Chapter 7 Periodic Properties of the Elements

7.1 Development of the Periodic Table

The **periodic table** is the most significant tool that chemists use for organizing and recalling chemical facts.

Group	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period																			
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	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
5	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
6	55 Cs	56 Ba	*	71 Lu	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
7	87 Fr	88 Ra	**	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
*Lanthanoids			*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
**Actinoids			**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

The periodic table arises from the periodic patterns in the electronic configurations of the elements

Ueber die Beziehungen der Eigenschaften zu den Atomgewichten der Elemente. Von D. Mendelejeff. — Ordnet man Elemente nach zunehmenden Atomgewichten in verticale Reihen so, dass die Horizontalreihen analoge Elemente enthalten, wieder nach zunehmendem Atomgewicht geordnet, so erhält man folgende Zusammenstellung, aus der sich einige allgemeinere Folgerungen ableiten lassen.

			Ti = 50	Zr = 90	? = 180
			V = 51	Nb = 94	Ta = 182
			Cr = 52	Mo = 96	W = 186
			Mn = 55	Rh = 104,4	Pt = 197,4
			Fe = 56	Ru = 104,4	Ir = 198
			Ni = Co = 59	Pd = 106,6	Os = 199
H = 1			Cu = 63,4	Ag = 108	Hg = 200
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,5	Br = 80	J = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		

1. Die nach der Grösse des Atomgewichts geordneten Elemente zeigen eine stufenweise Abänderung in den Eigenschaften.
2. Chemisch-analoge Elemente haben entweder übereinstimmende Atomgewichte (Pt, Ir, Os), oder letztere nehmen gleichviel zu (K, Rb, Cs).
3. Das Anordnen nach den Atomgewichten entspricht der *Werthigkeit* der Elemente und bis zu einem gewissen Grade der Verschiedenheit im chemischen Verhalten, z. B. Li, Be, B, C, N, O, F.
4. Die in der Natur verbreitetsten Elemente haben *kleine* Atomgewichte

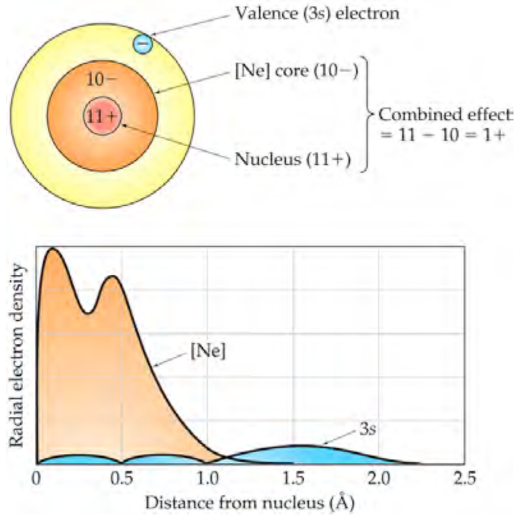
Mendeleev published the first modern PT in 1869

7.2 Effective Nuclear Charge

Effective nuclear charge (Z_{eff}) is the charge experienced by an electron on a many-electron atom.

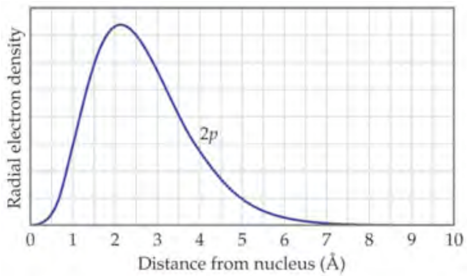
The electron is attracted to the nucleus, but repelled by electrons that shield or screen it from the full nuclear charge.

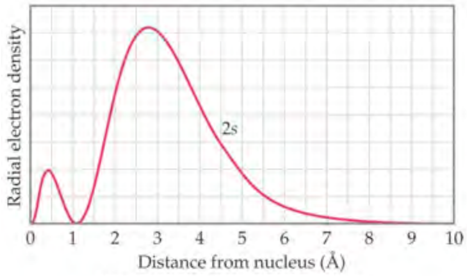
S is called the *screening constant.*



Core electrons are effective at screening the outer electrons from the full charge of the nucleus.

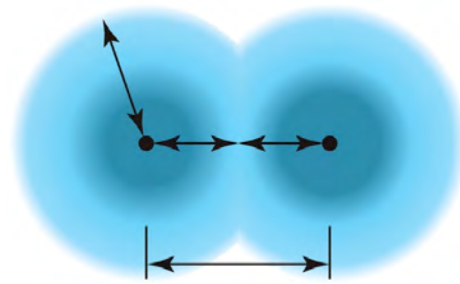
> *Q. If core electrons were perfect at screening valence electrons from the nuclear charge and valence electrons useless, what would S and Z_{eff} be for a 3p electron in a sulfur atom? S is actually 10.52; explain the discrepancy.*





7.3 Sizes of atoms and ions

We can define atomic size in several ways, based on distances between nuclei in different situations.

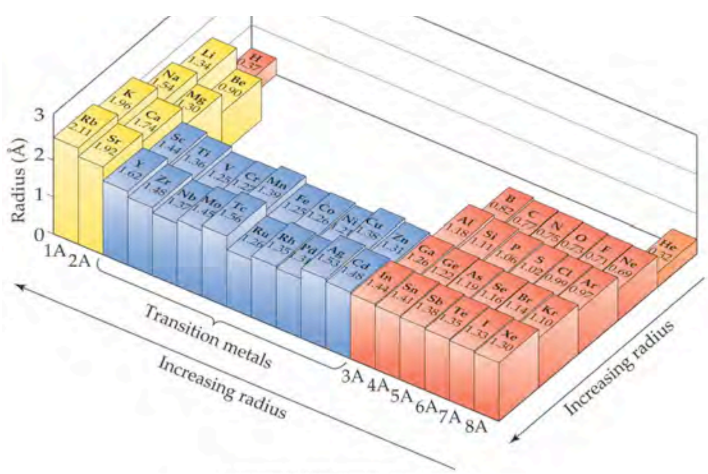


Knowing atomic radii allows estimation of bond lengths in molecules

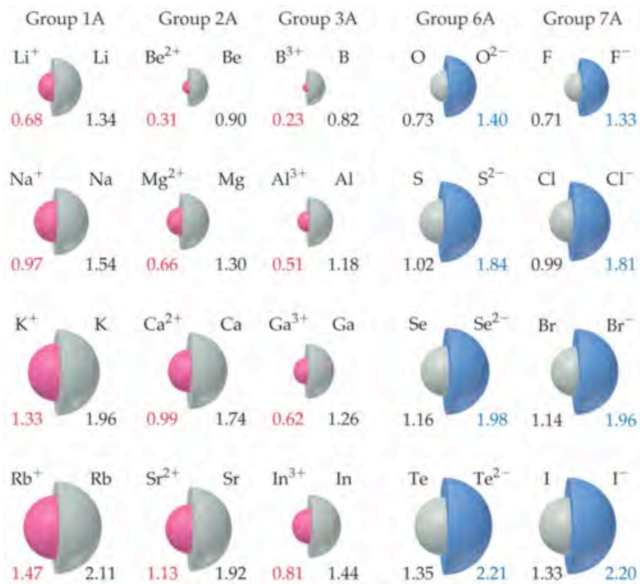
Atomic size varies consistently through the periodic table

Increase in principal quantum number, n – electrons are more likely to be further from the nucleus

Increase in Z_{eff} – valence electrons are drawn closer to the nucleus



Ionic size also important in predicting lattice energy and in determining the way in which ions pack in a solid. Like atomic size, it is also periodic.



All the members of an **isoelectronic series** have the same number of electrons

Q. Consider S, Cl and K and their most common ions. List (a) the atoms and (b) the ions in order of increasing size.

7.4 Ionization Energy

The **ionization energy** is the minimum energy required to remove an electron from the ground state of the isolated gaseous atom or ion.

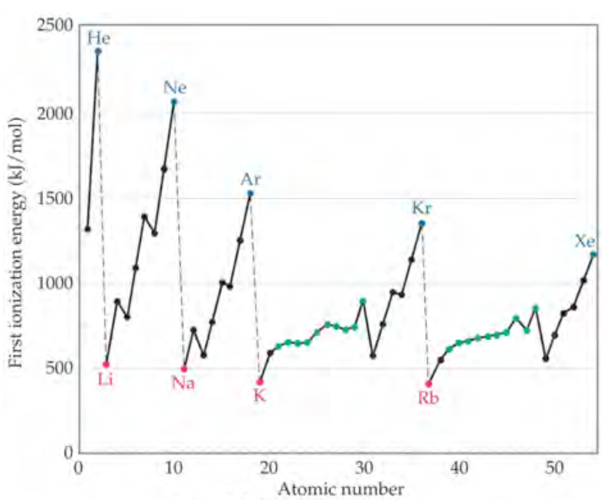
The larger the ionization energy, the more difficult it is to remove the electron.

Ionization energies for an element increase in magnitude as successive electrons are removed.

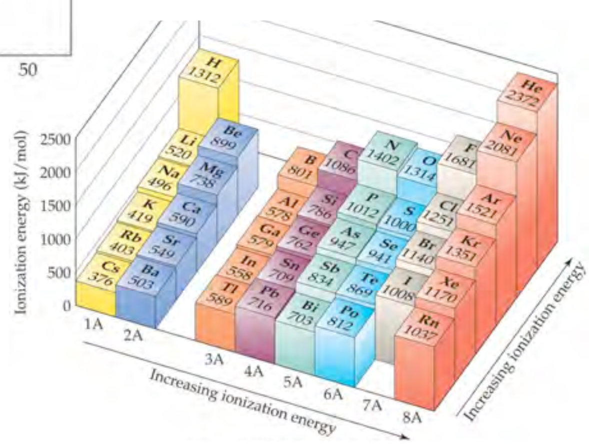
Element	I_1	I_2	I_3	I_4	I_5	I_6	I_7
Na	495	4562			(inner-shell electrons)		
Mg	738	1451	7733				
Al	578	1817	2745	11,577			
Si	786	1577	3232	4356	16,091		
P	1012	1907	2914	4964	6274	21,267	
S	1000	2252	3357	4556	7004	8496	27,107
Cl	1251	2298	3822	5159	6542	9362	11,018
Ar	1521	2666	3931	5771	7238	8781	11,995

Ionization energy generally increases across a period.

Two exceptions are removing the **first** *p* electron and removing the **fourth** *p* electron



Ionization energy **decreases** down a group



Electron configurations of ions are derived from the electron configurations of elements with the required number of electrons added or removed from the most accessible orbital.

Transition metals tend to lose the valence shell electrons first and then as many *d* electrons as are required to reach the desired charge on the ion.

Q. For each of the following pairs, use electron configuration and Z_{eff} to help explain which element has the larger first ionization energy:
(a) Rb, Mo; (b) N, P; (c) Ga, Cl; (d) Pb, Rn; (e) Sn, Te.

7.5 Electron Affinities

Electron affinity is the energy change when a gaseous atom ***gains*** an electron to form a gaseous ion.

Electron affinity and ionization energy measure the energy changes of **opposite** processes

Electron affinity:

Ionization energy:

Energy is *usually* released when an atom adds an electron. E_{ea} is **negative** for stable anions.

H −73							He > 0
Li −60	Be > 0	B −27	C −122	N > 0	O −141	F −328	Ne > 0
Na −53	Mg > 0	Al −43	Si −134	P −72	S −200	Cl −349	Ar > 0
K −48	Ca −2	Ga −30	Ge −119	As −78	Se −195	Br −325	Kr > 0
Rb −47	Sr −5	In −30	Sn −107	Sb −103	Te −190	I −295	Xe > 0
1A	2A	3A	4A	5A	6A	7A	8A

Electron affinity becomes more exothermic as we move left to right across a row