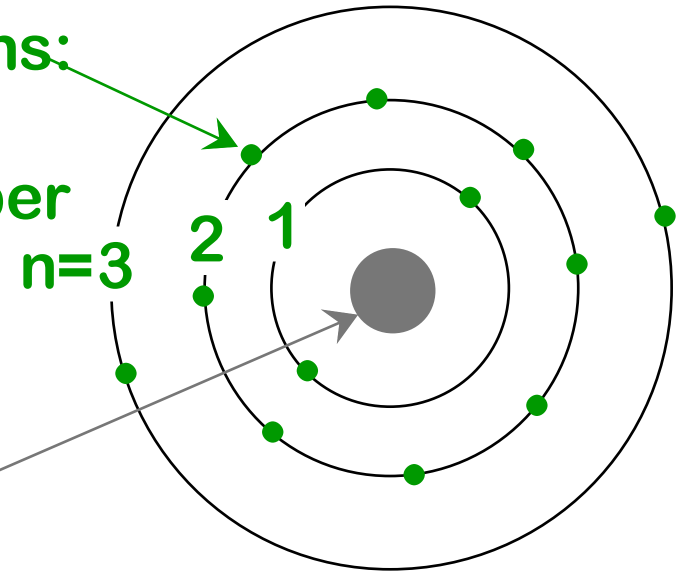
CHAPTER 2: BONDING AND PROPERTIES

ISSUES TO ADDRESS...

- What promotes bonding?
- What types of bonds are there?
- What properties are inferred from bonding?

BOHR ATOM

orbital electrons:
n = principal
quantum number



Adapted from Fig. 2.1, *Callister 6e.*

Nucleus: Z = # protons

= 1 for hydrogen to 94 for plutonium

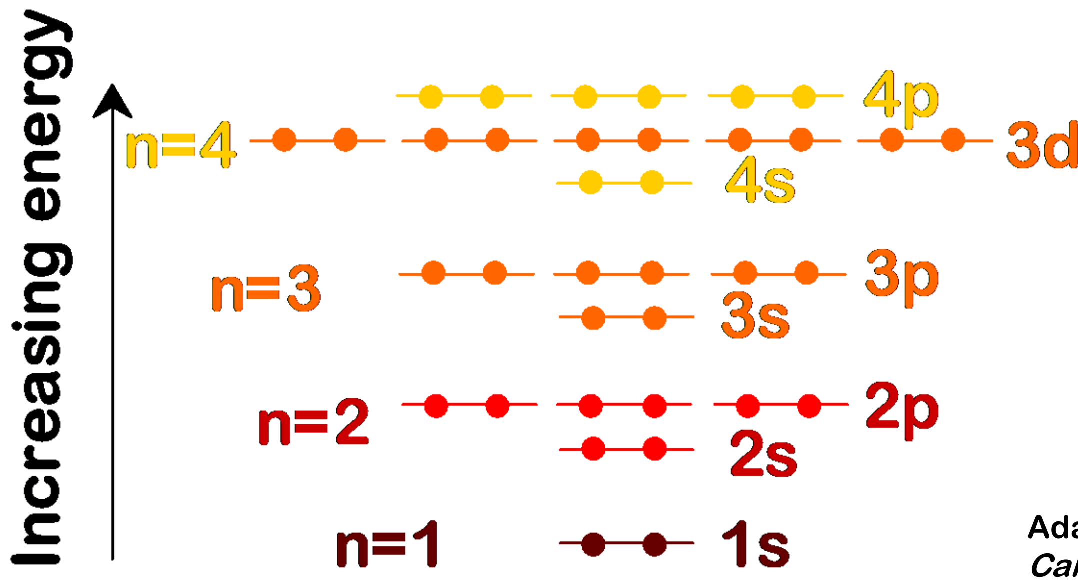
N = # neutrons

Atomic mass A ≈ Z + N

ELECTRON ENERGY STATES

Electrons...

- have discrete energy states
- tend to occupy lowest available energy state.



Adapted from Fig. 2.5, *Callister 6e.*

STABLE ELECTRON CONFIGURATIONS

Stable electron configurations...

- have complete s and p subshells
- tend to be unreactive.

Z	Element	Configuration
2	He	$1s^2$
10	Ne	$1s^2 2s^2 2p^6$
18	Ar	$1s^2 2s^2 2p^6 3s^2 3p^6$
36	Kr	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$

Adapted from Table 2.2, *Callister 6e.*

SURVEY OF ELEMENTS

- **Most elements: Electron configuration not stable.**

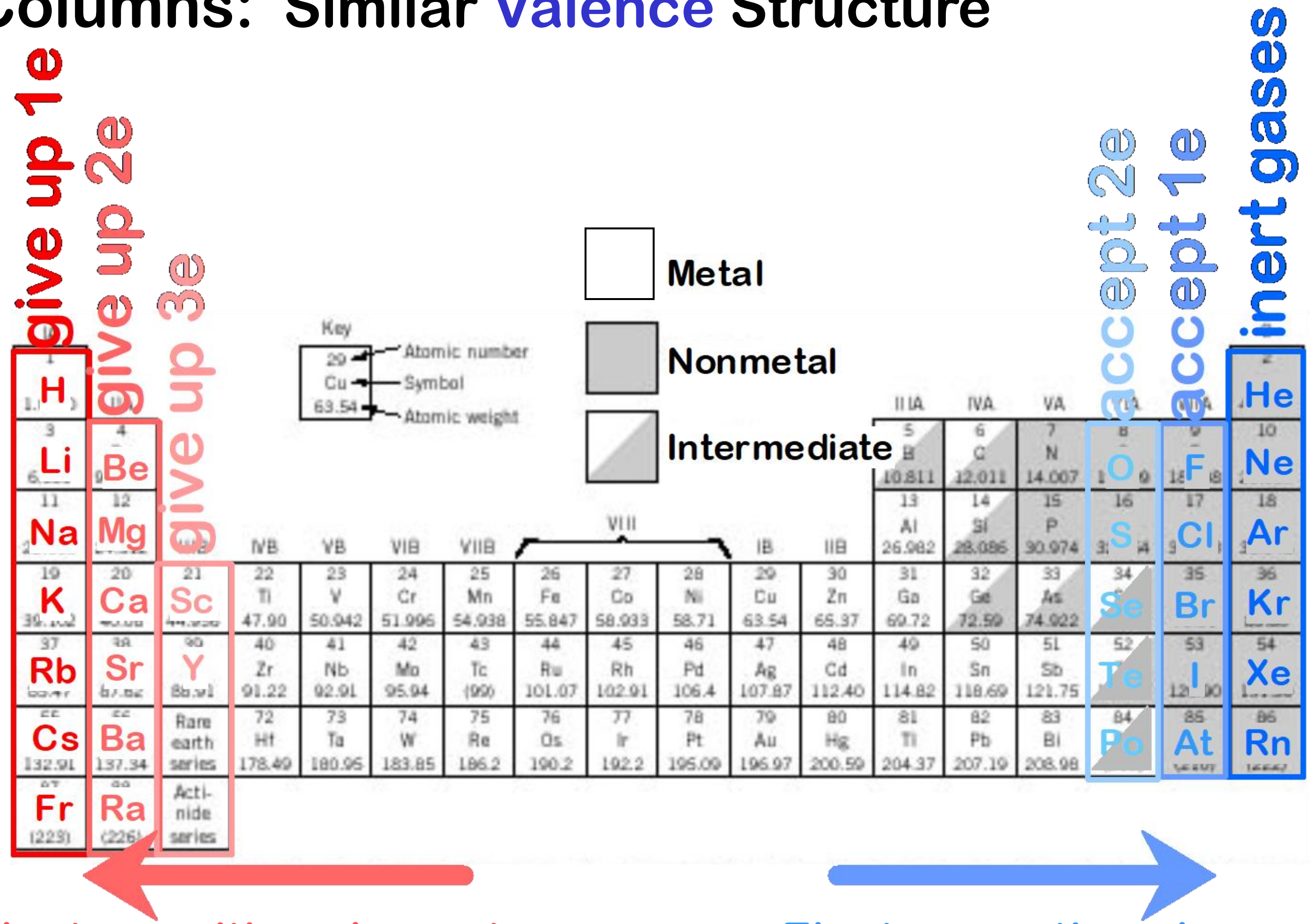
Element	Atomic #	Electron configuration	
Hydrogen	1	$1s^1$	
Helium	2	$1s^2$	(stable)
Lithium	3	$1s^2 2s^1$	
Beryllium	4	$1s^2 2s^2$	
Boron	5	$1s^2 2s^2 2p^1$	
Carbon	6	$1s^2 2s^2 2p^2$	
...		...	
Neon	10	$1s^2 2s^2 2p^6$	(stable)
Sodium	11	$1s^2 2s^2 2p^6 3s^1$	
Magnesium	12	$1s^2 2s^2 2p^6 3s^2$	
Aluminum	13	$1s^2 2s^2 2p^6 3s^2 3p^1$	
...		...	
Argon	18	$1s^2 2s^2 2p^6 3s^2 3p^6$	(stable)
...	...	...	
Krypton	36	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4^6$	(stable)

Adapted from Table 2.2, *Callister 6e.*

- **Why? Valence (outer) shell usually not filled completely.**

THE PERIODIC TABLE

- **Columns: Similar Valence Structure**



Adapted from Fig. 2.6, *Callister 6e.*

Electropositive elements:
Readily give up electrons
to become + ions.

Electronegative elements:
Readily acquire electrons
to become - ions.

ELECTRONEGATIVITY

- Ranges from 0.7 to 4.0,
- Large values: tendency to acquire electrons.

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
H 2.1																	He -
Li 1.0	Be 1.5											5 B 2.0	6 C 2.5	7 N 3.0	8 O 3.5	F 4.0	Ne -
Na 0.9	Mg 1.2											13 Al 1.5	14 Si 1.8	15 P 2.1	16 S 2.5	Cl 3.0	Ar -
K 0.8	Ca 1.0	21 Sc 1.3	Ti 1.5	23 V 1.6	Cr 1.6	25 Mn 1.5	Fe 1.8	27 Co 1.8	Ni 1.8	29 Cu 1.9	Zn 1.8	31 Ga 1.6	32 Ge 1.8	As 2.0	34 Se 2.4	Br 2.8	Kr -
Rb 0.8	Sr 1.0	39 Y 1.2	40 Zr 1.4	41 Nb 1.6	42 Mo 1.8	43 Tc 1.9	44 Ru 2.2	45 Rh 2.2	46 Pd 2.2	47 Ag 1.9	48 Cd 1.7	49 In 1.7	50 Sn 1.8	51 Sb 1.9	52 Te 2.1	I 2.5	Xe -
Cs 0.7	Ba 0.9	57-71 La-Lu 1.1-1.2	72 Hf 1.3	73 Ta 1.5	74 W 1.7	75 Re 1.9	76 Os 2.2	77 Ir 2.2	78 Pt 2.2	79 Au 2.4	80 Hg 1.9	81 Tl 1.8	82 Pb 1.8	83 Bi 1.9	84 Po 2.0	At 2.2	Rn -
Fr 0.7	Ra 0.9	89-102 Ac-No 1.1-1.7															

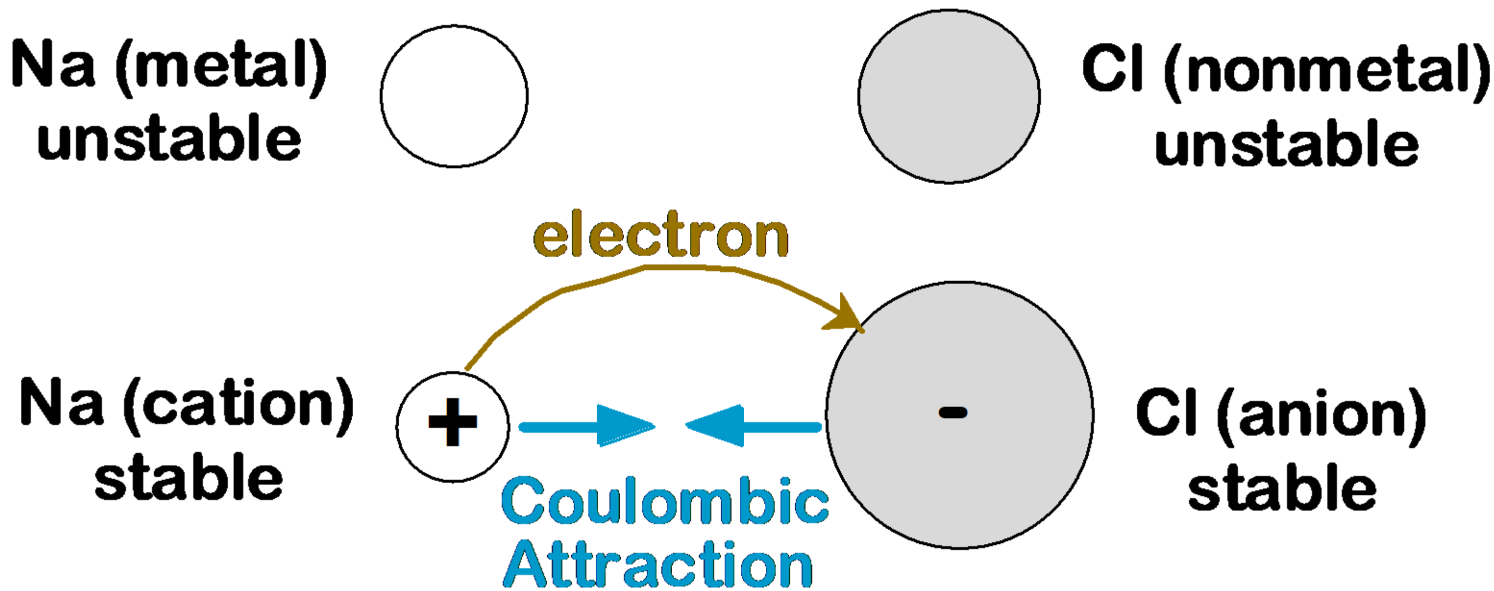
Smaller electronegativity

Larger electronegativity

Adapted from Fig. 2.7, *Callister 6e.* (Fig. 2.7 is adapted from Linus Pauling, *The Nature of the Chemical Bond*, 3rd edition, Copyright 1939 and 1940, 3rd edition. Copyright 1960 by Cornell University.

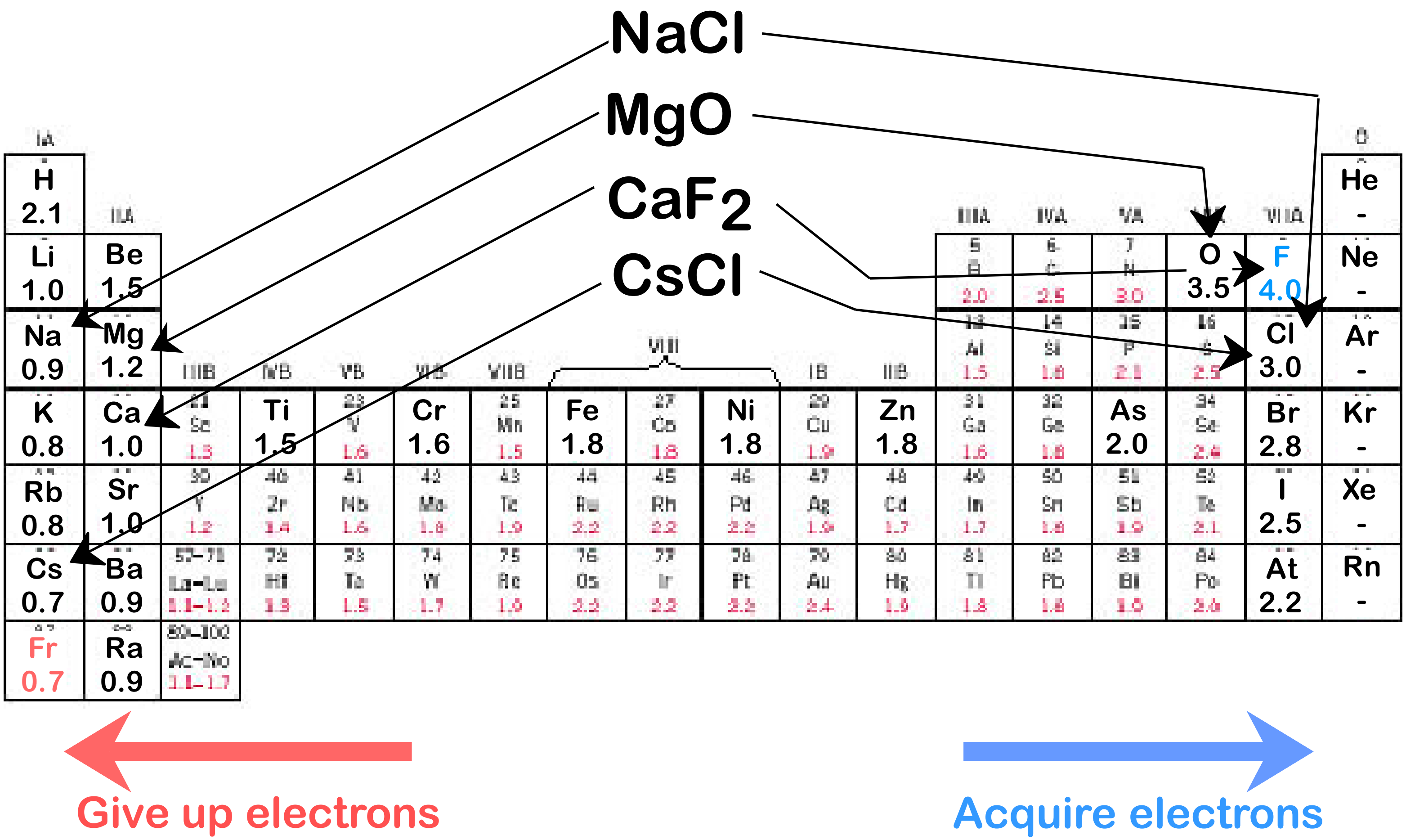
IONIC BONDING

- Occurs between + and - ions.
- Requires electron transfer.
- Large difference in electronegativity required.
- Example: NaCl



EXAMPLES: IONIC BONDING

- Predominant bonding in **Ceramics**



Adapted from Fig. 2.7, *Callister 6e.* (Fig. 2.7 is adapted from Linus Pauling, *The Nature of the Chemical Bond*, 3rd edition, Copyright 1939 and 1940, 3rd edition. Copyright 1960 by Cornell University.

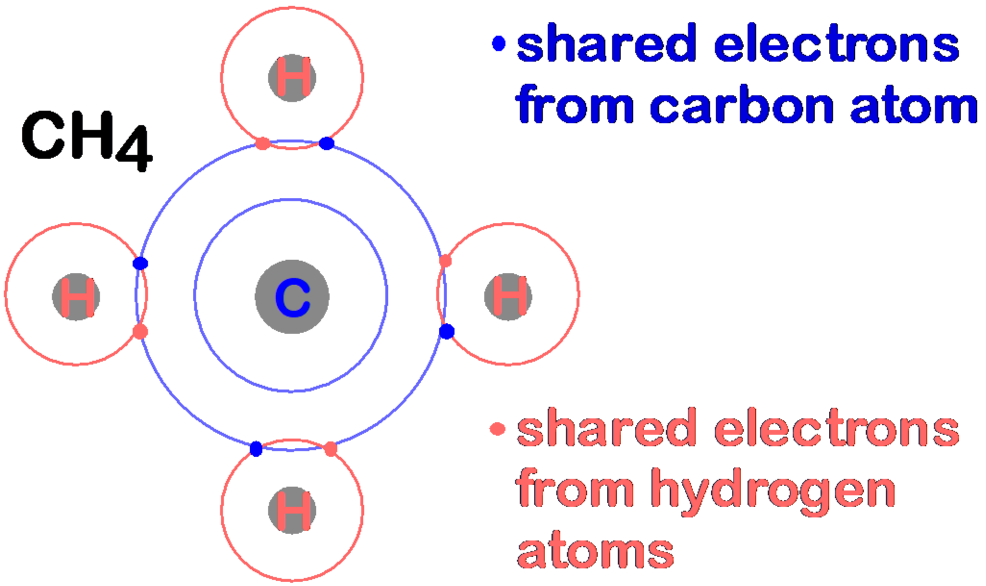
COVALENT BONDING

- Requires shared electrons
- Example: CH_4

C: has 4 valence e, needs 4 more

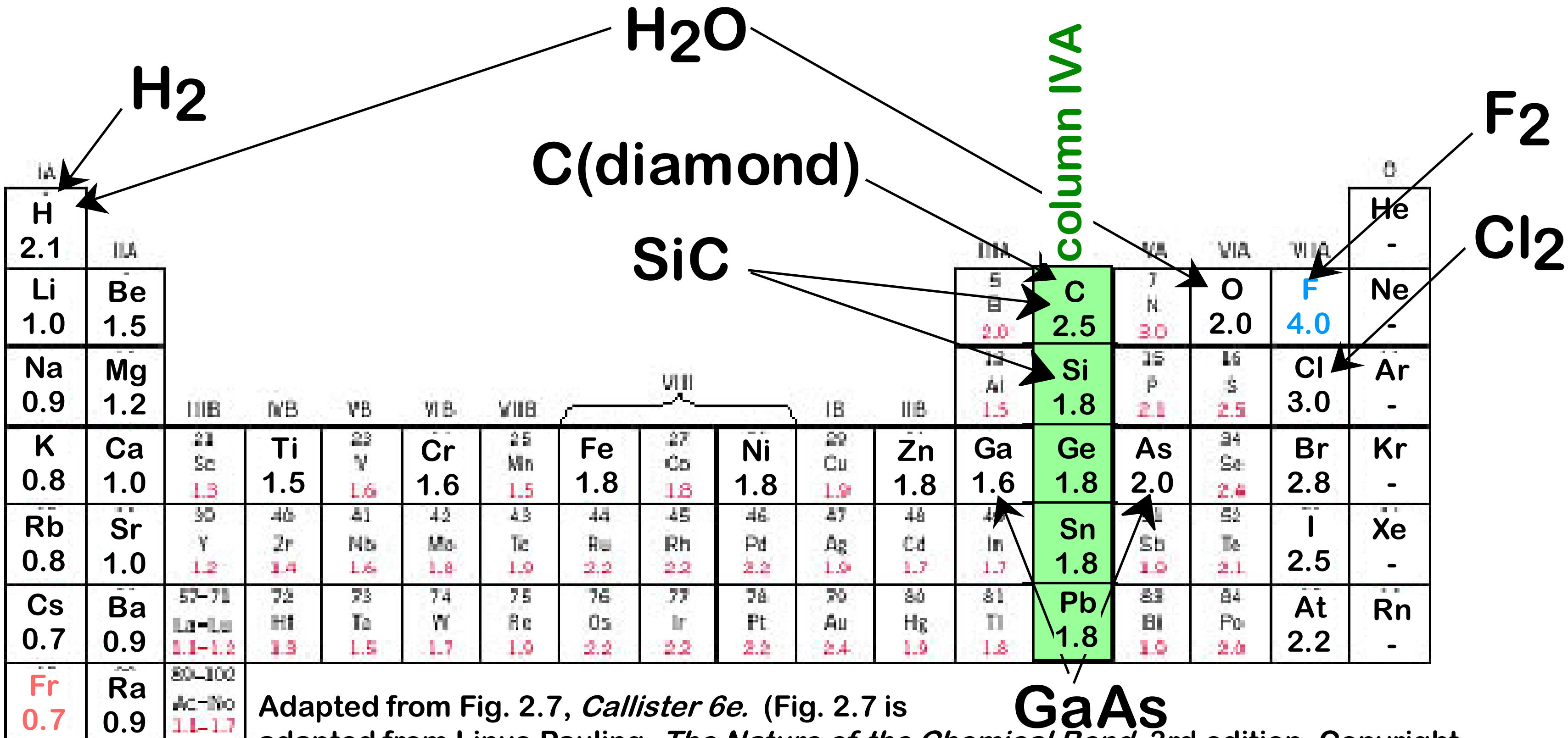
H: has 1 valence e, needs 1 more

Electronegativities are comparable.



Adapted from Fig. 2.10, *Callister 6e.*

EXAMPLES: COVALENT BONDING

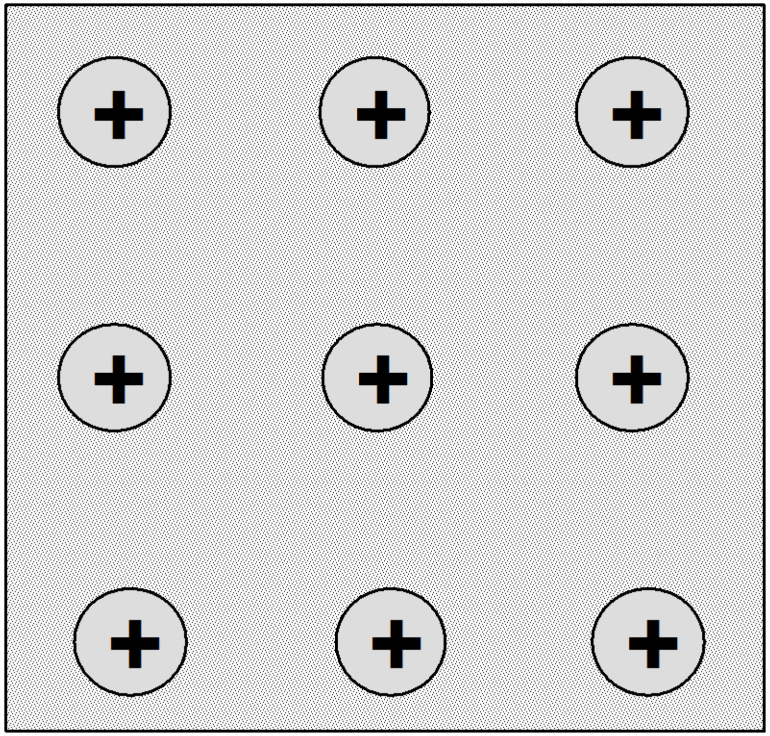


Adapted from Fig. 2.7, *Callister 6e.* (Fig. 2.7 is adapted from Linus Pauling, *The Nature of the Chemical Bond*, 3rd edition, Copyright 1939 and 1940, 3rd edition. Copyright 1960 by Cornell University.

- Molecules with nonmetals
- Molecules with metals and nonmetals
- Elemental solids (RHS of Periodic Table)
- Compound solids (about column IVA)

METALLIC BONDING

- Arises from a sea of donated valence electrons (1, 2, or 3 from each atom).



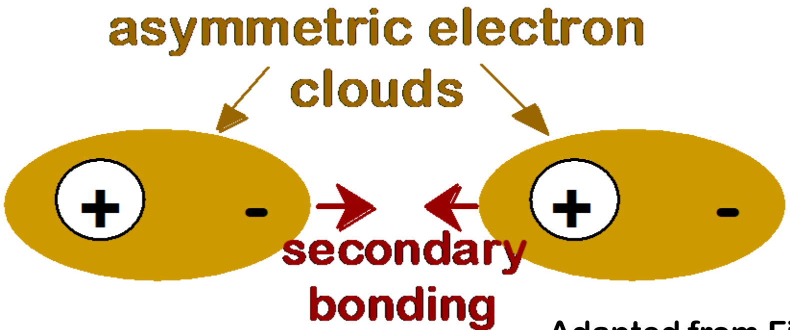
Adapted from Fig. 2.11, *Callister 6e.*

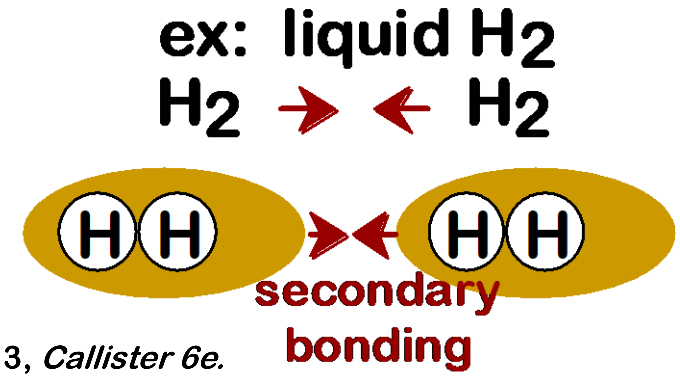
- Primary bond for metals and their alloys

SECONDARY BONDING

Arises from interaction between dipoles

- Fluctuating dipoles





Adapted from Fig. 2.13, *Callister 6e.*

- Permanent dipoles-molecule induced

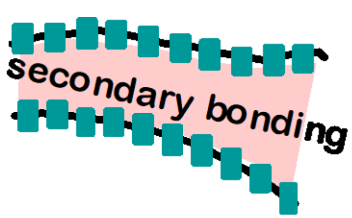
-general case:

Adapted from Fig. 2.14, *Callister 6e.*

-ex: liquid HCl

Adapted from Fig. 2.14, *Callister 6e.*

-ex: polymer

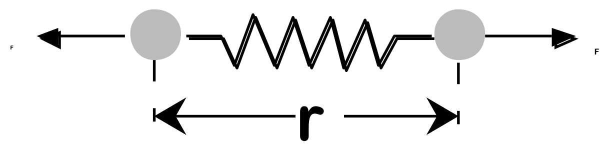


SUMMARY: BONDING

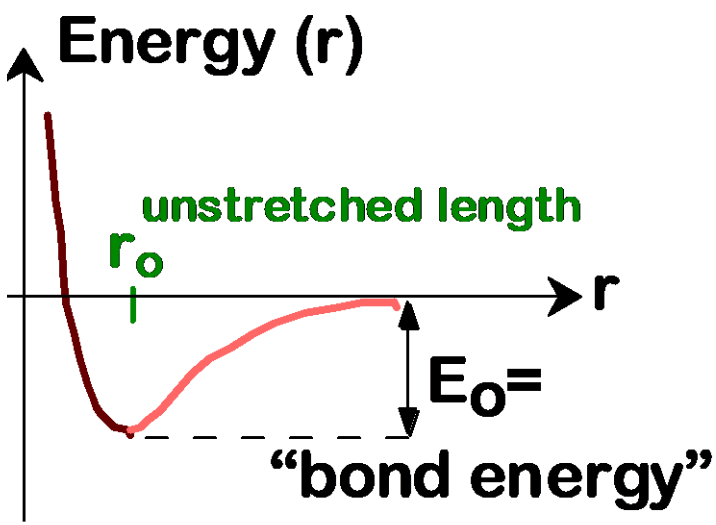
Type	Bond Energy	Comments
Ionic	Large!	Nondirectional (ceramics)
Covalent	Variable large-Diamond small-Bismuth	Directional semiconductors, ceramics polymer chains)
Metallic	Variable large-Tungsten small-Mercury	Nondirectional (metals)
Secondary	smallest	Directional inter-chain (polymer) inter-molecular

PROPERTIES FROM BONDING: T_M

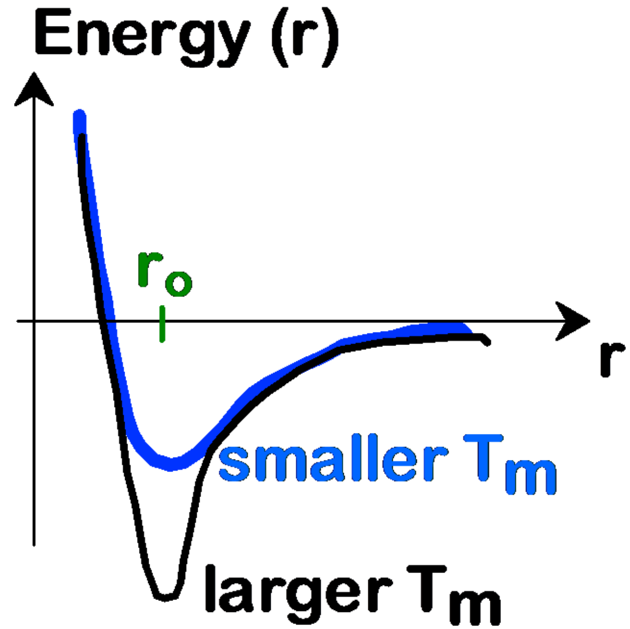
- **Bond length**, r



- **Bond energy**, E_o



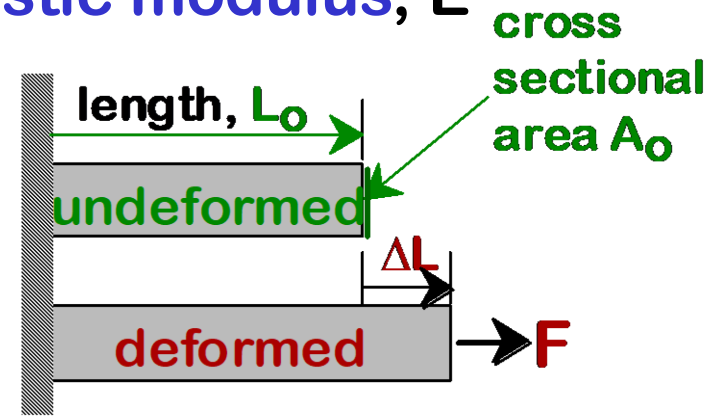
- **Melting Temperature**, T_m



T_m is larger if E_o is larger.

PROPERTIES FROM BONDING: E

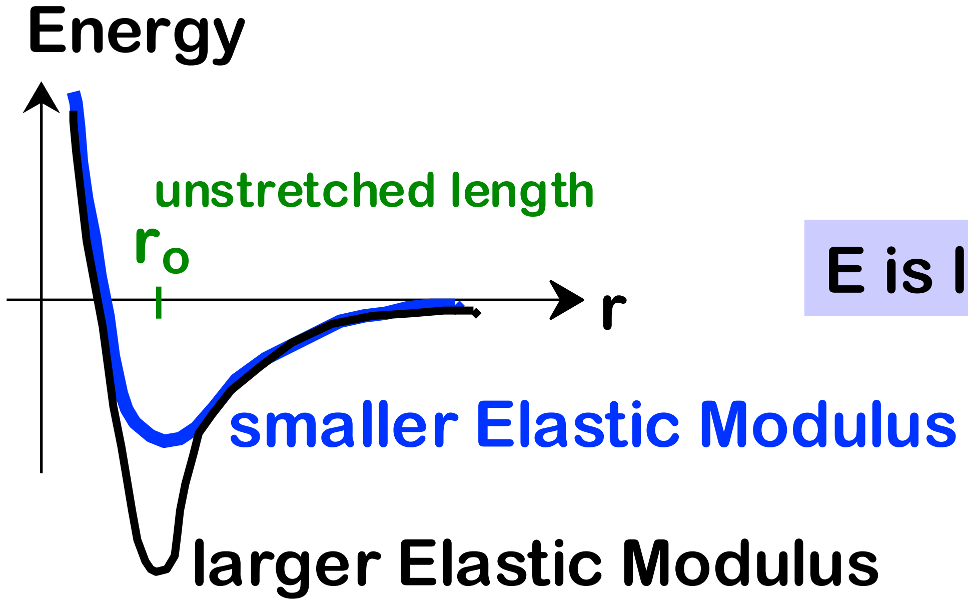
- Elastic modulus, E



Elastic modulus

$$\frac{F}{A_o} = E\,\frac{\Delta L}{L_o}$$

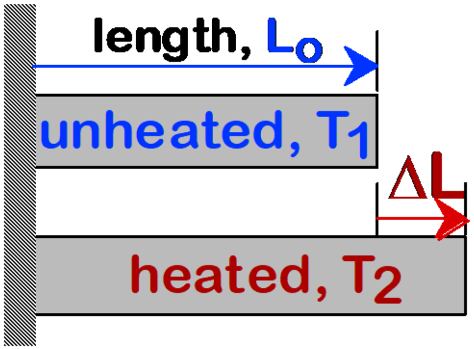
- E ~ curvature at r_o



E is larger if E_o is larger.

PROPERTIES FROM BONDING: α

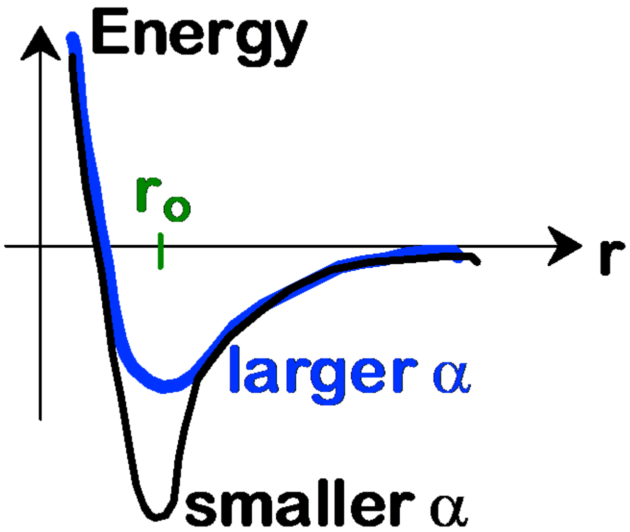
- Coefficient of thermal expansion, α



coeff. thermal expansion

$$\frac{\Delta L}{L_o} = \alpha\,(T_2 - T_1)$$

- α ~ symmetry at r_o



α is larger if E_o is smaller.

SUMMARY: PRIMARY BONDS

Ceramics

(Ionic & covalent bonding):

Large bond energy

large T_m
large E
small α

Metals

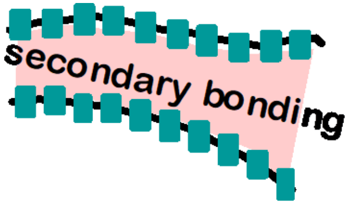
(Metallic bonding):

Variable bond energy

moderate T_m
moderate E
moderate α

Polymers

(Covalent & Secondary):



Directional Properties

Secondary bonding dominates
small T
small E
large α

ANNOUNCEMENTS

Reading:

Core Problems:

Self-help Problems:

Introduction to Materials Technology

Materials Technology is the branch of science and engineering that studies the properties, structure, processing, and applications of materials used in manufacturing and engineering systems. It bridges the gap between science and practical engineering by focusing on how materials can be selected, modified, and improved to meet design and performance requirements.

1. Importance of Materials Technology

Materials form the foundation of all engineering systems. From bridges and aircraft to microchips and medical implants, the performance, safety, and cost of a product depend largely on the materials used and how they are processed.

2. Classification of Engineering Materials

Engineering materials are generally classified into:

- **Metals** (e.g., steel, aluminum, copper)
- **Polymers** (e.g., plastics, rubber)
- **Ceramics** (e.g., glass, porcelain)
- **Composites** (e.g., fiberglass, carbon fiber)
- **Advanced materials** (e.g., smart materials, nanomaterials, biomaterials)

3. Structure–Property Relationship

Materials technology emphasizes the relationship between a material's **structure** (atomic or molecular arrangement) and its **properties** (mechanical, electrical, thermal, etc.). Understanding this relationship allows engineers to tailor materials for specific functions.

4. Material Processing

Processing involves shaping, joining, and treating materials to achieve the desired structure and properties. Common processes include casting, forging, welding, heat treatment, and additive manufacturing.

5. Material Selection

Choosing the right material involves balancing performance, cost, availability, and environmental impact. Tools such as Ashby charts help engineers compare materials based on their properties.

6. Applications

Materials technology is essential in fields such as:

- Mechanical and aerospace engineering
- Civil and structural engineering
- Electronics and energy systems
- Biomedical and environmental engineering

7. Future Trends

Emerging trends include:

- Development of **smart materials** that respond to environmental changes
- Use of **nanotechnology** for improved strength and conductivity
- Focus on **sustainable materials** and recycling to reduce environmental impact