

# Lecture 4

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

* 58 <b>Ce</b> $4f^1 6s^2$	59 <b>Pr</b> $4f^3 6s^2$	60 <b>Nd</b> $4f^4 6s^2$	61 <b>Pm</b> $4f^5 6s^2$	62 <b>Sm</b> $4f^6 6s^2$	63 <b>Eu</b> $4f^7 6s^2$	64 <b>Gd</b> $4f^7 5d^1 6s^2$	65 <b>Tb</b> $4f^9 6s^2$	66 <b>Dy</b> $4f^{10} 6s^2$	67 <b>Ho</b> $4f^{11} 6s^2$	68 <b>Er</b> $4f^{13} 6s^2$	69 <b>Tm</b> $4f^{14} 6s^2$	70 <b>Yb</b> $4f^{14} 6s^2$	71 <b>Lu</b> $4f^{14} 5d^1 6s^2$
† 90 <b>Th</b> $6d^2 7s^2$	91 <b>Pa</b> $5f^2 6d^1 7s^2$	92 <b>U</b> $5f^3 6d^1 7s^2$	93 <b>Np</b> $5f^4 7s^2$	94 <b>Pu</b> $5f^6 7s^2$	95 <b>Am</b> $5f^7 7s^2$	96 <b>Cm</b> $5f^7 6d^1 7s^2$	97 <b>Bk</b> $5f^9 7s^2$	98 <b>Cf</b> $5f^{10} 7s^2$	99 <b>Es</b> $5f^{11} 7s^2$	100 <b>Fm</b> $5f^{12} 7s^2$	101 <b>Md</b> $5f^{13} 7s^2$	102 <b>No</b> $5f^{14} 7s^2$	103 <b>Lr</b> $5f^{14} 6d^1 7s^2$

<http://www.tcd.ie/Chemistry/teaching/chemistry/jf/intro/intro.php>

# Lecture 4

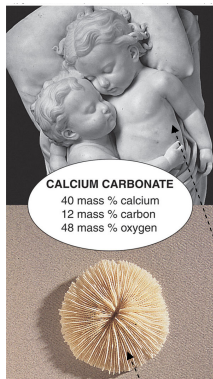
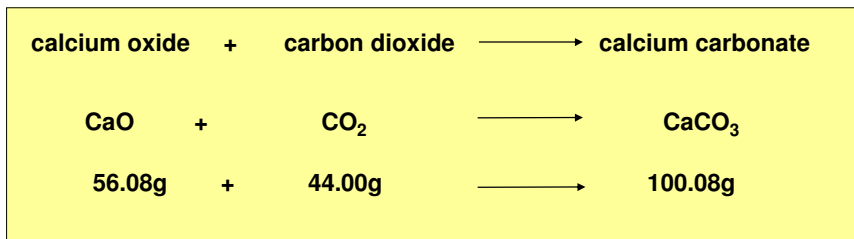
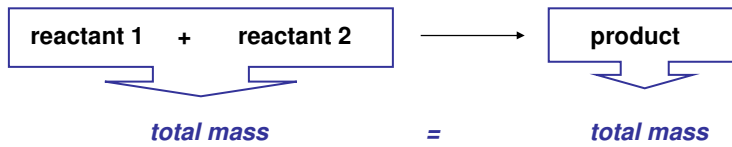
Chemical Bonding

## Outline

- 4.1 Law of conservation of mass
- 4.2 Law of definite composition
- 4.3 Bonding in chemical substances  
Ionic, covalent and metallic bonding
- 4.4 Electronegativity

**Law of Conservation of Mass:**

The total mass of substances does not change during a chemical reaction.



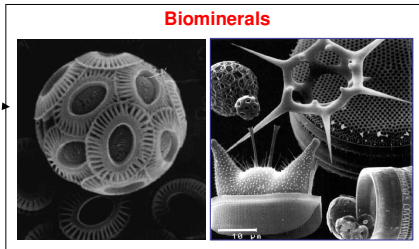
**Law of Definite (or Constant) Composition:**

No matter what its source, a particular chemical compound is composed of the same elements in the same parts (fractions) by mass.



1 atom of Ca	40.08 amu
1 atom of C	12.00 amu
3 atoms of O	3 x 16.00 amu
	100.08 amu

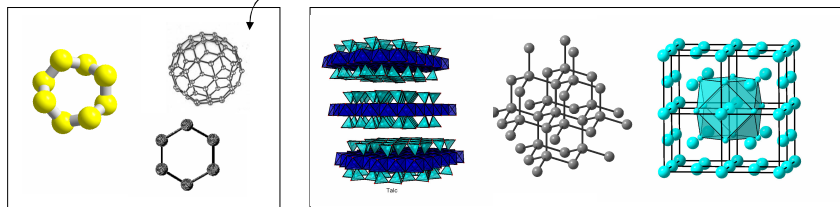
40.08 amu	= 0.401 parts Ca
100.08 amu	
12.00 amu	= 0.120 parts C
100.08 amu	
48.00 amu	= 0.480 parts O
100.08 amu	



## Bonding in chemical substances

Compounds:  $\rightarrow$  Inter-atomic interactions lead to aggregation

- A) "Infinite" assemblies of atoms  $\rightarrow$  e.g. metals, extended ionic or covalent compounds
- B) Clearly defined assemblies  $\rightarrow$  molecules



### Chemical Formula:

Element symbols of the atoms involved in the compound

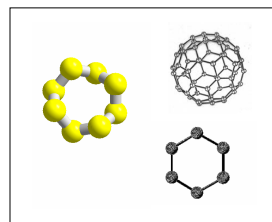
Composition given by the indices (bottom right of the element symbol)

## Bonding in chemical substances

### Molecules

H<sub>2</sub>: Molecule of two atoms of hydrogen  
 $\rightarrow$  Molecule of the element hydrogen

S<sub>8</sub>: Molecule of eight sulphur atoms  
 $\rightarrow$  Molecule of the element sulphur



HCl: Molecule built from one atom of hydrogen and one atom of chlorine  
 $\rightarrow$  Molecule of the compound hydrogenchloride

H<sub>2</sub>O: Molecule built from two atoms of hydrogen and one atom of oxygen  
 $\rightarrow$  H<sub>2</sub>O: Molecule of the compound water

## Bonding in chemical substances

A **molecular formula** shows the exact number of atoms of each element in the **smallest unit of a substance**.

An **empirical formula** shows the simplest whole-number ratio of the atoms in a substance.

Molecular formula in inorganic chemistry:

- No information how the atoms are connected (constitution)
- No information about the 3D arrangement (structure)

<u>molecular</u>	<u>empirical</u>
H <sub>2</sub> O	H <sub>2</sub> O
N <sub>2</sub> H <sub>4</sub>	NH <sub>2</sub>

## Bonding in chemical substances

**Chemical Bonds** - Forces that hold the atoms together in the compound:

- 1) Inter-atomic electrostatic interactions
- 2) Formation of stable compounds if the attractive forces between positive protons and negative electrons over-compensate the proton-proton and electron-electron repulsion.

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**Covalent Compounds**    Electrons are shared between atoms of different elements to form covalent compounds

**Ionic Compounds**        Electrons are transferred from one atom to another to form ionic compounds.

## **Bonding in chemical substances**

### **Important Rule: Octet rule (Lewis, 1916)**

Compounds of building units with **noble gas configuration** are especially stable (8 valence electrons for 2<sup>nd</sup> period)

—————→ can also be extended to 18 electrons

## **Bonding in chemical substances**

### **Different types of bonding:**

Ionic bond .....(e.g. NaCl, CsI; MgO)

Covalent bond .....(H<sub>2</sub>, HF, O<sub>2</sub>, S<sub>8</sub>)

Metallic bond .....(e.g. Ag, Cu<sub>3</sub>Au; Pb)

strong

Hydrogen bonds .....(H<sub>2</sub>O)

van der Waals bonding ...(organic compounds, hydrocarbons)

weak

## Bonding in chemical substances

**Bond energy:** Is the energy that is released when a bond is formed

**Dissociation energy:** Is the energy necessary to break a bond

Bond Type	Bond Energy	Examples
Ionic bonds	400-700KJ/mol	NaCl, CsF, MgO (salts)
Covalent	100-400KJ/mol	H <sub>2</sub> , HF, O <sub>2</sub> , S <sub>8</sub> (molecules)
Metallic	100-400KJ/mol	Ag, Cu <sub>3</sub> Au, Pb (metals)

## Ionic Bonding

An **ion** is an atom, or group of atoms, that has a net positive or negative charge.

**cation** – ion with a positive charge. If a neutral atom **loses** one or more electrons it becomes a cation.



11 protons  
11 electrons

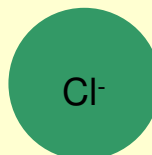


11 protons  
10 electrons

**anion** – ion with a negative charge. If a neutral atom **gains** one or more electrons it becomes an anion.



17 protons  
17 electrons



17 protons  
18 electrons

MAIN-GROUP ELEMENTS												TRANSITION ELEMENTS										MAIN-GROUP ELEMENTS							
1A (1)		2A (2)												3A (13)		4A (14)		5A (15)		6A (16)		7A (17)		8A (18)					
1	H 1.008																					He 4.003							
2	Li 6.941	Be 9.012																			Ne 20.18								
3	Na 22.99	Mg 24.31																			Ar 39.95								
4	K 39.10	Ca 40.08	Sc 44.96	Ti 47.88	V 50.94	Cr 52.00	Mn 54.94	Fe 55.85	Co 58.93	Ni 58.69	Cu 63.55	Zn 65.39	Ga 69.72	Ge 72.61	As 74.92	Se 78.96	Br 79.90	Kr 83.80											
	Rb 85.47	Sr 87.62	Y 88.91	Zr 91.22	Nb 92.91	Mo 95.94	Tc 98	Ru 101.1	Rh 102.9	Pd 106.4	Ag 107.9	Cd 112.4	In 114.8	Sn 118.7	Sb 121.8	Te 127.6	I 126.9	Xe 131.3											
5																													
6	Cs 132.9	Ba 137.3	La 138.9	Hf 178.5	Ta 180.9	W 183.9	Re 186.2	Os 190.2	Ir 192.2	Pt 195.1	Au 197.0	Hg 200.6	Tl 204.4	Pb 207.2	Bi 209.0	Po (209)	At (210)	Rn (222)											
7	Fr (223)	Ra (226)	Ac (227)	Rf (261)	Db (262)	Sg (266)	Bh (265)	Hs (266)	Mt (269)																				
												INNER TRANSITION ELEMENTS																	
6	Lanthanides		Ce 140.1	Pr 140.9	Nd 144.2	Pm (145)	Sm 150.4	Eu 152.0	Gd 157.3	Tb 158.9	Dy 162.5	Ho 164.9	Er 167.3	Tm 168.9	Yb 173.0	Lu 175.0													
7	Actinides		Th 232.0	Pa (231)	U 238.0	Np (237)	Pu (242)	Am (243)	Cm (247)	Bk (247)	Cf (251)	Es (252)	Fm (257)	Md (258)	No (259)	Lr (260)													

## Ionic Bonding

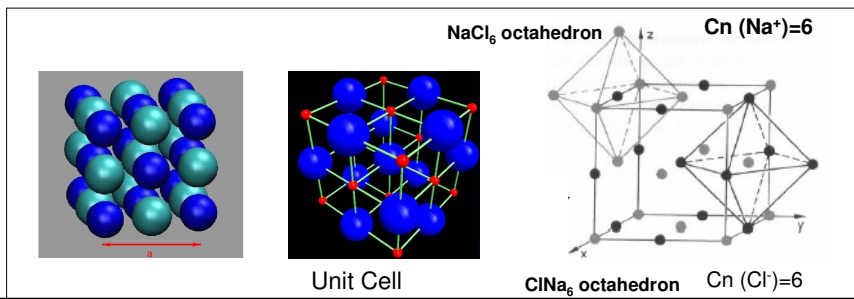
### ionic compounds

- ➔ consist of a combination of cations and anions
- ➔ the formula is usually the same as the empirical formula
- ➔ the sum of the charges on the cation(s) and anion(s) in each formula unit must equal zero

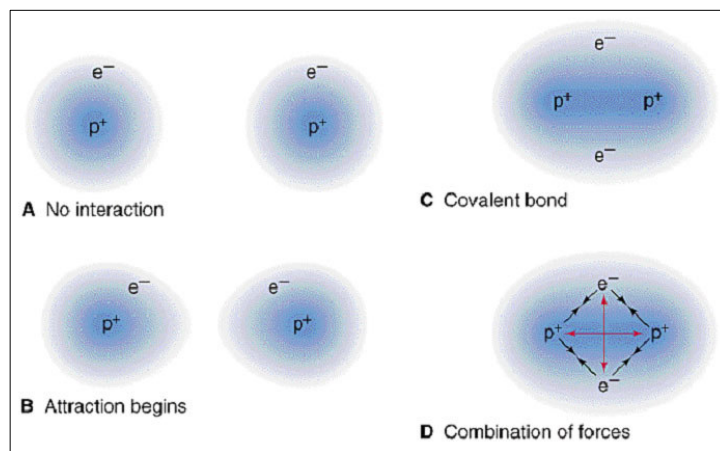


## ***Ionic Bonding***

- Formed between elements with a high difference of their electronegativity
- Strong bond; the bonding is not directed in space (electrostatic bonding)
- This type of bonding results in “infinite” aggregates built from cations and anions
- The compounds form ionic lattices
- Substances with ionic lattices are called “salts”



## **Formation of a Covalent Bond between Two H Atoms**





## Bonding in chemical substances

### Characteristics - Covalent Bonding:

2 or more valence electrons belong at the same time to the electron shell of different atoms.

High probability that the bonding electrons are located between the two bonding partners.

Different models to describe covalent bonds:

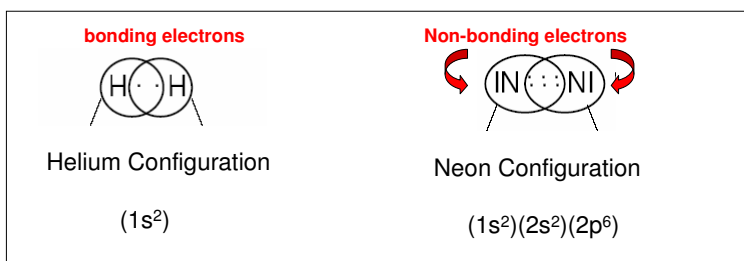
- Lewis formula (Element symbols, dots, lines)
- Valence bond model (orbitals, dots)
- Molecular orbital model (Energy level diagrams, arrows)

## Bonding in chemical substances

Covalent Bonding

### Lewis Formula

- ➔ According to Lewis: At least two electrons are shared between two atoms. These atoms reach noble gas configuration.
- ➔ The electrons are symbolised by dots or a line (bond = 2 electrons) between the elements.
- ➔ Further valence electrons which do not contribute to the bond remain as non-bonding "free" electrons next to the element symbol.



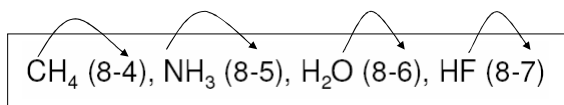
1 IA 1s <sup>1</sup>	2A																2 8A 1s <sup>2</sup>																												
3 Li 2s <sup>1</sup>	4 Be 2s <sup>2</sup>																	5 B 2s <sup>2</sup> 2p <sup>1</sup>	6 C 2s <sup>2</sup> 2p <sup>2</sup>	7 N 2s <sup>2</sup> 2p <sup>3</sup>	8 O 2s <sup>2</sup> 2p <sup>4</sup>	9 F 2s <sup>2</sup> 2p <sup>5</sup>	10 Ne 2s <sup>2</sup> 2p <sup>6</sup>																						
11 Na 3s <sup>1</sup>	12 Mg 3s <sup>2</sup>	3B	4B	5B	6B	7B	8B		1B	2B	13 Al 3s <sup>2</sup> 3p <sup>1</sup>	14 Si 3s <sup>2</sup> 3p <sup>2</sup>	15 P 3s <sup>2</sup> 3p <sup>3</sup>	16 S 3s <sup>2</sup> 3p <sup>4</sup>	17 Cl 3s <sup>2</sup> 3p <sup>5</sup>	18 Ar 3s <sup>2</sup> 3p <sup>6</sup>																													
19 K 4s <sup>1</sup>	20 Ca 4s <sup>2</sup>	21 Sc 3d <sup>1</sup> 4s <sup>2</sup>	22 Ti 3d <sup>2</sup> 4s <sup>2</sup>	23 V 3d <sup>3</sup> 4s <sup>2</sup>	24 Cr 3d <sup>5</sup> 4s <sup>1</sup>	25 Mn 3d <sup>5</sup> 4s <sup>2</sup>	26 Fe 3d <sup>6</sup> 4s <sup>2</sup>	27 Co 3d <sup>7</sup> 4s <sup>2</sup>	28 Ni 3d <sup>8</sup> 4s <sup>2</sup>	29 Cu 3d <sup>10</sup> 4s <sup>1</sup>	30 Zn 3d <sup>10</sup> 4s <sup>2</sup>	31 Ga 4s <sup>2</sup> 4p <sup>1</sup>	32 Ge 4s <sup>2</sup> 4p <sup>2</sup>	33 As 4s <sup>2</sup> 4p <sup>3</sup>	34 Se 4s <sup>2</sup> 4p <sup>4</sup>	35 Br 4s <sup>2</sup> 4p <sup>5</sup>	36 Kr 4s <sup>2</sup> 4p <sup>6</sup>																												
37 Rb 5s <sup>1</sup>	38 Sr 5s <sup>2</sup>	39 Y 4d <sup>1</sup> 5s <sup>2</sup>	40 Zr 4d <sup>2</sup> 5s <sup>2</sup>	41 Nb 4d <sup>4</sup> 5s <sup>1</sup>	42 Mo 4d <sup>5</sup> 5s <sup>1</sup>	43 Tc 4d <sup>5</sup> 5s <sup>2</sup>	44 Ru 4d <sup>7</sup> 5s <sup>1</sup>	45 Rh 4d <sup>8</sup> 5s <sup>1</sup>	46 Pd 4d <sup>10</sup>	47 Ag 4d <sup>10</sup> 5s <sup>1</sup>	48 Cd 4d <sup>10</sup> 5s <sup>2</sup>	49 In 5s <sup>2</sup> 5p <sup>1</sup>	50 Sn 5s <sup>2</sup> 5p <sup>2</sup>	51 Sb 5s <sup>2</sup> 5p <sup>3</sup>	52 Te 5s <sup>2</sup> 5p <sup>4</sup>	53 I 5s <sup>2</sup> 5p <sup>5</sup>	54 Xe 5s <sup>2</sup> 5p <sup>6</sup>																												
55 Cs 6s <sup>1</sup>	56 Ba 6s <sup>2</sup>	57 *La 5d <sup>1</sup> 6s <sup>2</sup>	72 Hf 5d <sup>2</sup> 6s <sup>2</sup>	73 Ta 5d <sup>3</sup> 6s <sup>2</sup>	74 W 5d <sup>4</sup> 6s <sup>2</sup>	75 Re 5d <sup>5</sup> 6s <sup>2</sup>	76 Os 5d <sup>6</sup> 6s <sup>2</sup>	77 Ir 5d <sup>7</sup> 6s <sup>2</sup>	78 Pt 5d <sup>9</sup> 6s <sup>1</sup>	79 Au 5d <sup>10</sup> 6s <sup>1</sup>	80 Hg 5d <sup>10</sup> 6s <sup>2</sup>	81 Tl 6s <sup>2</sup> 6p <sup>1</sup>	82 Pb 6s <sup>2</sup> 6p <sup>2</sup>	83 Bi 6s <sup>2</sup> 6p <sup>3</sup>	84 Po 6s <sup>2</sup> 6p <sup>4</sup>	85 At 6s <sup>2</sup> 6p <sup>5</sup>	86 Rn 6s <sup>2</sup> 6p <sup>6</sup>																												
87 Fr 7s <sup>1</sup>	88 Ra 7s <sup>2</sup>	89 ‡Ac 6d <sup>1</sup> 7s <sup>2</sup>	104 Rf 6d <sup>2</sup> 7s <sup>2</sup>	105 Db 6d <sup>3</sup> 7s <sup>2</sup>	106 Sg 6d <sup>4</sup> 7s <sup>2</sup>	107 Bh 6d <sup>5</sup> 7s <sup>2</sup>	108 Hs 6d <sup>6</sup> 7s <sup>2</sup>	109 Mt 6d <sup>7</sup> 7s <sup>2</sup>	110	111	112	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown																												
		<table border="1"> <tr> <td>* 58 Ce 4f<sup>2</sup>6s<sup>2</sup></td> <td>59 Pr 4f<sup>3</sup>6s<sup>2</sup></td> <td>60 Nd 4f<sup>4</sup>6s<sup>2</sup></td> <td>61 Pm 4f<sup>5</sup>6s<sup>2</sup></td> <td>62 Sm 4f<sup>6</sup>6s<sup>2</sup></td> <td>63 Eu 4f<sup>7</sup>6s<sup>2</sup></td> <td>64 Gd 4f<sup>7</sup>5d<sup>1</sup>6s<sup>2</sup></td> <td>65 Tb 4f<sup>9</sup>6s<sup>2</sup></td> <td>66 Dy 4f<sup>10</sup>6s<sup>2</sup></td> <td>67 Ho 4f<sup>11</sup>6s<sup>2</sup></td> <td>68 Er 4f<sup>12</sup>6s<sup>2</sup></td> <td>69 Tm 4f<sup>13</sup>6s<sup>2</sup></td> <td>70 Yb 4f<sup>14</sup>6s<sup>2</sup></td> <td>71 Lu 4f<sup>14</sup>5d<sup>1</sup>6s<sup>2</sup></td> </tr> <tr> <td>† 90 Th 6d<sup>2</sup>7s<sup>2</sup></td> <td>91 Pa 5f<sup>2</sup>6d<sup>1</sup>7s<sup>2</sup></td> <td>92 U 5f<sup>3</sup>6d<sup>1</sup>7s<sup>2</sup></td> <td>93 Np 5f<sup>4</sup>6d<sup>1</sup>7s<sup>2</sup></td> <td>94 Pu 5f<sup>6</sup>7s<sup>2</sup></td> <td>95 Am 5f<sup>7</sup>7s<sup>2</sup></td> <td>96 Cm 5f<sup>7</sup>6d<sup>1</sup>7s<sup>2</sup></td> <td>97 Bk 5f<sup>9</sup>7s<sup>2</sup></td> <td>98 Cf 5f<sup>10</sup>7s<sup>2</sup></td> <td>99 Es 5f<sup>11</sup>7s<sup>2</sup></td> <td>100 Fm 5f<sup>12</sup>7s<sup>2</sup></td> <td>101 Md 5f<sup>13</sup>7s<sup>2</sup></td> <td>102 No 5f<sup>14</sup>7s<sup>2</sup></td> <td>103 Lr 5f<sup>14</sup>6d<sup>1</sup>7s<sup>2</sup></td> </tr> </table>																* 58 Ce 4f <sup>2</sup> 6s <sup>2</sup>	59 Pr 4f <sup>3</sup> 6s <sup>2</sup>	60 Nd 4f <sup>4</sup> 6s <sup>2</sup>	61 Pm 4f <sup>5</sup> 6s <sup>2</sup>	62 Sm 4f <sup>6</sup> 6s <sup>2</sup>	63 Eu 4f <sup>7</sup> 6s <sup>2</sup>	64 Gd 4f <sup>7</sup> 5d <sup>1</sup> 6s <sup>2</sup>	65 Tb 4f <sup>9</sup> 6s <sup>2</sup>	66 Dy 4f <sup>10</sup> 6s <sup>2</sup>	67 Ho 4f <sup>11</sup> 6s <sup>2</sup>	68 Er 4f <sup>12</sup> 6s <sup>2</sup>	69 Tm 4f <sup>13</sup> 6s <sup>2</sup>	70 Yb 4f <sup>14</sup> 6s <sup>2</sup>	71 Lu 4f <sup>14</sup> 5d <sup>1</sup> 6s <sup>2</sup>	† 90 Th 6d <sup>2</sup> 7s <sup>2</sup>	91 Pa 5f <sup>2</sup> 6d <sup>1</sup> 7s <sup>2</sup>	92 U 5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup>	93 Np 5f <sup>4</sup> 6d <sup>1</sup> 7s <sup>2</sup>	94 Pu 5f <sup>6</sup> 7s <sup>2</sup>	95 Am 5f <sup>7</sup> 7s <sup>2</sup>	96 Cm 5f <sup>7</sup> 6d <sup>1</sup> 7s <sup>2</sup>	97 Bk 5f <sup>9</sup> 7s <sup>2</sup>	98 Cf 5f <sup>10</sup> 7s <sup>2</sup>	99 Es 5f <sup>11</sup> 7s <sup>2</sup>	100 Fm 5f <sup>12</sup> 7s <sup>2</sup>	101 Md 5f <sup>13</sup> 7s <sup>2</sup>	102 No 5f <sup>14</sup> 7s <sup>2</sup>	103 Lr 5f <sup>14</sup> 6d <sup>1</sup> 7s <sup>2</sup>
* 58 Ce 4f <sup>2</sup> 6s <sup>2</sup>	59 Pr 4f <sup>3</sup> 6s <sup>2</sup>	60 Nd 4f <sup>4</sup> 6s <sup>2</sup>	61 Pm 4f <sup>5</sup> 6s <sup>2</sup>	62 Sm 4f <sup>6</sup> 6s <sup>2</sup>	63 Eu 4f <sup>7</sup> 6s <sup>2</sup>	64 Gd 4f <sup>7</sup> 5d <sup>1</sup> 6s <sup>2</sup>	65 Tb 4f <sup>9</sup> 6s <sup>2</sup>	66 Dy 4f <sup>10</sup> 6s <sup>2</sup>	67 Ho 4f <sup>11</sup> 6s <sup>2</sup>	68 Er 4f <sup>12</sup> 6s <sup>2</sup>	69 Tm 4f <sup>13</sup> 6s <sup>2</sup>	70 Yb 4f <sup>14</sup> 6s <sup>2</sup>	71 Lu 4f <sup>14</sup> 5d <sup>1</sup> 6s <sup>2</sup>																																
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## Bonding in chemical substances Covalent Bonding

Lewis formula	No. of Bonds	Electron Pairs	
		bonding	not bonding
H · · H      H—H	Single Bond	1	0
$\overline{\text{O}} :: \overline{\text{O}}$ $\overline{\text{O}} = \overline{\text{O}}$	Double Bond	2	4
IN :: :: NI      IN≡NI	Triple Bond	3	2

Atoms from the 2<sup>nd</sup> period of the Periodic Table can form a maximum of 4 covalent bonds.

**8-n bonds:**



main group of periodic table

..... all neutral

## **Bonding in chemical substances**

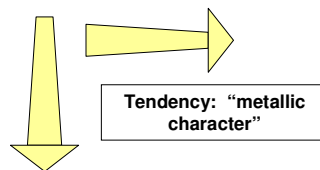
Metallic Bonding: → Formed by atoms with a low ionisation energy;

Characteristics: "Infinite" aggregates with highly flexible/moveable electrons delocalised over the whole metallic aggregate

→ "electron gas"

Bonding: electrostatic attraction between electron gas and positively charged atom nuclei.

Properties: High electrical and thermal conductivity as a result of the highly moveable electrons.



## **Electronegativity (EN)**

Related to the chemical bond:

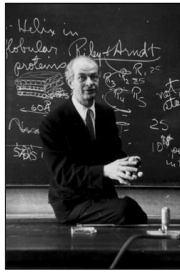
→ ability of an atom or molecule to attract electrons

If the difference of EN between atoms is very high, the electron will be transferred to one atom and an ionic bond will form. In a covalent bond, if one atom pulls slightly "harder" than the other, a polar covalent bond will form.

→ Most important: Pauling scale (1932):

The most electronegative chemical element (fluorine) is given an electronegativity value of 3.98 (or in text books 4.0); Francium is the most electropositive atom and has a value of 0.7. The other elements have values in between. Hydrogen is arbitrarily assigned a value of 2.1 or 2.2.

## Electronegativity (EN)



Linus Pauling (1901–1994)

$\Delta EN$  is the difference in electronegativity between two atoms or elements.

But many exceptions !!!!

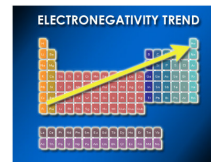
$\Delta EN \geq 1.7$ : often considered to be ionic bonds

$\Delta EN = 1.7-0.4$ : often considered as polar covalent

below 0.4–0: are considered as non-polar bonds

1A	2A									3A	4A	5A	6A	7A
2.1 H										2.0	2.5	3.0	3.5	4.0
1.0 Li	1.5 Be									B	C	N	O	F
0.9 Na	1.2 Mg									1.5	1.8	2.1	2.5	3.0
0.8 K	1.0 Ca	1.3 Sc	1.5 Ti	1.6 V	1.6 Cr	1.5 Mn	1.8 Fe	1.8 Co	1.8 Ni	1.9 Cu	1.6 Zn	1.8 Ga	2.0 Ge	2.4 As
0.8 Rb	1.0 Sr	1.2 Y	1.4 Zr	1.6 Nb	1.8 Mo	1.9 Tc	2.2 Ru	2.2 Rh	2.2 Pd	1.9 Ag	1.7 Cd	1.8 In	1.9 Sn	2.1 Sb
0.7 Cs	0.9 Ba	1.1-1.2 La-Lu	1.3 Hf	1.5 Ta	1.7 W	1.9 Re	2.2 Os	2.2 Ir	2.2 Pt	2.4 Au	1.9 Hg	1.8 Tl	1.9 Pb	2.0 Bi
0.7 Fr	0.9 Ra	1.1-1.7 Ac-Lr												2.2 Po

Decreasing electronegativity (upward arrow) and Increasing electronegativity (rightward arrow)



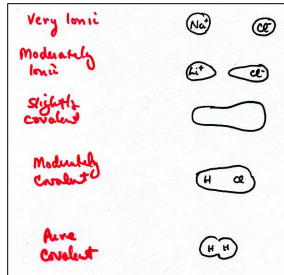
Tendencies

## Electronegativity (EN)

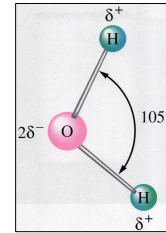
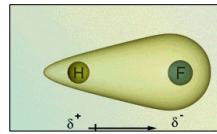
1A	2A									3A	4A	5A	6A	7A	8A			
1 H										5 B	6 C	7 N	8 O	9 F	2 He			
1s <sup>1</sup>										2s <sup>2</sup> 2p <sup>1</sup>	2s <sup>2</sup> 2p <sup>2</sup>	2s <sup>2</sup> 2p <sup>3</sup>	2s <sup>2</sup> 2p <sup>4</sup>	2s <sup>2</sup> 2p <sup>5</sup>	1s <sup>2</sup>			
3 Li	4 Be									13 Al	14 Si	15 P	16 S	17 Cl	10 Ne			
2s <sup>1</sup>	2s <sup>2</sup>									3s <sup>2</sup> 3p <sup>1</sup>	3s <sup>2</sup> 3p <sup>2</sup>	3s <sup>2</sup> 3p <sup>3</sup>	3s <sup>2</sup> 3p <sup>4</sup>	3s <sup>2</sup> 3p <sup>5</sup>	2s <sup>2</sup> 2p <sup>6</sup>			
11 Na	12 Mg									31 Ga	32 Ge	33 As	34 Se	35 Br	18 Ar			
3s <sup>1</sup>	3s <sup>2</sup>									4s <sup>2</sup> 4p <sup>1</sup>	4s <sup>2</sup> 4p <sup>2</sup>	4s <sup>2</sup> 4p <sup>3</sup>	4s <sup>2</sup> 4p <sup>4</sup>	4s <sup>2</sup> 4p <sup>5</sup>	3s <sup>2</sup> 3p <sup>6</sup>			
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	
4s <sup>1</sup>	4s <sup>2</sup>	3d <sup>1</sup> 4s <sup>2</sup>	3d <sup>2</sup> 4s <sup>2</sup>	3d <sup>3</sup> 4s <sup>2</sup>	3d <sup>4</sup> 4s <sup>1</sup>	3d <sup>5</sup> 4s <sup>1</sup>	3d <sup>6</sup> 4s <sup>2</sup>	3d <sup>7</sup> 4s <sup>2</sup>	3d <sup>8</sup> 4s <sup>2</sup>	3d <sup>10</sup> 4s <sup>1</sup>	3d <sup>10</sup> 4s <sup>2</sup>	4s <sup>2</sup> 4p <sup>1</sup>	4s <sup>2</sup> 4p <sup>2</sup>	4s <sup>2</sup> 4p <sup>3</sup>	4s <sup>2</sup> 4p <sup>4</sup>	4s <sup>2</sup> 4p <sup>5</sup>	3s <sup>2</sup> 3p <sup>6</sup>	
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	
5s <sup>1</sup>	5s <sup>2</sup>	4d <sup>1</sup> 5s <sup>2</sup>	4d <sup>2</sup> 5s <sup>2</sup>	4d <sup>3</sup> 5s <sup>2</sup>	4d <sup>4</sup> 5s <sup>1</sup>	4d <sup>5</sup> 5s <sup>1</sup>	4d <sup>6</sup> 5s <sup>2</sup>	4d <sup>7</sup> 5s <sup>1</sup>	4d <sup>8</sup> 5s <sup>1</sup>	4d <sup>10</sup>	4d <sup>10</sup> 5s <sup>1</sup>	4d <sup>10</sup> 5s <sup>2</sup>	5s <sup>2</sup> 5p <sup>1</sup>	5s <sup>2</sup> 5p <sup>2</sup>	5s <sup>2</sup> 5p <sup>3</sup>	5s <sup>2</sup> 5p <sup>4</sup>	5s <sup>2</sup> 5p <sup>5</sup>	4s <sup>2</sup> 4p <sup>6</sup>
55 Cs	56 Ba	57 La	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	
6s <sup>1</sup>	6s <sup>2</sup>	5d <sup>1</sup> 6s <sup>2</sup>	5d <sup>2</sup> 6s <sup>2</sup>	5d <sup>3</sup> 6s <sup>2</sup>	5d <sup>4</sup> 6s <sup>1</sup>	5d <sup>5</sup> 6s <sup>1</sup>	5d <sup>6</sup> 6s <sup>2</sup>	5d <sup>7</sup> 6s <sup>1</sup>	5d <sup>8</sup> 6s <sup>1</sup>	5d <sup>10</sup> 6s <sup>1</sup>	5d <sup>10</sup> 6s <sup>2</sup>	6s <sup>2</sup> 6p <sup>1</sup>	6s <sup>2</sup> 6p <sup>2</sup>	6s <sup>2</sup> 6p <sup>3</sup>	6s <sup>2</sup> 6p <sup>4</sup>	6s <sup>2</sup> 6p <sup>5</sup>	4s <sup>2</sup> 4p <sup>6</sup>	
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112	Unknown	114	Unknown	116	Unknown	118	
7s <sup>1</sup>	7s <sup>2</sup>	6d <sup>1</sup> 7s <sup>2</sup>	6d <sup>2</sup> 7s <sup>2</sup>	6d <sup>3</sup> 7s <sup>2</sup>	6d <sup>4</sup> 7s <sup>1</sup>												3s <sup>2</sup> 3p <sup>6</sup>	

Annotations:  
 - A blue oval highlights the s-block elements (groups 1 and 2).  
 - A red line and oval highlight the p-block elements (groups 13-18).  
 - Text "often ionic compounds" is placed over the s-block.  
 - Text "often molecular" is placed over the p-block.  
 - Lanthanides (La-Lu) and Actinides (Ac-Lr) are shown at the bottom with their configurations.

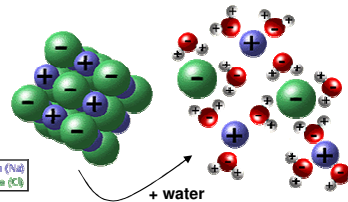
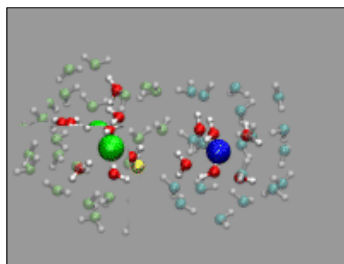
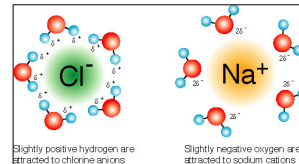
## Electronegativity (EN)



Polar Bonds:



Hydration:



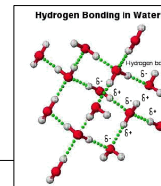
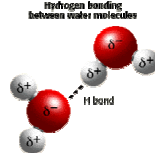
## Bonding in chemical substances

### Weaker Bonds

Type	Bond Energy (KJ/mol)	Example
Hydrogen bonding	< 30	HF; H <sub>2</sub> O; NH <sub>3</sub> ; CH <sub>3</sub> CO <sub>2</sub> H
van der Waals	< 3	He, Ne, hydrocarbons

→ Interactions between positively and negatively polarised centres

Permanent dipoles (H-bond)



→ Interactions between temporary positively and negatively polarised centres

Induced dipoles (van der Waals bond)

