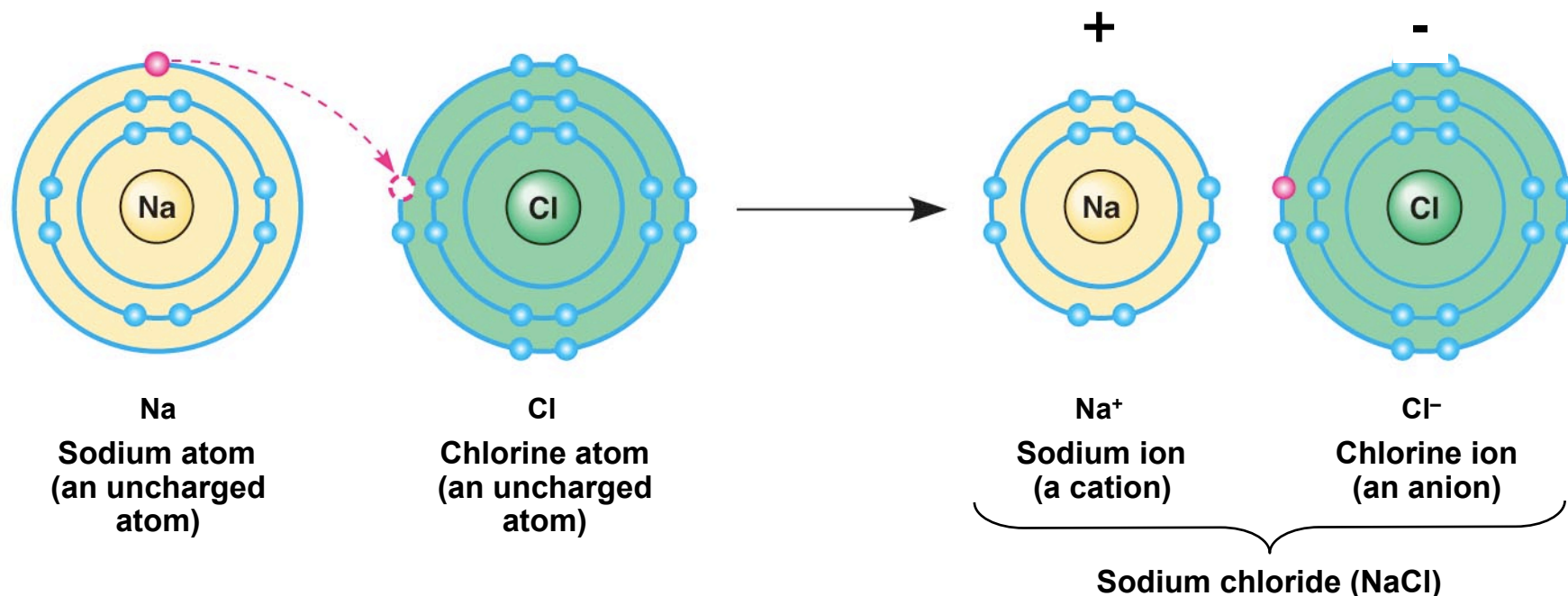




**Fig. 2.16: Hydrogen Bonds**  
can form between water  
and other polar molecules.



**Fig. 2.14: Ionic Bonds**



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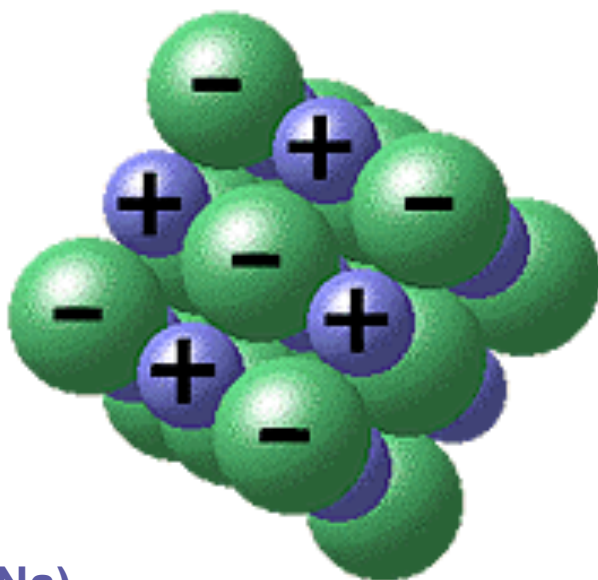
**Electronegativity:** Na = 0.9 & Cl = 3.1

Electrically charged **ions** form when an atom gains or loses one or more electrons to an atom of **very** different **electronegativity**.

**Ionic Bonds** are electrical attractions between oppositely charged ions.

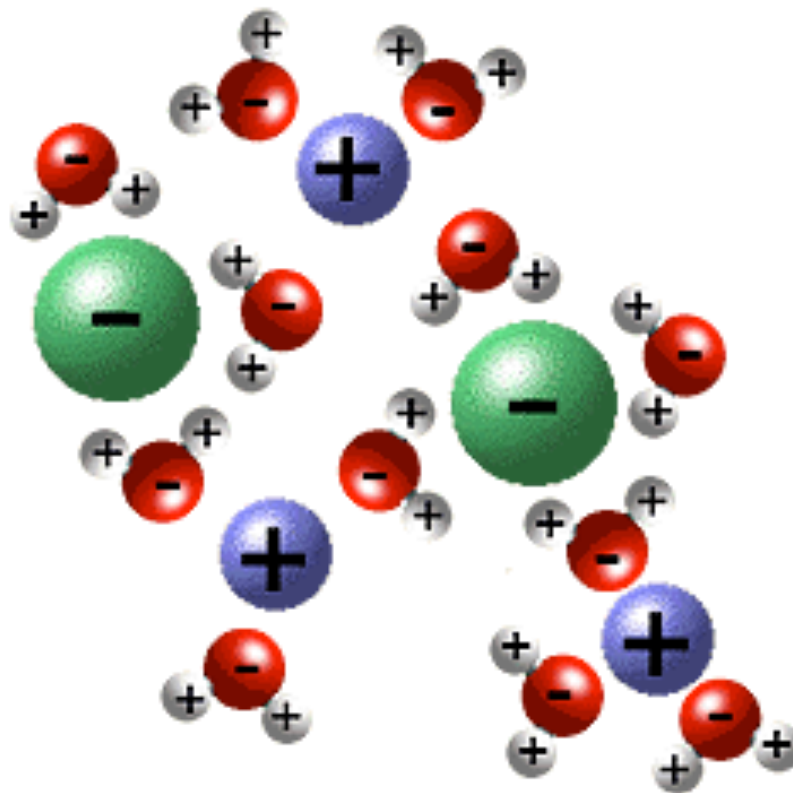
**Solvation:** Water molecules surround ions and neutralize their charge.

NaCl crystal structure



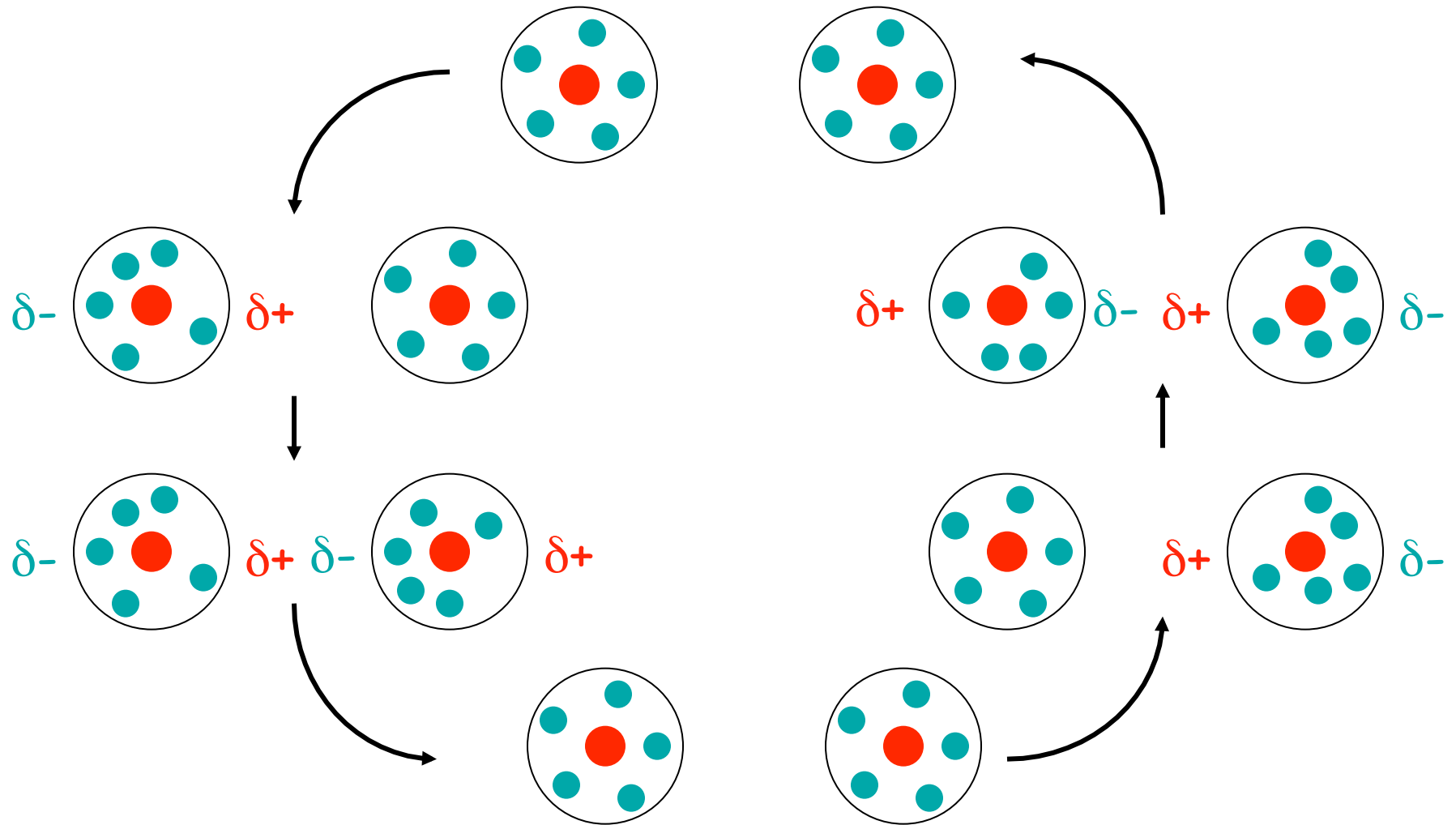
Sodium (Na)  
Chlorine (Cl)

NaCl in water





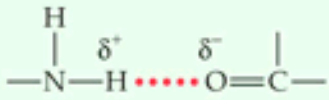

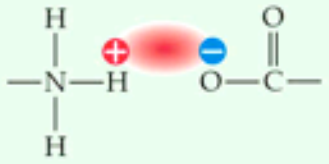

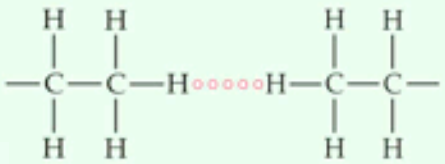

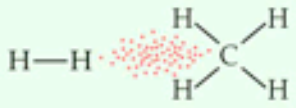

# Weak Chemical Bonds: van der Waals Interactions

Weak attraction of atoms due to constant motion of electrons:



# Chemical Bonds and Interactions

## 2.1 Chemical Bonds and Interactions

NAME	BASIS OF INTERACTION	STRUCTURE	BOND ENERGY <sup>a</sup> (KCAL/MOL)
Covalent bond	Sharing of electron pairs		50–110 
Hydrogen bond	Sharing of H atom		3–7 
Ionic bond	Attraction of opposite charges		3–7 
Hydrophobic interaction	Interaction of nonpolar substances in the presence of polar substances		1–2 
van der Waals interaction	Weak attraction of atoms due to the constant motion of electrons		1 

<sup>a</sup>Bond energy is the amount of energy needed to separate two bonded or interacting atoms under physiological conditions.

 High Energy 
  Low Energy 
  Very Low Energy