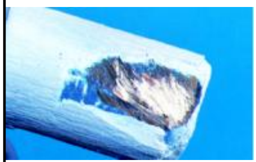
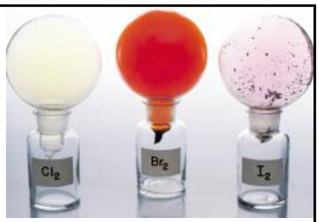
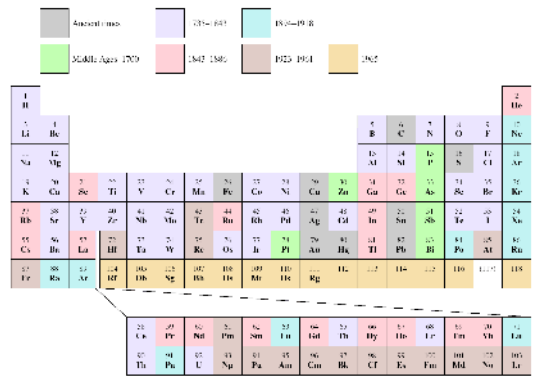




Periodic Relationships Among the Elements

Chapter 8

When the Elements Were Discovered



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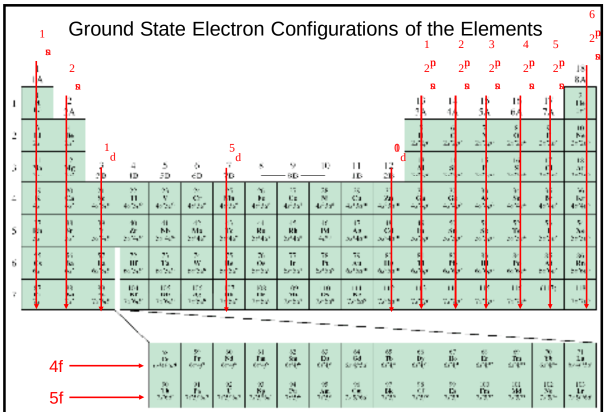
Ground State Electron Configurations of the Elements



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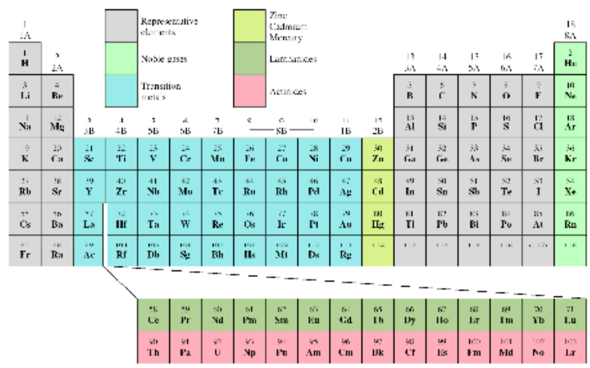
Classification of the Elements



4

Electron Configurations of Cations and Anions Of Representative Elements

Na [Ne]3s¹ → Na^+ [Ne]

Ca [Ar]4s² → Ca^{2+} [Ar]

Al [Ne]3s²3p¹ → Al^{3+} [Ne]

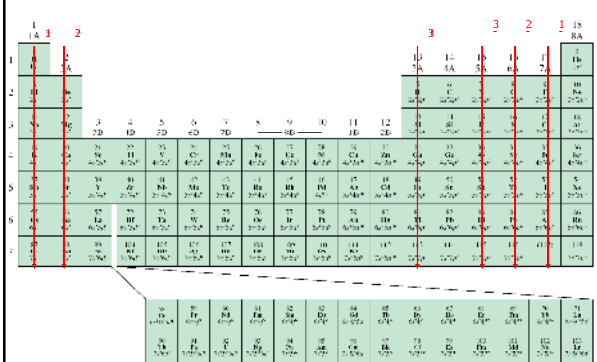
Atoms lose electrons so that cation has a noble-gas outer electron configuration.

Atoms gain electrons so that anion has a noble-gas outer electron configuration.

H $1s^1$	H^- $1s^2$ or [He]
F $1s^22s^22p^5$	F^- $1s^22s^22p^6$ or [Ne]
O $1s^22s^22p^4$	O^{2-} $1s^22s^22p^6$ or [Ne]
N $1s^22s^22p^3$	N^{3-} $1s^22s^22p^6$ or [Ne]

5

Cations and Anions Of Representative Elements



6

Isoelectronic: have the same number of electrons, and hence the same ground-state electron configuration

Na^{+}: [Ne] Al^{3+}: [Ne] F^{-}: $1s^2 2s^2 2p^6$ or [Ne]

O^{2-}: $1s^2 2s^2 2p^6$ or [Ne] N^{3-}: $1s^2 2s^2 2p^6$ or [Ne]

Na^{+}, Al^{3+}, F^{-}, O^{2-}, and N^{3-} are all ***isoelectronic*** with Ne

What neutral atom is isoelectronic with H^{-} ?

H^{-}: $1s^2$ same electron configuration as He

Electron Configurations of Cations of Transition Metals

When a cation is formed from an atom of a transition metal, electrons are always removed first from the *ns* orbital and then from the (*n* – 1)*d* orbitals.

Fe: $[Ar]4s^2 3d^6$

Fe^{2+}: $[Ar]4s^0 3d^6$ or $[Ar]3d^6$

Fe^{3+}: $[Ar]4s^0 3d^5$ or $[Ar]3d^5$

Mn: $[Ar]4s^2 3d^5$

Mn^{2+}: $[Ar]4s^0 3d^5$ or $[Ar]3d^5$

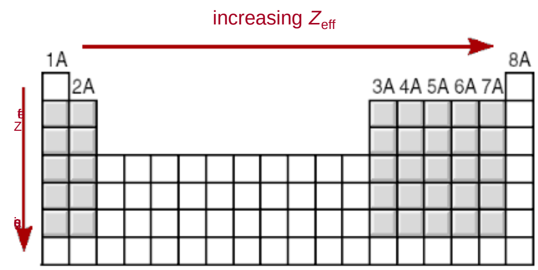
Effective nuclear charge (Z_{eff}) is the "positive charge" felt by an electron.

$Z_{eff} = Z - \sigma$ $0 < \sigma < Z$ (σ = shielding constant)

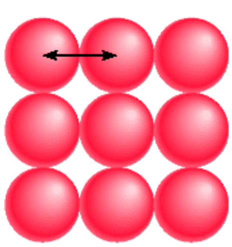
$Z_{eff} \approx Z$ – number of inner or core electrons

	Z	Core	Z_{eff}	Radius (pm)
Na	11	10	1	186
Mg	12	10	2	160
Al	13	10	3	143
Si	14	10	4	132

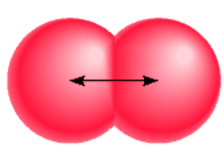
Effective Nuclear Charge (Z_{eff})



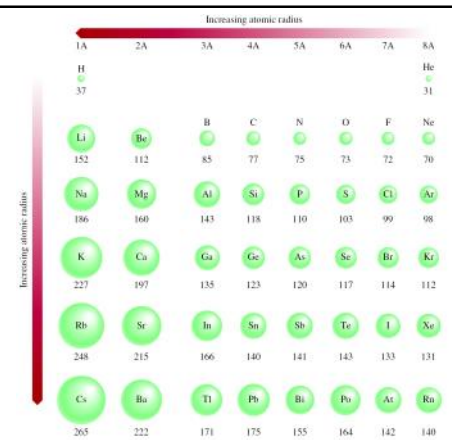
Atomic Radii



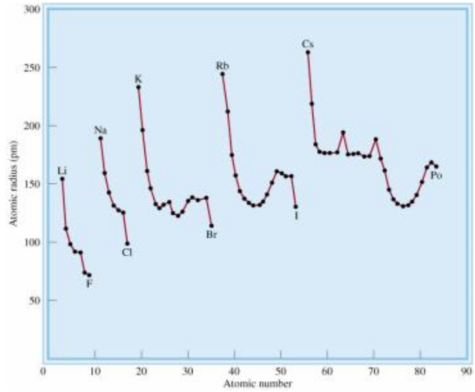
metallic radius



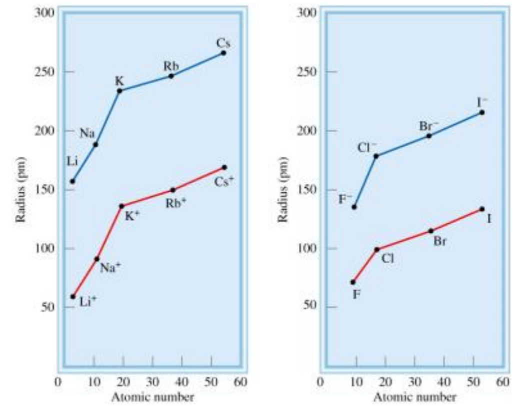
covalent radius

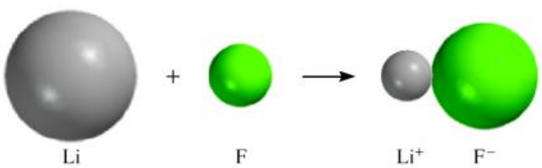


Trends in Atomic Radii



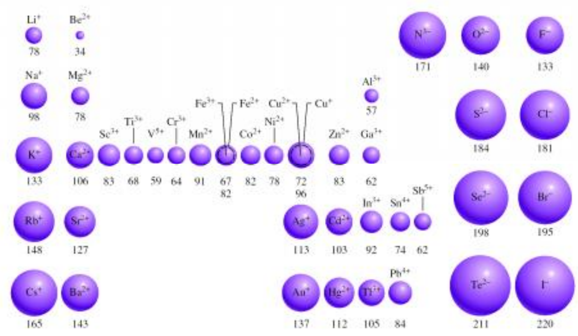
Comparison of Atomic Radii with Ionic Radii





Cation is always smaller than atom from which it is formed.
Anion is always larger than atom from which it is formed.

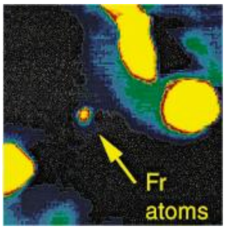
The Radii (in pm) of Ions of Familiar Elements

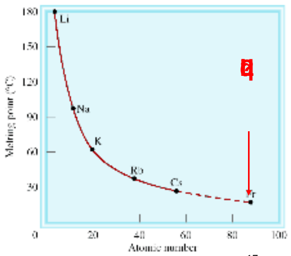


Chemistry in Action: The 3rd Liquid Element?

117 elements, 2 are liquids at 25^0C – Br_2 and Hg

^{223}Fr, $t_{1/2}$ = 21 minutes





Ionization energy is the minimum energy (kJ/mol) required to remove an electron from a gaseous atom in its ground state.

$I_1 + X_{(g)} \longrightarrow X^+_{(g)} + e^-$ — I_1 first ionization energy

$I_2 + X^+_{(g)} \longrightarrow X^{2+}_{(g)} + e^-$ — I_2 second ionization energy

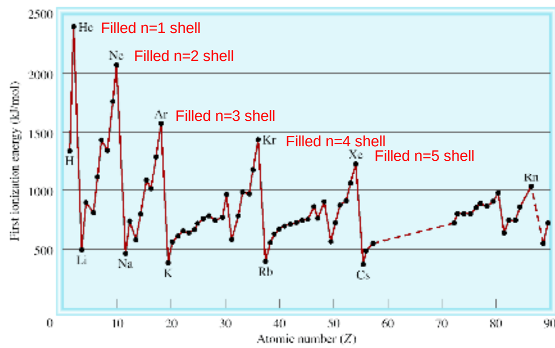
$I_3 + X^{2+}_{(g)} \longrightarrow X^{3+}_{(g)} + e^-$ — I_3 third ionization energy

$I_1 < I_2 < I_3$

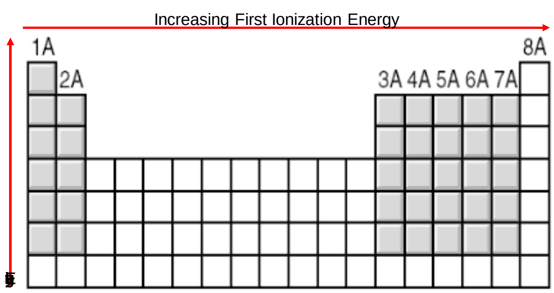
TABLE 8.2 The Ionization Energies (kJ/mol) of the First 20 Elements

Z	Element	First	Second	Third	Fourth	Fifth	Sixth
1	H	1,312					
2	He	2,373	5,251				
3	Li	520	7,300	11,815			
4	Be	899	1,757	14,850	21,005		
5	B	801	2,430	3,660	25,000	32,820	
6	C	1,086	2,350	4,620	6,220	38,000	47,261
7	N	1,400	2,860	4,580	7,500	9,400	53,000
8	O	1,314	3,390	5,300	7,470	11,000	13,000
9	F	1,680	3,370	6,050	8,400	11,000	15,200
10	Ne	2,080	3,950	6,120	9,370	12,200	15,000
11	Na	495.9	4,560	6,900	9,540	13,400	16,600
12	Mg	738.1	1,450	7,730	10,500	13,600	18,000
13	Al	577.9	1,820	2,750	11,600	14,800	18,400
14	Si	786.3	1,580	3,230	4,360	16,000	20,000
15	P	1,012	1,904	2,910	4,960	6,240	21,000
16	S	999.5	2,250	3,360	4,660	6,990	8,500
17	Cl	1,251	2,297	3,820	5,160	6,540	9,300
18	Ar	1,521	2,666	3,900	5,770	7,240	8,800
19	K	418.7	3,052	4,410	5,900	8,000	9,600
20	Ca	589.5	1,145	4,900	6,500	8,100	11,000

Variation of the First Ionization Energy with Atomic Number



General Trends in First Ionization Energies



Electron affinity is the negative of the energy change that occurs when an electron is accepted by an atom in the gaseous state to form an anion.

$$X_{(g)} + e^- \longrightarrow X^-_{(g)}$$

$F_{(g)} + e^- \longrightarrow X^-_{(g)}$ ΔH = -328 kJ/mol EA = +328 kJ/mol

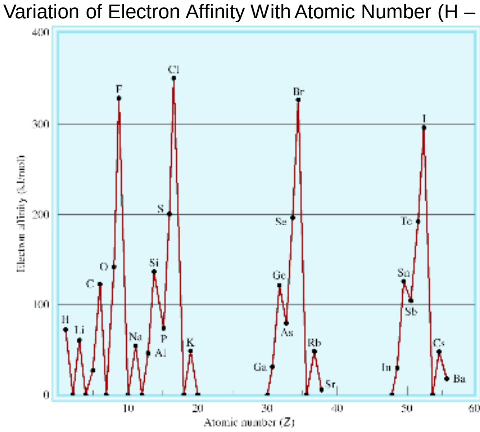
$O_{(g)} + e^- \longrightarrow O^-_{(g)}$ ΔH = -141 kJ/mol EA = +141 kJ/mol

TABLE 8.3 Electron Affinities (kJ/mol) of Some Representative Elements and the Noble Gases*

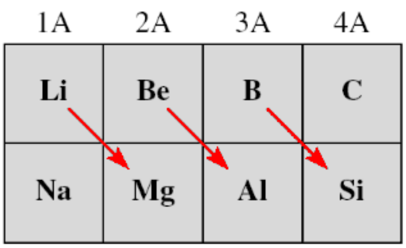
1A	2A	3A	4A	5A	6A	7A	8A
H							He
73							< 0
Li	Be	B	C	N	O	F	Ne
60	≤ 0	27	122	0	141	328	< 0
Na	Mg	Al	Si	P	S	Cl	Ar
53	≤ 0	44	134	72	200	349	< 0
K	Ca	Ga	Ge	As	Se	Br	Kr
48	2.4	29	118	77	195	325	< 0
Rb	Sr	In	Sn	Sb	Te	I	Xe
47	4.7	29	121	101	190	295	< 0
Cs	Ba	Tl	Pb	Bi	Po	At	Rn
45	14	30	110	110	?	?	< 0

*The electron affinities of the noble gases, Be, and Mg have not been determined experimentally, but are believed to be close to zero or negative.

Variation of Electron Affinity With Atomic Number (H – Ba)



Diagonal Relationships on the Periodic Table

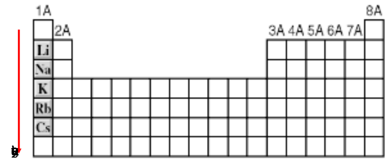


Group 1A Elements (ns^1, $n \geq 2$)

$M \longrightarrow M^{+1} + 1e^-$

$2M_{(s)} + 2H_2O_{(l)} \longrightarrow 2MOH_{(aq)} + H_{2(g)}$

$4M_{(s)} + O_{2(g)} \longrightarrow 2M_2O_{(s)}$



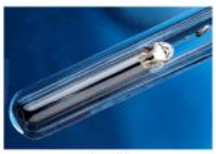
Group 1A Elements (ns^1, $n \geq 2$)


Lithium (Li)


Sodium (Na)


Potassium (K)


Rubidium (Rb)


Cesium (Cs)

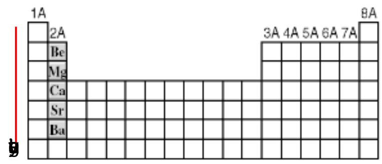
Group 2A Elements (ns^2, $n \geq 2$)

$M \longrightarrow M^{+2} + 2e^-$

$Be_{(s)} + 2H_2O_{(l)} \longrightarrow$ No Reaction

$Mg_{(s)} + 2H_2O_{(g)} \longrightarrow Mg(OH)_{2(aq)} + H_{2(g)}$

$M_{(s)} + 2H_2O_{(l)} \longrightarrow M(OH)_{2(aq)} + H_{2(g)}$ M = Ca, Sr, or Ba



Group 2A Elements (ns^2, $n \geq 2$)


Beryllium (Be)


Magnesium (Mg)


Calcium (Ca)


Strontium (Sr)

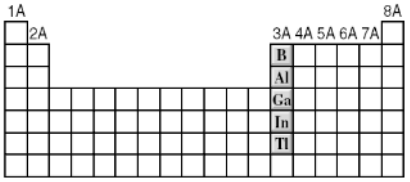

Barium (Ba)


Radium (Ra)

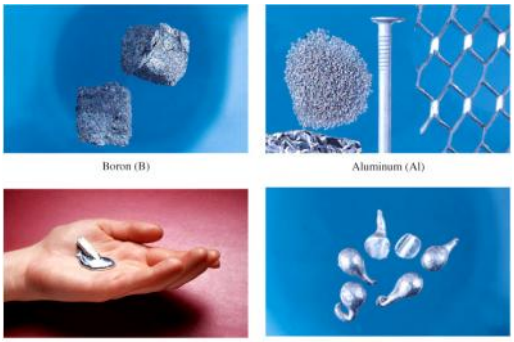
Group 3A Elements (ns^2np^1, $n \geq 2$)

$4Al_{(s)} + 3O_{2(g)} \longrightarrow 2Al_2O_{3(s)}$

$2Al_{(s)} + 6H^+_{(aq)} \longrightarrow 2Al^{3+}_{(aq)} + 3H_{2(g)}$



Group 3A Elements (ns^2np^1, $n \geq 2$)

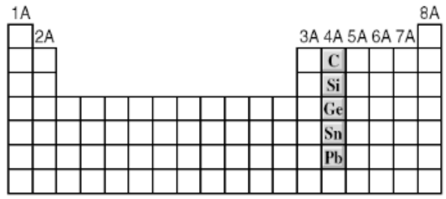


Boron (B) — Aluminum (Al) — Gallium (Ga) — Indium (In)

Group 4A Elements (ns^2np^2, $n \geq 2$)

$$Sn_{(s)} + 2H^+_{(aq)} \longrightarrow Sn^{2+}_{(aq)} + H_{2\,(g)}$$

$$Pb_{(s)} + 2H^+_{(aq)} \longrightarrow Pb^{2+}_{(aq)} + H_{2\,(g)}$$



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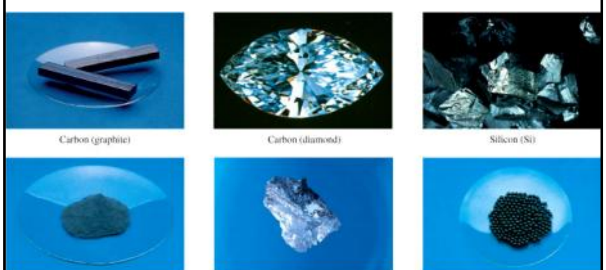
Group 4A Elements (ns^2np^2, $n \geq 2$)



Carbon (graphite) — Carbon (diamond) — Silicon (Si)

Germanium (Ge) — Tin (Sn) — Lead (Pb)

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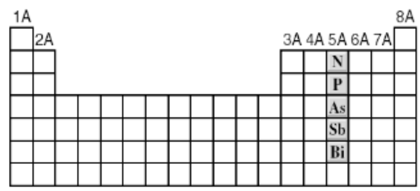
Group 5A Elements (ns^2np^3, $n \geq 2$)

$$N_2O_{5(s)} + H_2O_{(l)} \longrightarrow 2HNO_{3(aq)}$$

$$P_4O_{10(s)} + 6H_2O_{(l)} \longrightarrow 4H_3PO_{4(aq)}$$



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Group 5A Elements (ns^2np^3, $n \geq 2$)

Nitrogen (N_2) — White and red phosphorus (P)

Arsenic (As) — Antimony (Sb) — Bismuth (Bi)

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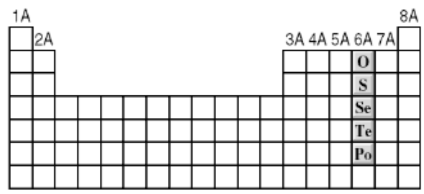
Group 6A Elements (ns^2np^4, $n \geq 2$)

$$SO_{3(g)} + H_2O_{(l)} \longrightarrow H_2SO_{4(aq)}$$



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Group 6A Elements (ns^2np^4, n ≥ 2)

Sulfur (S_8) Selenium (Se_8) Tellurium (Te)

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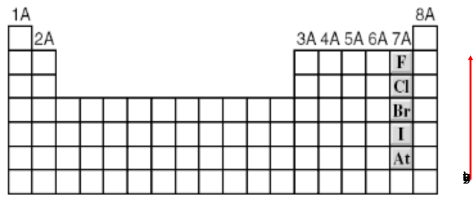
Group 7A Elements (ns^2np^5, n ≥ 2)

$X + 1e^- \longrightarrow X^{-1}$

$X_{2(g)} + H_{2(g)} \longrightarrow 2HX_{(g)}$



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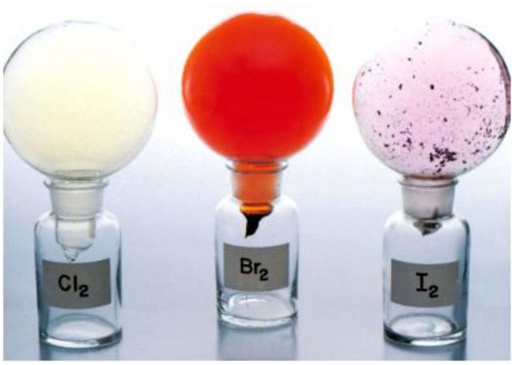
Group 7A Elements (ns^2np^5, n ≥ 2)



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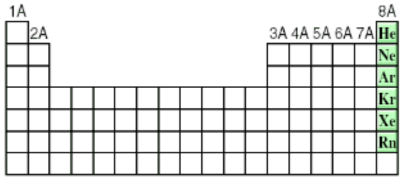
Group 8A Elements (ns^2np^6, n ≥ 2)

Completely filled *ns* and *np* subshells.
Highest ionization energy of all elements.
No tendency to accept extra electrons.



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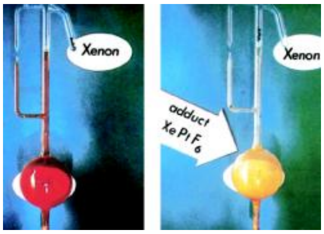
Compounds of the Noble Gases



A number of xenon compounds XeF_4, XeO_3, XeO_4, $XeOF_4$ exist.
A few krypton compounds (KrF_2, for example) have been prepared.

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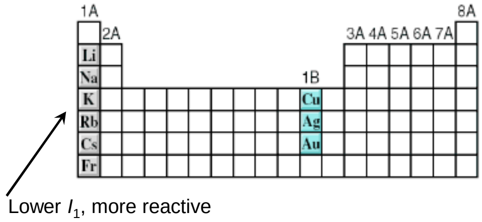
Comparison of Group 1A and 1B

The metals in these two groups have similar outer electron configurations, with one electron in the outermost *s* orbital.
Chemical properties are quite different due to difference in the ionization energy.



Lower I_1, more reactive

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Properties of Oxides Across a Period

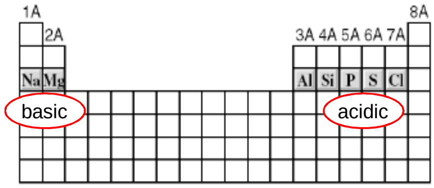

TABLE 8.4 Some Properties of Oxides of the Third-Period Elements

	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_3	Cl_2O_7
Type of compound	← Ionic →			← Molecular →			
Structure	← Extensive three-dimensional →				← Discrete molecular units →		
Melting point (°C)	1275	2800	2045	1610	580	16.8	−91.5
Boiling point (°C)	?	3600	2980	2230	?	44.8	82
Acid-base nature	Basic	Basic	Amphoteric	← Acidic →			

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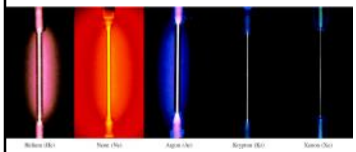
Chemistry in Action: Discovery of the Noble Gases



Sir William Ramsay

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