

CHAPTER 2: BONDING AND PROPERTIES

ISSUES TO ADDRESS...

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

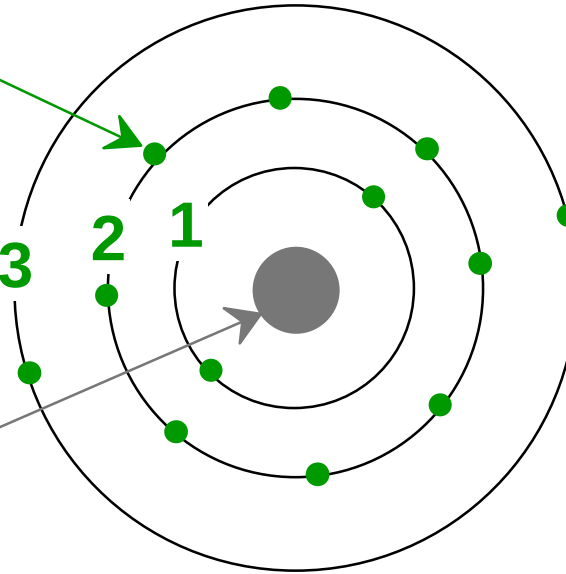
BOHR ATOM

orbital electrons:
 n = principal
quantum number

$n=3$

2

1



Adapted from Fig. 2.1,
Callister 6e.

Nucleus: Z = # protons

= 1 for hydrogen to 94 for plutonium

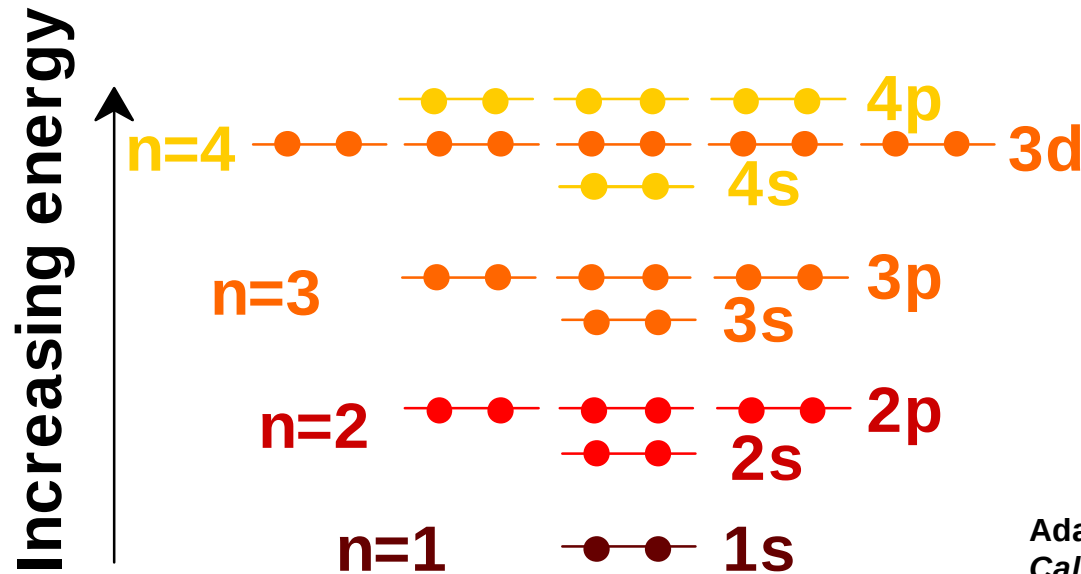
N = # neutrons

Atomic mass $A \approx Z + N$

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
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2	He	$1s^2$
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10	Ne	$1s^2 2s^2 2p^6$
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18	Ar	$1s^2 2s^2 2p^6 3s^2 3p^6$
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36	Kr	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$
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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	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$ (stable)

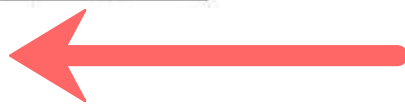
Adapted from Table 2.2,
Callister 6e.

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

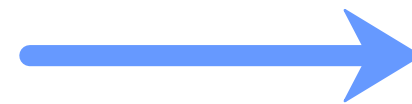
ELECTRONEGATIVITY

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

IA																	0				
H 2.1	IIA											IIIA	IVA	VA	VIA	VIIA	He -				
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne -				
Na 0.9	Mg 1.2	IIIB	IVB	VB	VIB	VIIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA					
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					
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					
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					
Fr 0.7	Ra 0.9	89-102 Ac-No 1.1-1.7															Rn -				



Smaller electronegativity

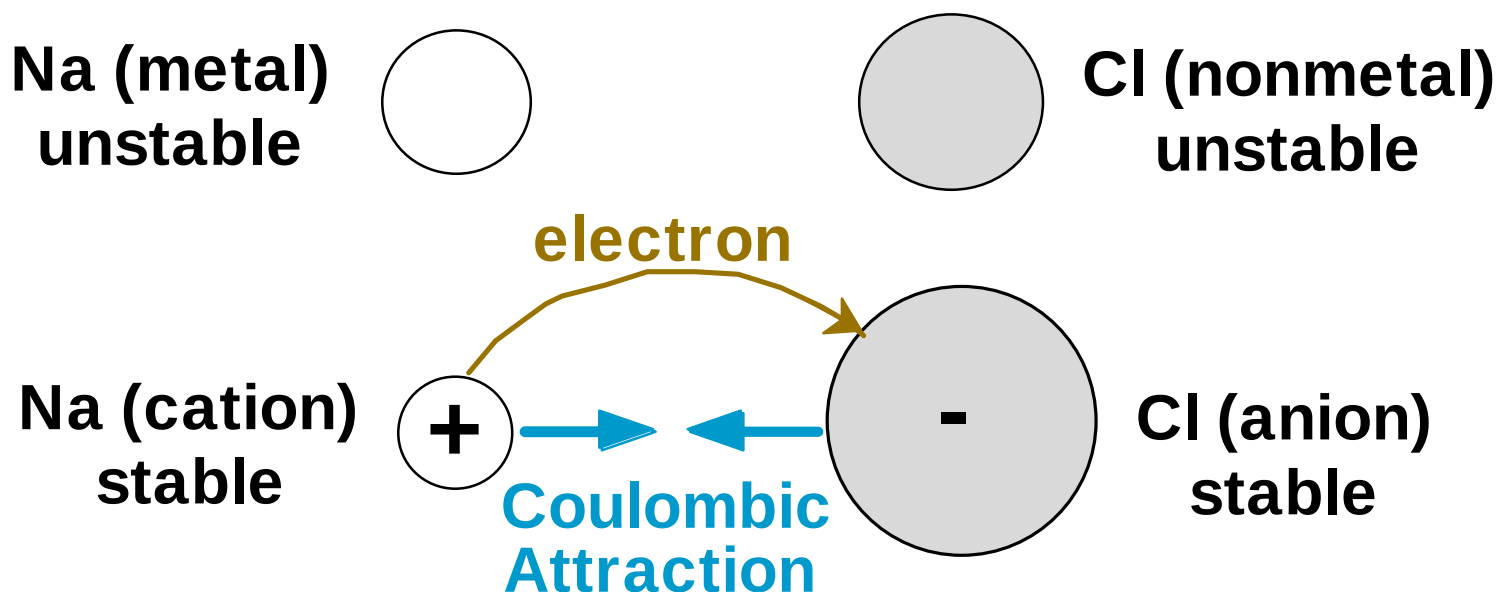


Larger electronegativity

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**

NaCl

MgO

CaF₂

CsCl

IA	IIA																	III A	IV A	V A		VII A	0
H 2.1																		B	C	N	O	F	He
Li 1.0	Be 1.5																	Al	Si	P	S	Cl	Ne
Na 0.9	Mg 1.2																	Al	Si	P	S	Cl	Ar
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.8	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr						
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe						
Cs 0.7	Ba 0.9	La-Lu 1.1-1.2	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.6	At 2.2	Rn						
Fr 0.7	Ra 0.9	Ac-No 1.1-1.7																					

Give up electrons

Acquire electrons

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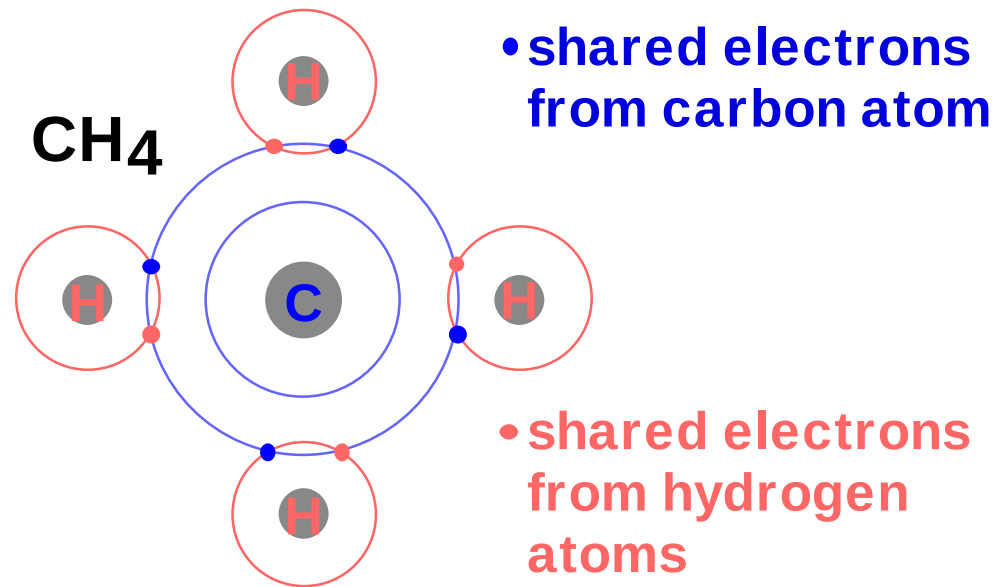
COVALENT BONDING

- Requires **shared electrons**
- Example: CH₄

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

IA												IIIA		column IVA		VA		VIA		VIIA		0			
H	2.1											B	2.0	C	2.5	N	3.0	O	2.0	F	4.0	He	-		
Li	1.0	Be	1.5											Al	1.5	Si	1.8	P	2.1	S	2.5	Cl	3.0	Ne	-
Na	0.9	Mg	1.2	IIIB	IVB	VB	VIB	VIIIB	VIII			IB	IIIB	Ga	1.6	Ge	1.8	As	2.0	Se	2.4	Br	2.8	Ar	-
K	0.8	Ca	1.0	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	Kr	-
Rb	0.8	Sr	1.0	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	Xe	-
Cs	0.7	Ba	0.9	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	Rn	-
Fr	0.7	Ra	0.9	La-Lu	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90		
				1.1-1.2	1.3	1.5	1.7	1.9	2.2	2.2	2.2	2.4	1.9	1.8	1.8	1.9	2.0	2.0	2.2	2.2	2.2	2.4	2.6		

H₂

H₂O

C(diamond)

SiC

F₂

Cl₂

GaAs

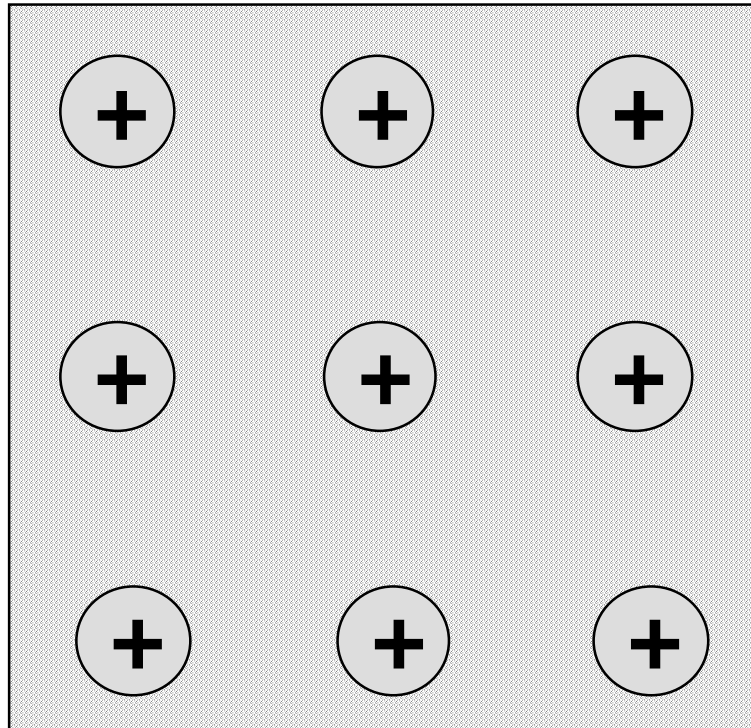
Adapted from Fig. 2.7, Callister 6e. (Fig. 2.7 is adapted from Linus Pauling, The Nature of the Chemical Bond, 3rd edition, Copyright

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- 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).



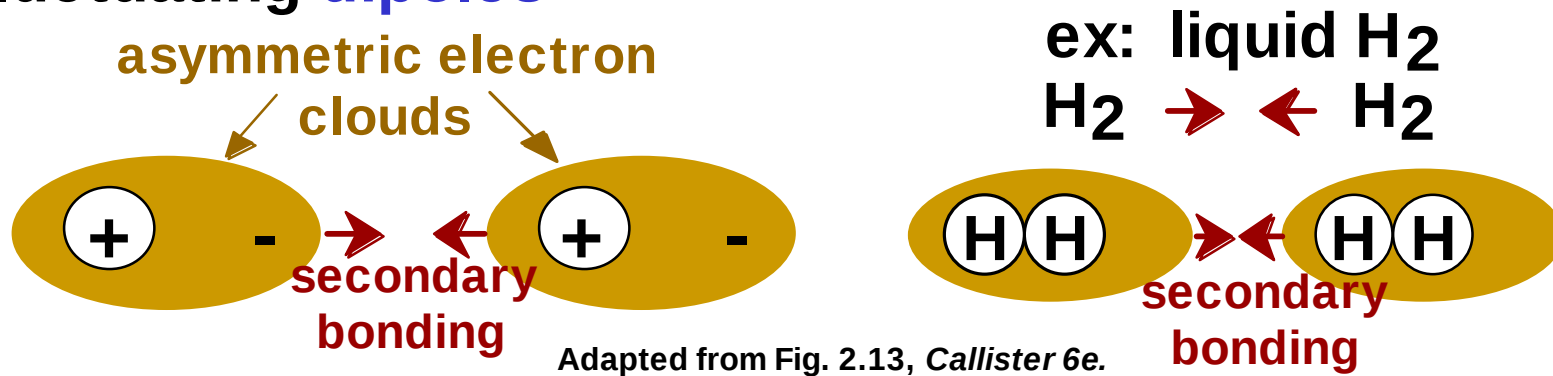
Adapted from Fig. 2.11, *Callister 6e*.

- Primary bond for **metals** and their **alloys**

SECONDARY BONDING

Arises from interaction between **dipoles**

- Fluctuating **dipoles**



- Permanent **dipoles**-molecule induced

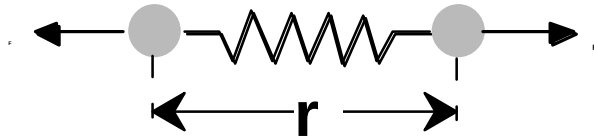


SUMMARY: BONDING

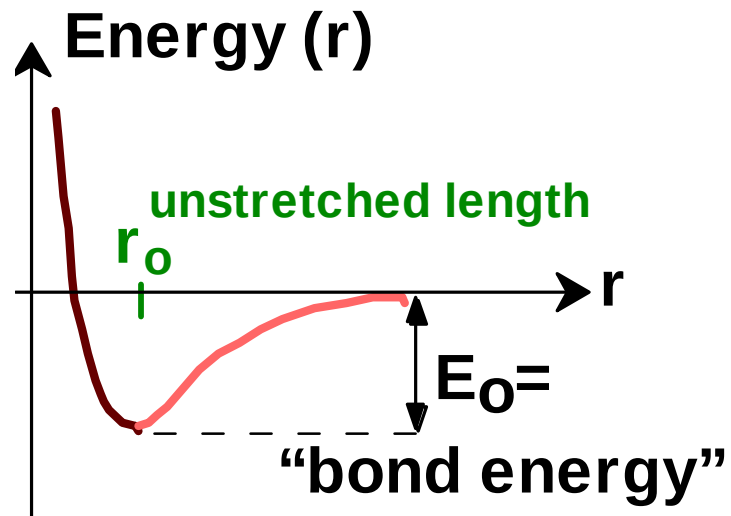
Type	Bond Energy	Comments
Ionic	Large!	Nondirectional (ceramics)
Covalent	Variable large-Diamond small-Bismuth	Directional semiconductors , ceramics polymer chains)
Metallic	Variable large-Tungsten small-Mercury	Nondirectional (metals)
Secondary	smallest	Directional inter-chain (polymer) inter-molecular

PROPERTIES FROM BONDING: T_M

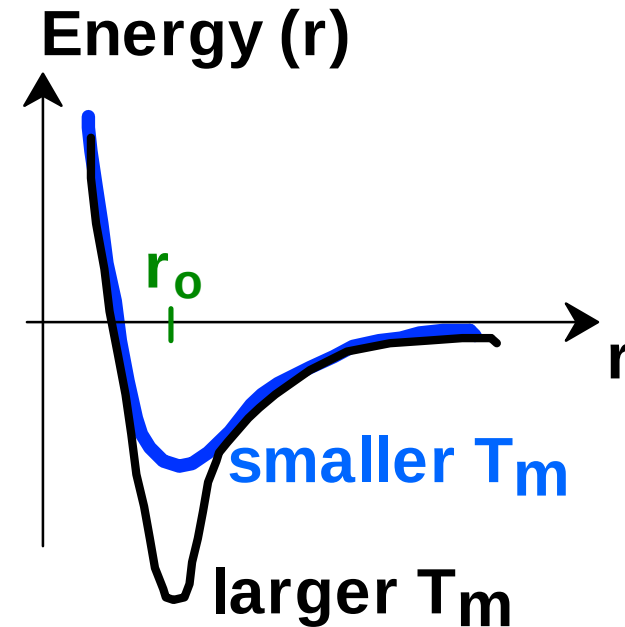
- **Bond length, r**



- **Bond energy, E_o**



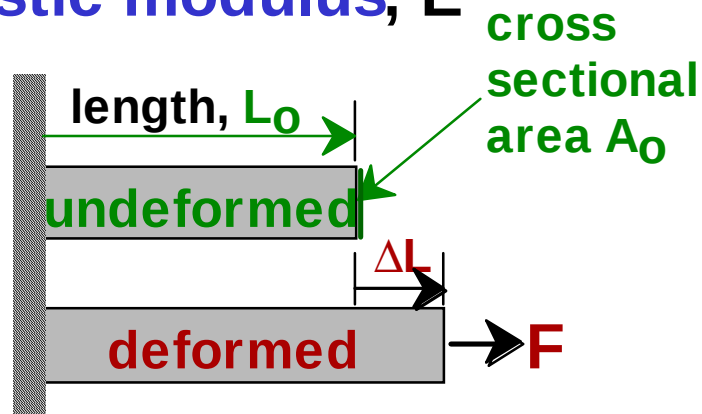
- **Melting Temperature, T_m**



T_m is larger if E_o is larger.

PROPERTIES FROM BONDING: E

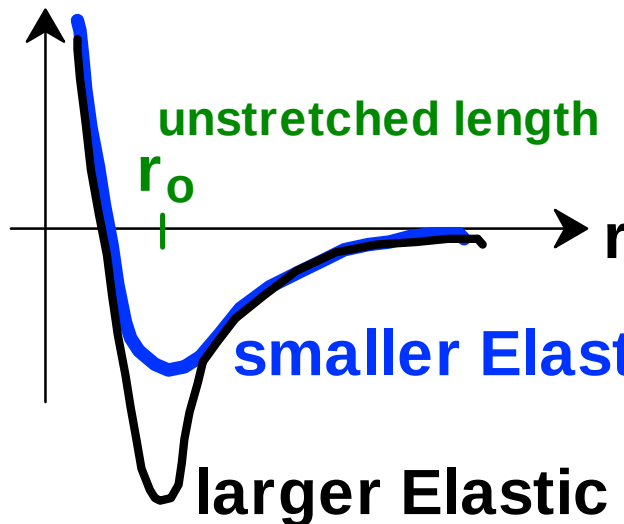
- Elastic modulus, E



Elastic modulus

$$\frac{F}{A_0} = E \frac{\Delta L}{L_0}$$

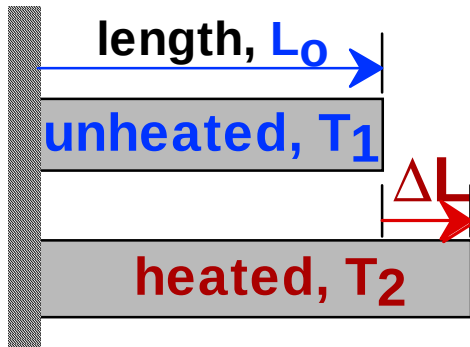
- $E \sim$ curvature at r_0
Energy



E is larger if E_0 is larger.

PROPERTIES FROM BONDING: α

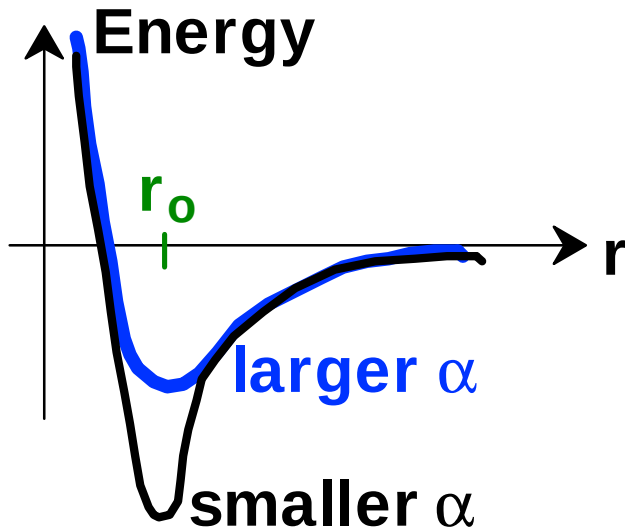
- Coefficient of thermal expansion, α



coeff. thermal expansion

$$\frac{\Delta L}{L_0} = \alpha (T_2 - T_1)$$

- $\alpha \sim$ symmetry at r_0



α is larger if E_0 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

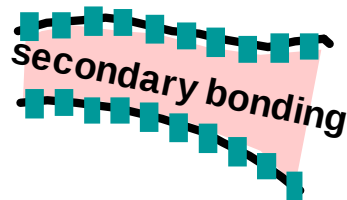
moderate T_m

moderate E

moderate α

Polymers

(Covalent & Secondary):



Directional Properties

Secondary bonding dominates

small T

small E

large α