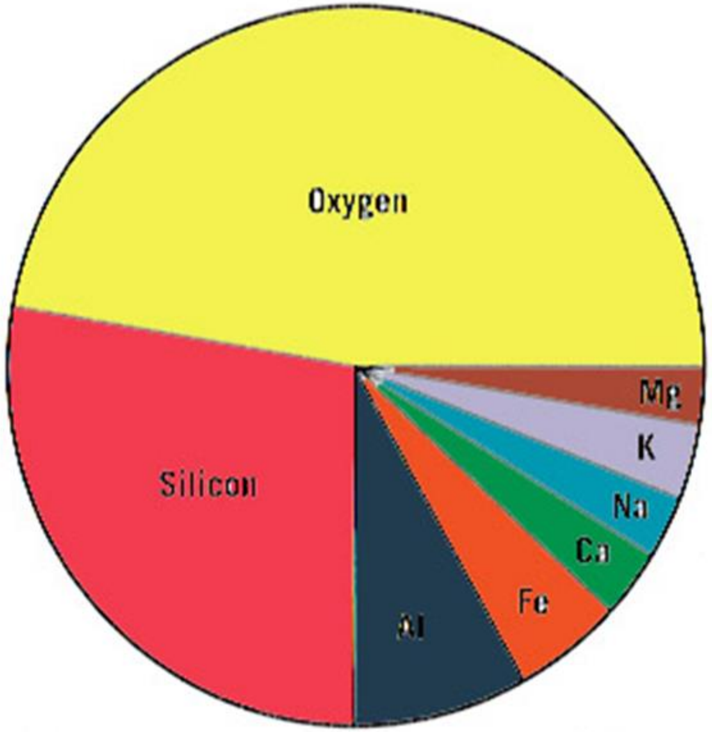
AVERAGE COMPOSITION OF THE EARTH'S CRUST (BY WEIGHT, ELEMENTS, AND VOLUME)

	Weight percent*	Atom percent	Ionic+ radius (Å)	Volume percent
O	46.60	62.55	1.36	~ 94
Si	26.72	21.22	0.26 [4]	~ 6% in total
Al	8.13	6.47	0.39 [4]	
Fe	5.00	1.92	0.78 [6]	
Ca	3.63	1.94	1.00 [6]	
Na	2.83	2.64	1.02 [6]	
K	2.59	1.42	1.51 [8]	
Mg	2.09	1.84	0.72 [8]	
	98.59	100.00		



CHEMICAL CLASSIFICATION

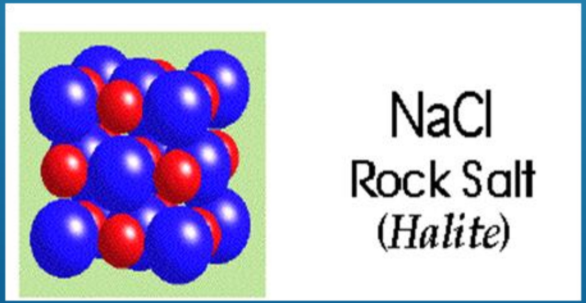
- 1) **Elements**
- 2) **Sulfides**
- 3) **Oxides/Hydroxides**
- 4) **Halides**
- 5) **Carbonates**
- 6) **Phosphates, Tungstates, Nitrates and Borates**
- **7) Sulfates and sulfosalts**
- 8) **Silicates**

CHEMICAL BONDING IN MINERALS

- Bonding forces are electrical in nature (related to charged particles)
- Bond strength controls most physical and chemical properties of minerals
- (in general, the stronger the bond, the harder the crystal, higher the melting point, and the lower the coefficient of thermal expansion)
- Five general types bonding types:
- *Ionic* *Covalent* *Metallic*
- *van der Waals* *Hydrogen*
- Commonly different bond types occur in the same mineral

1-IONIC BONDING

- Common between elements that will...
- easily <u>exchange</u> electrons so as to stabilize their outer shells (i.e. become more inert gas-like)
- create an electronically neutral bond between cations and anions
- Example: NaClNa (1s22s22p63s1) –> Na+(1s22s22p6) + e-
- Cl (1s22s22p63s23p5) + e- –> Cl-(1s22s22p63s23p6)



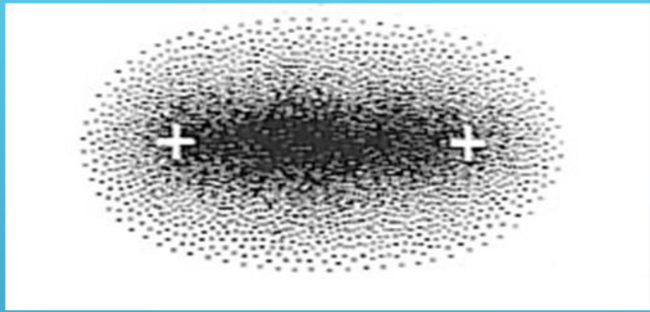
PROPERTIES OF IONIC BONDS

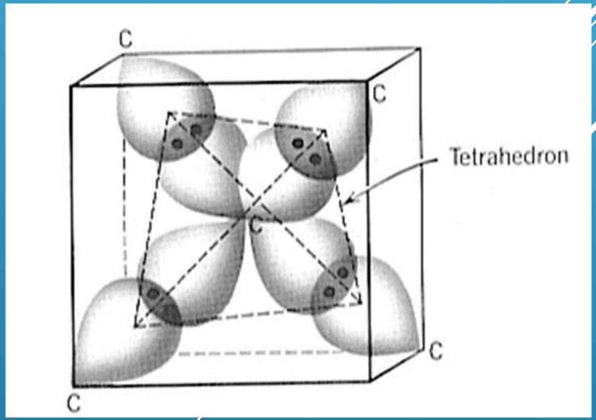
- Results in minerals displaying moderate degrees of hardness and specific gravity, moderately high melting points, high degrees of symmetry, and are poor conductors of heat (due to ionic stability)

- Strength of ionic bonds are related:
- 1) the spacing between ions
- 2) the charge of the ions

2- COVALENT BONDING

- formed by sharing of outer shell electrons
- strongest of all chemical bonds
- produces minerals that are insoluble, high melting points, hard, nonconductive (due to localization of electrons), have low symmetry (due to directional bonding).
- common among elements with high numbers of vacancies in the outer shell (e.g. C, Si, Al, S)





Tendencies for Ionic vs. Covalent Pairing

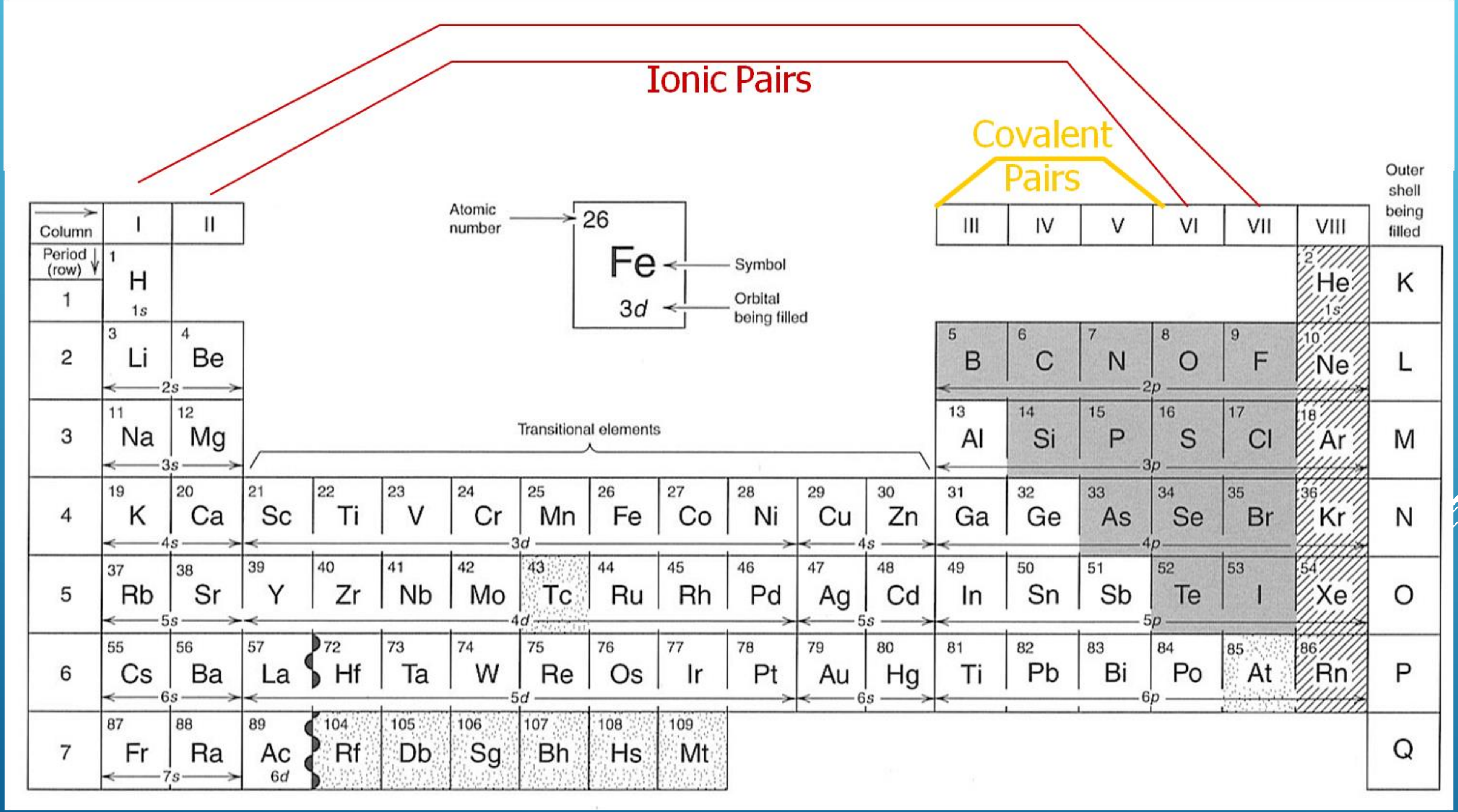


TABLE 3.7 First Ionization Potentials, Electronegativity Values, and Electronic Structure of the Elements Through Atomic Number 37

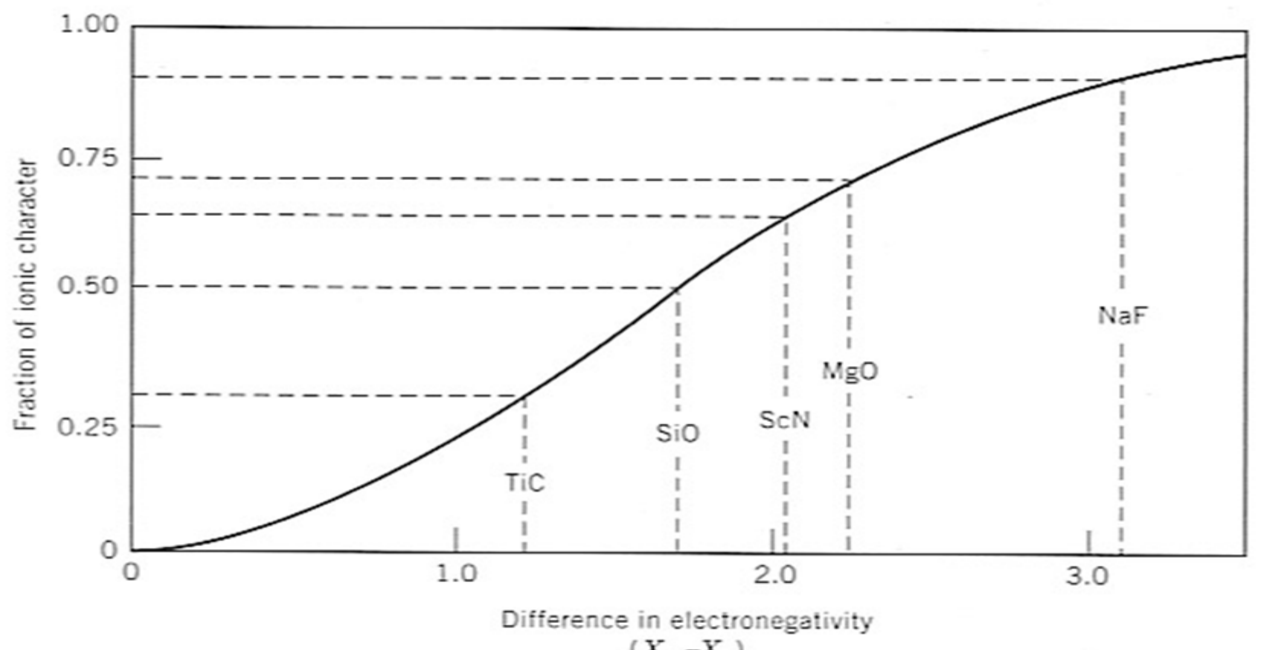
Z	Element	First Ionization Potential, in Electron Volts (e.v.)*,†	Electro-negativity‡	Electronic Structure
1	H	13.598	2.1	$1s^1$
2	He	24.587	0	$1s^2$
3	Li	5.392	1.0	$1s^22s^1$
4	Be	9.322	1.5	$1s^22s^2$
5	B	8.298	2.0	$1s^22s^22p^1$
6	C	11.260	2.5	$1s^22s^22p^2$
7	N	14.534	3.1	$1s^22s^22p^3$
8	O	13.618	3.5	$1s^22s^22p^4$
9	F	17.422	4.1	$1s^22s^22p^5$
10	Ne	21.564	0	$1s^22s^22p^6$
11	Na	5.139	1.0	$[Ne]3s^1$
12	Mg	7.646	1.3	$[Ne]3s^2$
13	Al	5.986	1.5	$[Ne]3s^23p^1$
14	Si	8.151	1.8	$[Ne]3s^23p^2$
15	P	10.486	2.1	$[Ne]3s^23p^3$
16	S	10.360	2.4	$[Ne]3s^23p^4$
17	Cl	12.967	2.9	$[Ne]3s^23p^5$
18	Ar	15.759	0	$[Ne]3s^23p^6$
19	K	4.341	0.9	$[Ar]4s^1$
20	Ca	6.113	1.1	$[Ar]4s^2$
21	Sc	6.54	1.2	$[Ar]3d^14s^2$
22	Ti	6.82	1.3	$[Ar]3d^24s^2$
23	V	6.74	1.5	$[Ar]3d^34s^2$
24	Cr	6.766	1.6	$[Ar]3d^54s^1$
25	Mn	7.435	1.6	$[Ar]3d^54s^2$
26	Fe	7.870	1.7	$[Ar]3d^64s^2$
27	Co	7.86	1.7	$[Ar]3d^74s^2$
28	Ni	7.635	1.8	$[Ar]3d^84s^2$
29	Cu	7.726	1.8	$[Ar]3d^{10}4s^1$
30	Zn	9.394	1.7	$[Ar]3d^{10}4s^2$
31	Ga	5.999	1.8	$[Ar]3d^{10}4s^24p^1$
32	Ge	7.899	2.0	$[Ar]3d^{10}4s^24p^2$
33	As	9.81	2.2	$[Ar]3d^{10}4s^24p^3$
34	Se	9.752	2.5	$[Ar]3d^{10}4s^24p^4$
35	Br	11.814	2.8	$[Ar]3d^{10}4s^24p^5$
36	Kr	13.999		$[Ar]3d^{10}4x^24p^6$
37	Rb	4.177	0.9	$[K]5s^1$

*e.v. = electron volt = 23 kilocalories/mole.
†From Lide, D. R., ed., 1991, *CRC Handbook of Chemistry and Physics*, 72nd ed. CRC Press, Boca Raton, Fla.
‡From J. E. Brady, J. W. Russell, and J. R. Holum, 2000, *Chemistry, matter and its changes*, 3rd ed. (New York: Wiley).

Ionic-Covalent Gradation

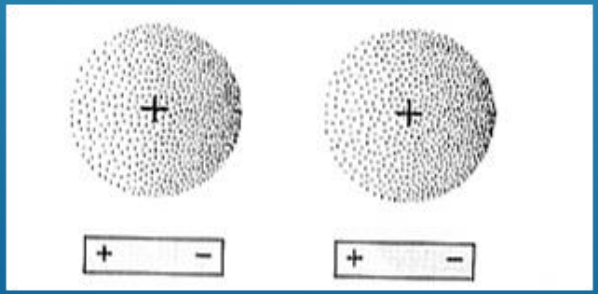
These bond types share characteristics of each other

The degree of ionic character (exchange rather than sharing) can be estimated from the contrasting electronegativity (ability to attract electrons) of the elements involved.



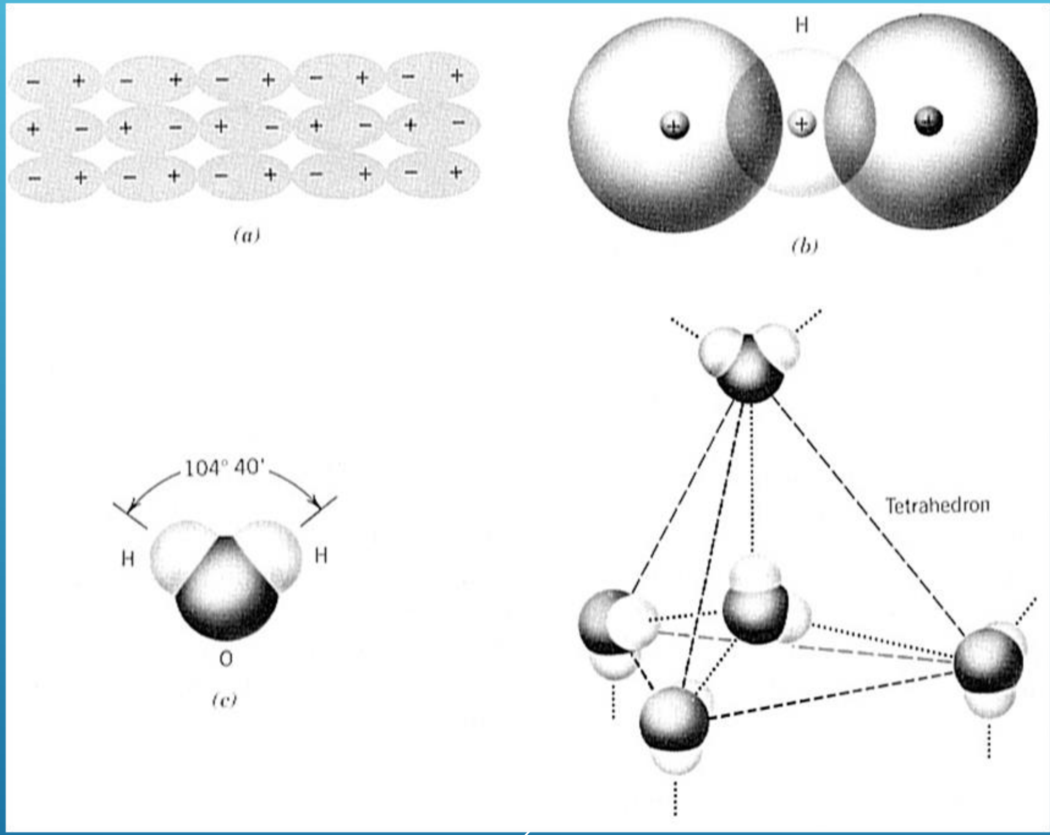
4- VAN DER WAALS (RESIDUAL) BONDING

- created by weak bonding of oppositely dipolarized electron clouds
- commonly occurs around covalently bonded elements
- produces solids that are soft, very poor conductors, have low melting points, low symmetry crystals



5-HYDROGEN BONDING

- Electrostatic bonding between an H+ ion with an anion or anionic complex or with a polarized molecules
- Weaker than ionic or covalent; stronger than van der Waals

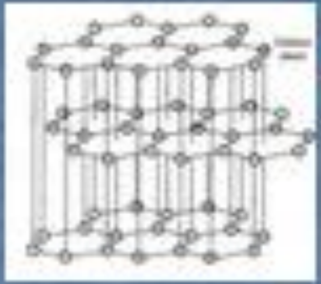


SUMMARY OF BONDING CHARACTERISTICS

TABLE 3.9 Examples of Properties Conferred by the Principal Types of Chemical Bond

Property	Bond Type: Ionic (Electrostatic)	Covalent (Electron-shared)	Metallic	van der Waals (Residual)
Bond strength	Strong	Very strong	Variable strength, generally moderate	Weak
Mechanical	Hardness moderate to high, depending on interionic distance and charge; brittle	Hardness great Brittle	Hardness low to moderate; gliding common; high plasticity; sectile, ductile, malleable	Crystals soft and somewhat plastic
Electrical	Poor conductors in the solid state; melts and solutions conduct by ion transport	Insulators in solid state and melt	Good conductors; conduction by electron transport	Insulators in both solid and liquid state
Thermal (melting point = m.p.; coefficient of thermal expansion = coef.)	m.p. moderate to high depending on interionic distance and charge; low coef.	m.p. high; low coef.; atoms and molecules in melt	Variable m.p. and coef.; atoms in melt	Low m.p.; high coef.; liquid crystal molecules in melt
Solubility	Soluble in polar solvents to yield solutions containing ions	Very low solubilities	Insoluble, except in acids or alkalis by chemical reaction	Soluble in organic solvents to yield solutions
Structure	Nondirected; gives structures of high coordination and symmetry	Highly directional; gives structures of lower coordination and symmetry	Nondirected; gives structures of very high coordination and symmetry	Nondirected; symmetry low because of shape of molecules
Examples	Halite, NaCl; Fluorite, CaF_2; most minerals	Diamond, C; Sphalerite, ZnS; molecules of O_2; organic molecules; graphite (strong bond)	Copper, Cu; Silver, Ag; Gold, Au; Electrum, (Au, Ag); most metals	Sulfur (weak bond); organic compounds; graphite (weak bond)

Multiple Bonding in Minerals



- Graphite – covalently bonded sheets of C loosely bound by van der Waals bonds.

- Mica – strongly bonded silica tetrahedra sheets (mixed covalent and ionic) bound by weak ionic and hydrogen bonds

- Cleavage planes commonly correlate to planes of weak ionic bonding in an otherwise tightly bound atomic structure