Petrucci • Harwood • Herring • Madura

Ninth Edition

GENERAL CHEMISTRY

Principles and Modern Applications

Chapter 9: The Periodic Table and Some Atomic Properties

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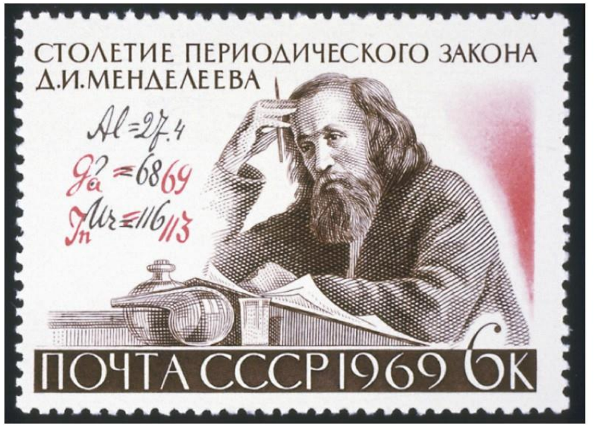
Contents

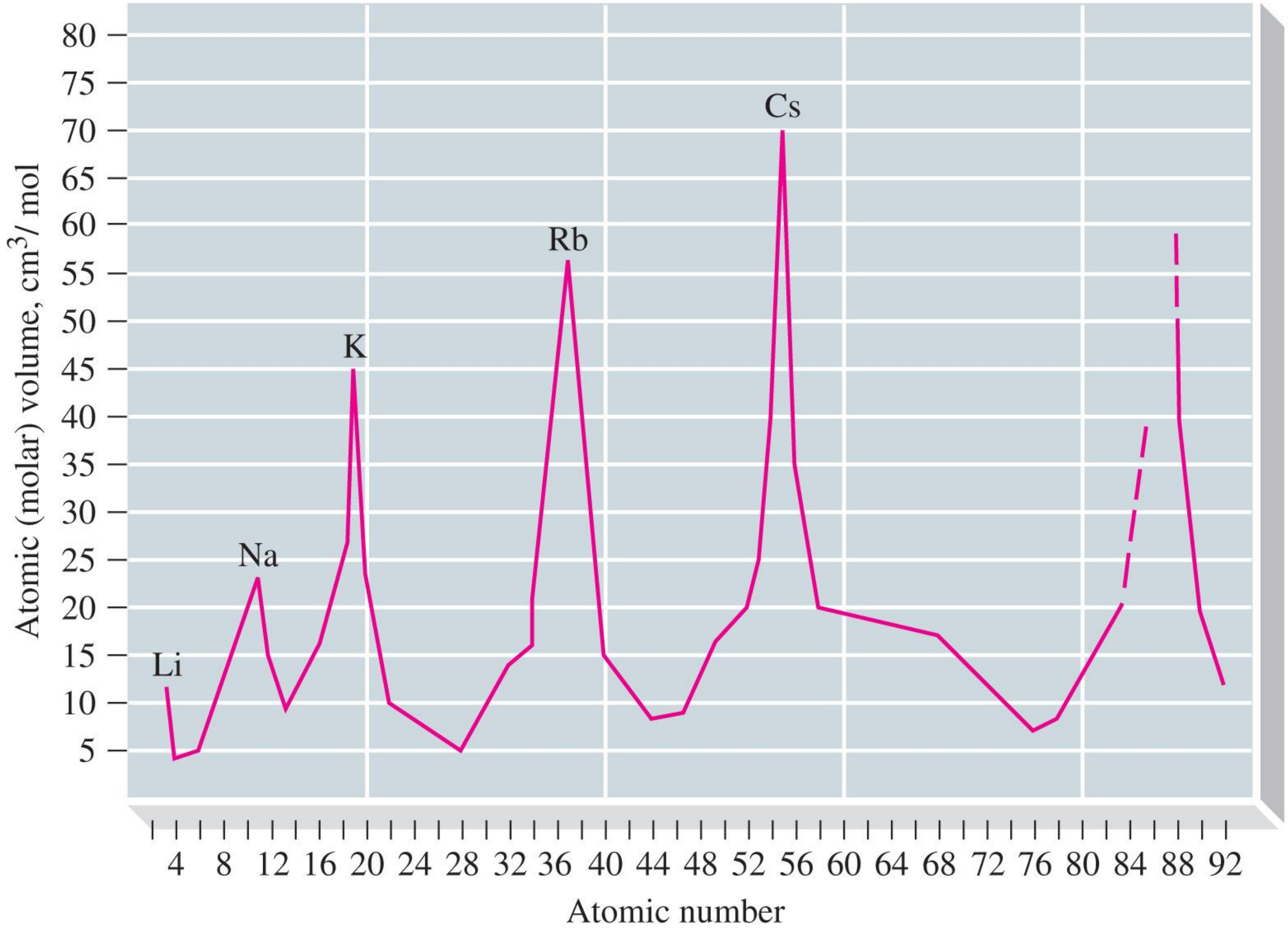
9-1 Classifying the Elements: The Periodic Law and the Periodic Table

- 1869, Dimitri Mendeleev
  Lother Meyer



When the elements are arranged in order of increasing atomic mass, certain sets of properties recur periodically.

Periodic Law



Mendeleev's Periodic Table

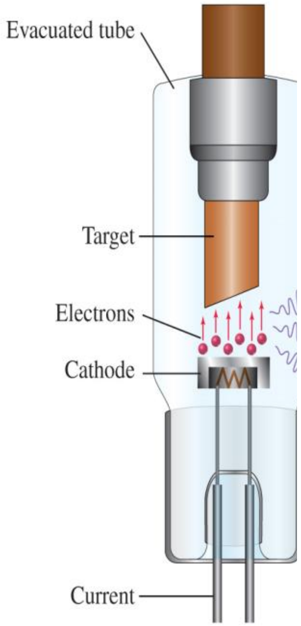
1871

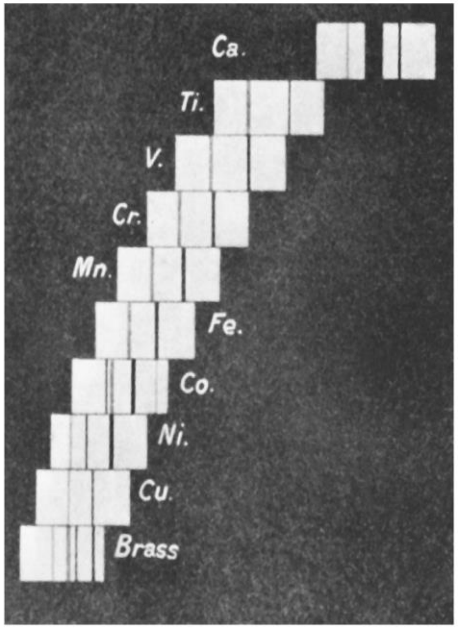
Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H = 1							
2	Li = 7	Be = 9,4	B = 11	C = 12	N = 14	O = 16	F = 19	
3	Na = 23	Mg = 24	Al = 27,3	Si = 28	P = 31	S = 32	Cl = 35,5	
4	K = 39	Ca = 40	**— = 44**	Ti = 48	V = 51	Cr = 52	Mn = 55	Fe = 56, Co = 59, Ni = 59, Cu = 63.
5	(Cu = 63)	Zn = 65	**— = 68**	**— = 72**	As = 75	Se = 78	Br = 80	
6	Rb = 85	Sr = 87	?Yt = 88	Zr = 90	Nb = 94	Mo = 96	**— = 100**	Ru = 104, Rh = 104, Pd = 106, Ag = 108
7	(Ag = 108)	Cd = 112	In = 113	Sn = 118	Sb = 122	Te = 125	J = 127	
8	Cs = 133	Ba = 137	?Di = 138	?Ce = 140	–	–	–	– – – –
9	(–)	–	–	–	–	–	–	
10	–	–	?Er = 178	?La = 180	Ta = 182	W = 184	–	Os = 195, Ir = 197, Pt = 198, Au = 199
11	(Au = 199)	Hg = 200	Tl = 204	Pb = 207	Bi = 208			
12	–	–	–	Th = 231	–	U = 240		

TABLE 9.1 Properties of Germanium: Predicted and Observed

Property	Predicted Eka-silicon (1871)	Observed Germanium (1886)
Atomic mass	72	72.6
Density, g/cm^3	5.5	5.47
Color	dirty gray	grayish white
Density of oxide, g/cm^3	EsO_2: 4.7	GeO_2: 4.703
Boiling point of chloride	$EsCl_4$: below 100 °C	$GeCl_4$: 86 °C
Density of chloride, g/cm^3	$EsCl_4$: 1.9	$GeCl_4$: 1.887

X-Ray Spectra





- Moseley 1913
  - X-ray emission is explained in terms of transitions in which e^- drop into orbits close to the atomic nucleus.
  - Correlated frequencies to nuclear charges.
- $\nu = A\,(Z - b)^2$
  - Used to predict new elements (43, 61, 75) later discovered.

The Periodic table

Alkali Metals

Alkaline Earths

Transition Metals

Halogens

Main Group

Noble Gases

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 H 1.00794																	2 He 4.00260
3 Li 6.941	4 Be 9.01218											5 B 10.811	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.1797
11 Na 22.9898	12 Mg 24.3050											13 Al 26.9815	14 Si 28.0855	15 P 30.9738	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
19 K 39.0983	20 Ca 40.078	21 Sc 44.9559	22 Ti 47.88	23 V 50.9415	24 Cr 51.9961	25 Mn 54.9381	26 Fe 55.847	27 Co 58.9332	28 Ni 58.693	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.224	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.757	52 Te 127.60	53 I 126.904	54 Xe 131.29
55 Cs 132.905	56 Ba 137.327	57 *La 138.906	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.025	89 †Ac 227.028	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 (269)	111 (272)	112 (272)		114 (287)		116 (289)		118 (293)

*Lanthanide series	58 Ce 140.115	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.965	64 Gd 157.25	65 Tb 158.925	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
†Actinide series	90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np 237.048	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

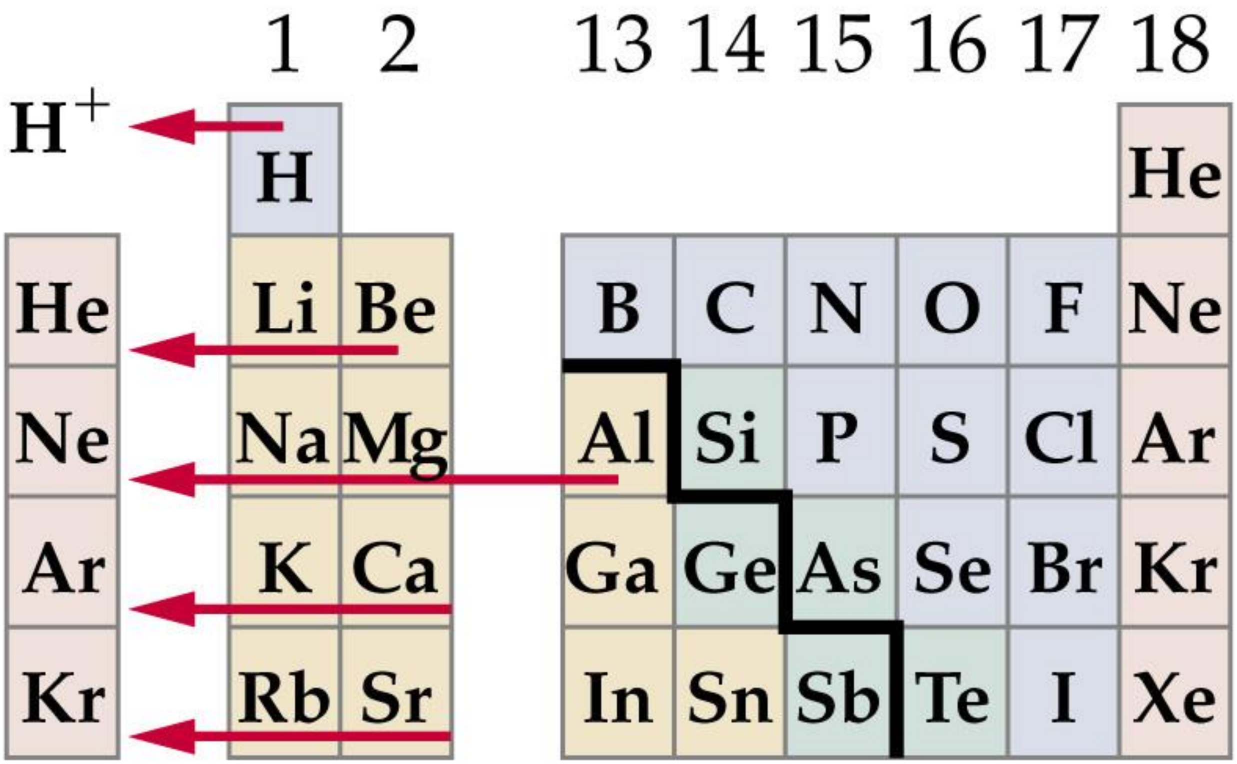
Main Group

Lanthanides and Actinides

9-2 Metals and Nonmetals and Their Ions

- Metals
  - Good conductors of heat and electricity.
  - Malleable and ductile.
  - Moderate to high melting points.
- Nonmetals
  - Nonconductors of heat and electricity.
  - Brittle solids.
  - Some are gases at room temperature.

Metals Tend to Lose Electrons



Nonmetals Tend to Gain Electrons

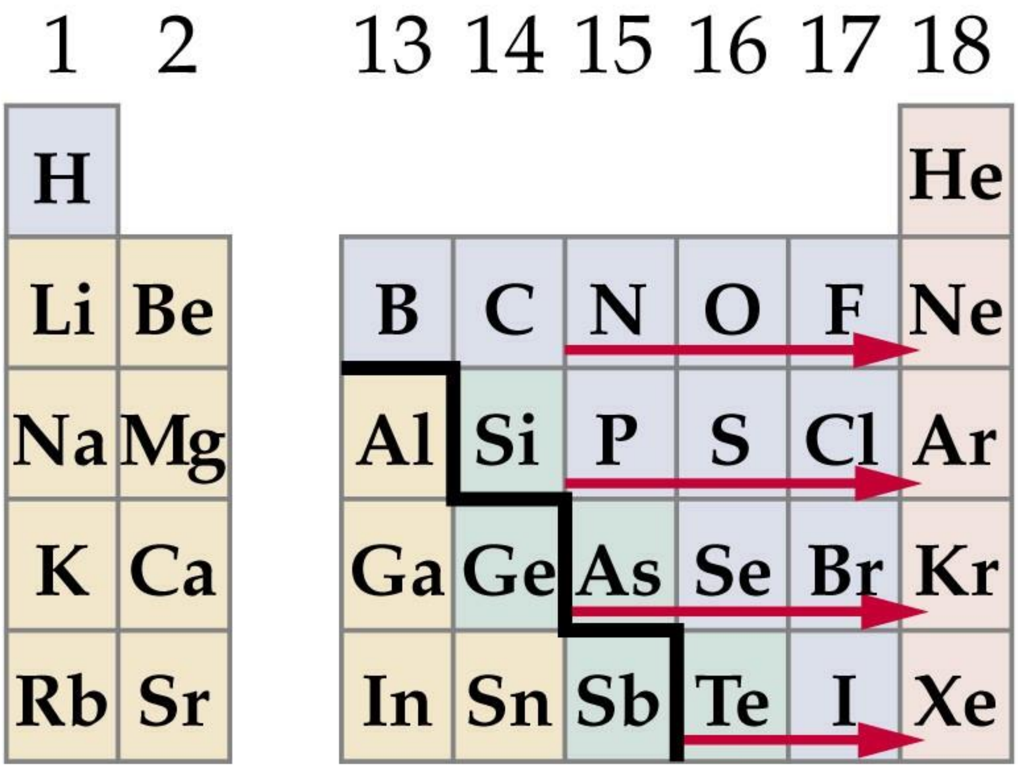
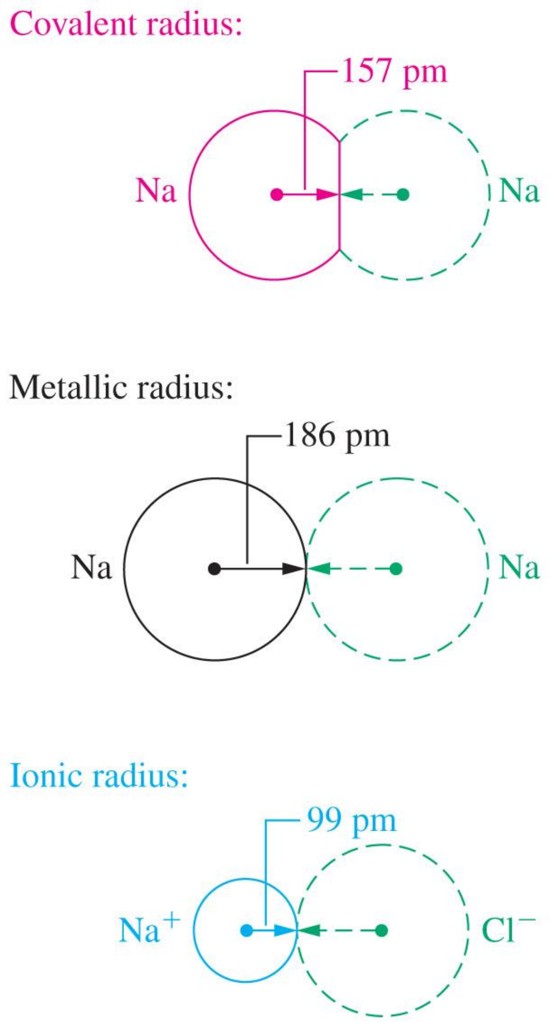


TABLE 9.2 Electron Configurations of Some Metal Ions[a]

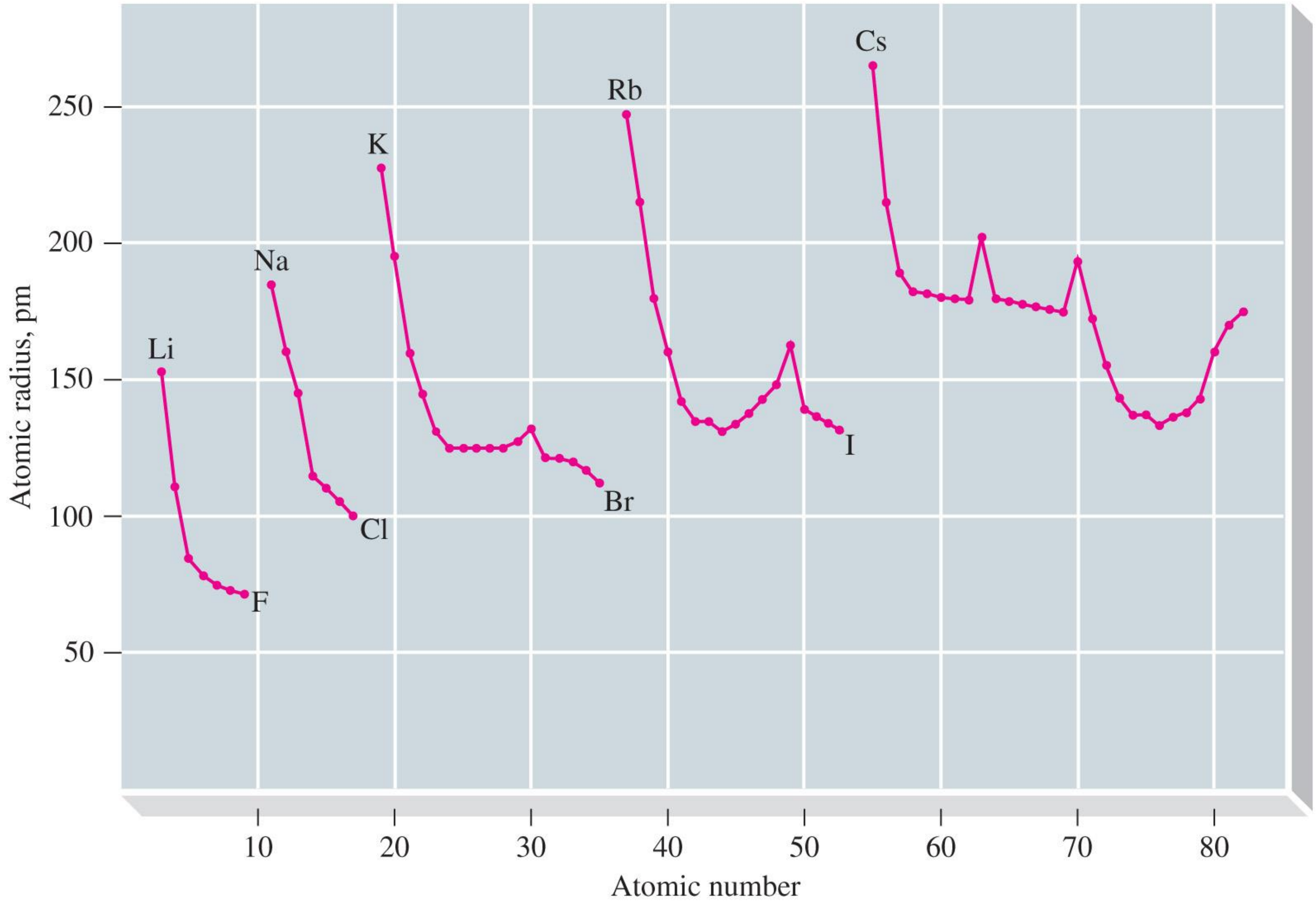
"Noble Gas"		"Pseudo-Noble Gas"[b]	"18 + 2"[c]	Other
Li^+	Be^{2+}	Ga^{3+}	In^+	Cr^{2+}, Cr^{3+}
Na^+	Mg^{2+}	Tl^{3+}	Tl^+	Mn^{2+}, Fe^{2+}
K^+	Ca^{2+}	Cu^+	Sn^{2+}	Fe^{3+}, Co^{2+}
Rb^+	Sr^{2+}	Ag^+, Au^+	Pb^{2+}	Ni^{2+}, Cu^{2+}
Cs^+	Ba^{2+}	Zn^2	Sb^{3+}	
Fr^+	Ra^{2+}		Bi^{3+}	
Al^{3+}				

[a]Main-group metal ions are printed in black and transition metal ions in blue.
[b]In the configuration labeled "pseudo-noble gas," all electrons of the outermost shell have been lost. The next-to-outermost electron shell of the atom becomes the outermost shell of the ion and contains 18 electrons, for example, Ga^{3+}: $[Ne]3s^23p^63d^{10}$.
[c]In the configuration labeled "18 + 2" all outer-shell electrons except the two *s* electrons are lost, producing an ion with 18 electrons in the next-to-outermost shell and 2 electrons in the outermost, for example, Sn^{2+}: $[Ar]3d^{10}4s^24p^64d^{10}5s^2$.

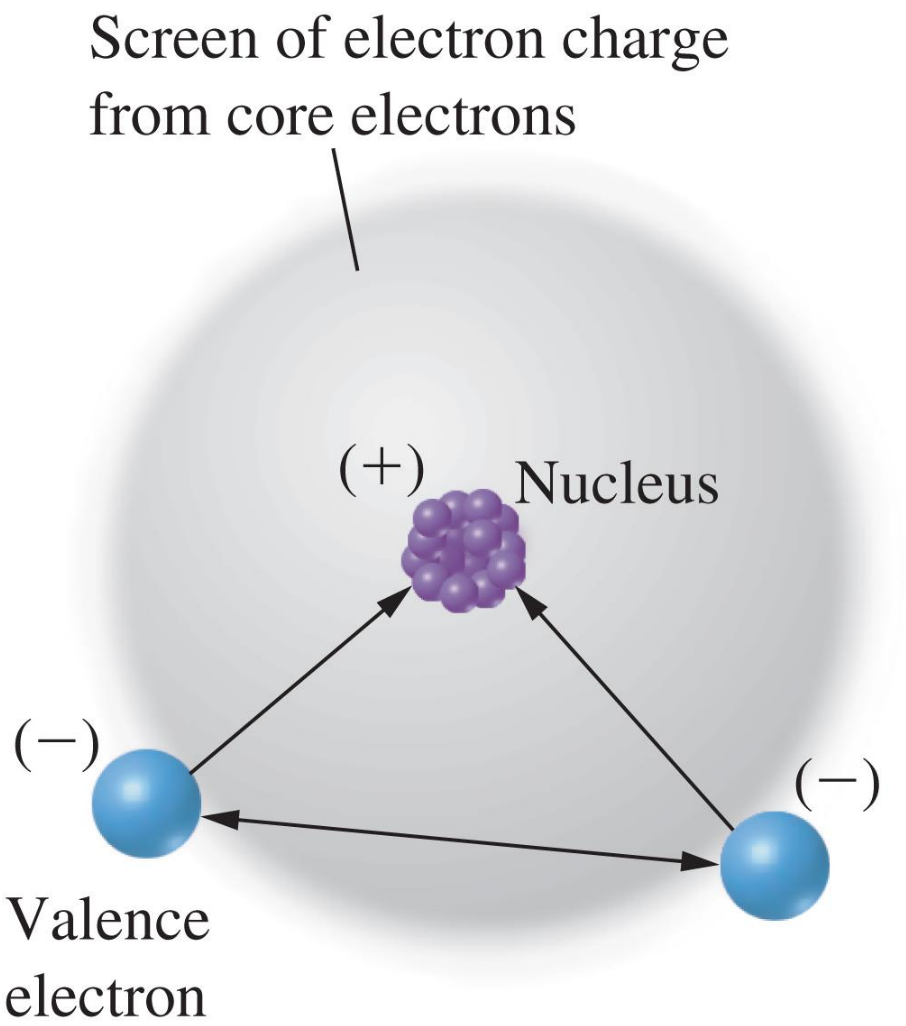
9-3 Sizes of Atoms and Ions



Atomic Radius



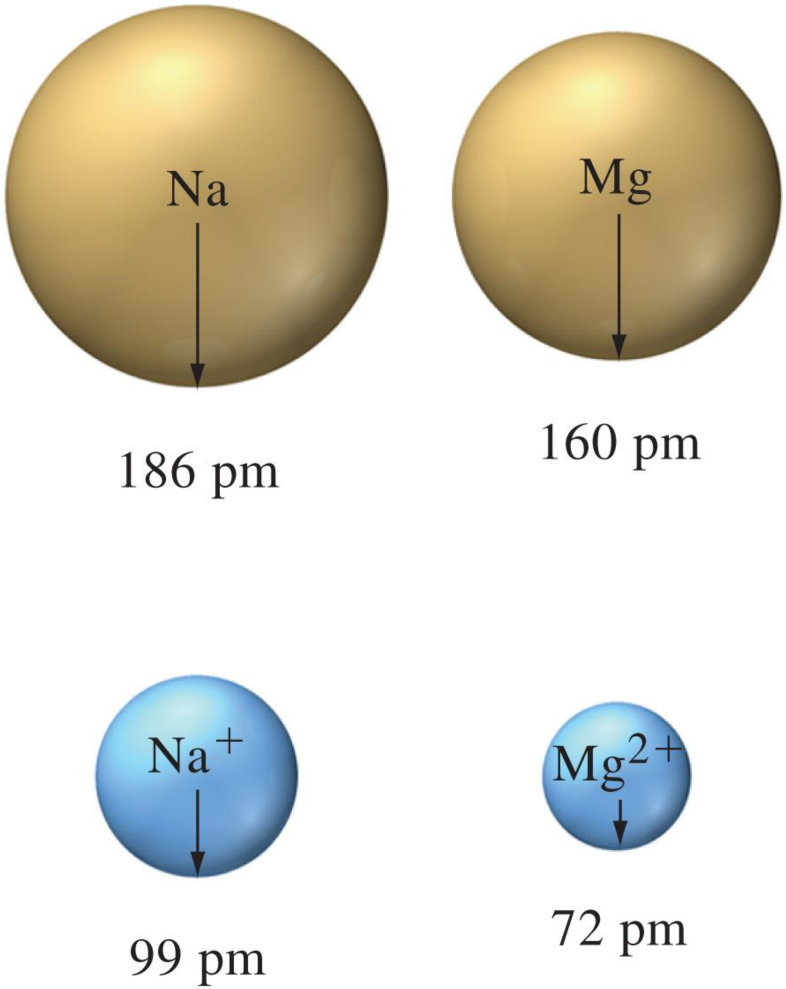
Screening and Penetration



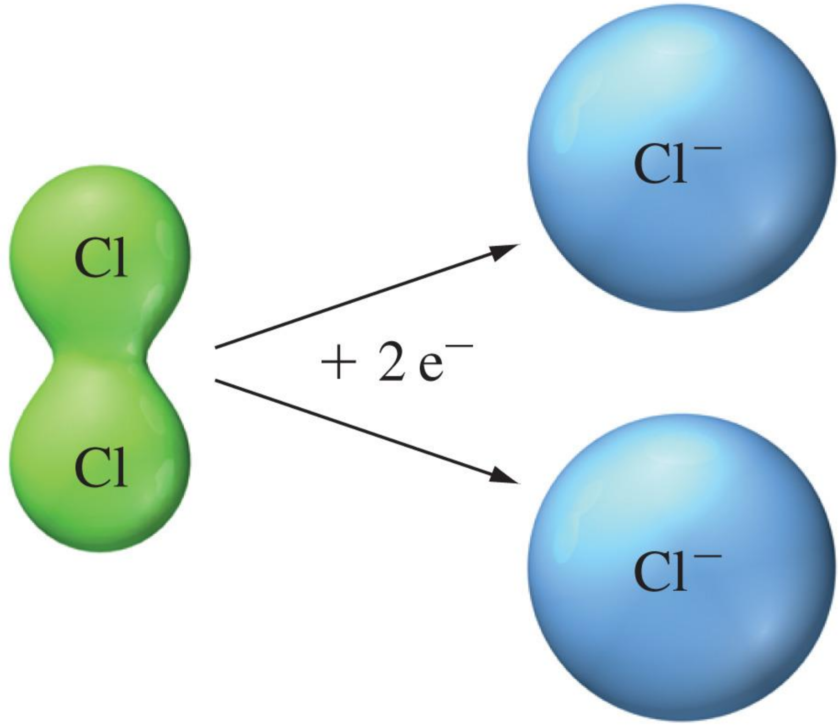
$$Z_{eff} = Z - S$$

$$E_n = -R_H \frac{Z_{eff}^2}{n^2}$$

Cationic Radii



Anionic Radii



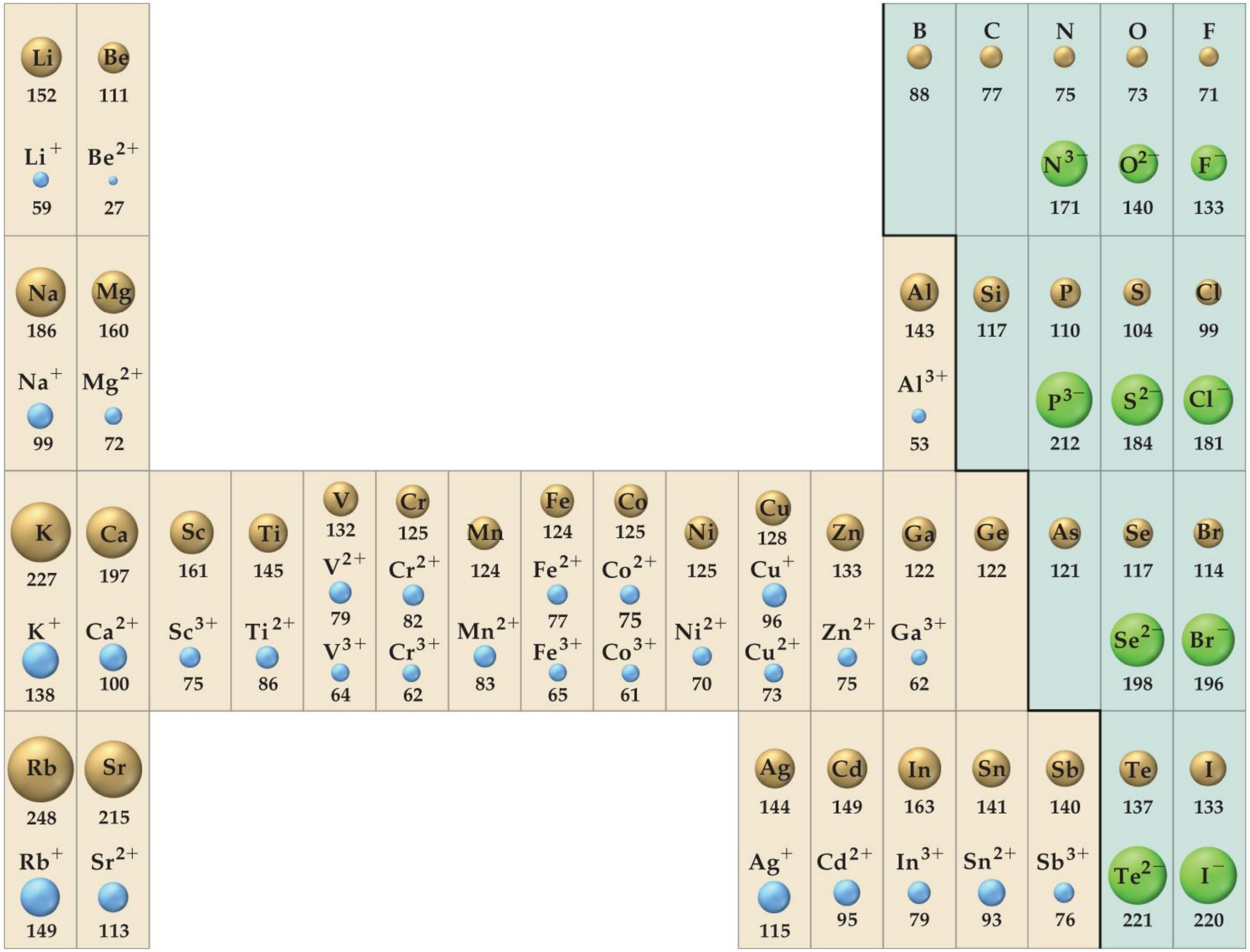
Covalent radius

99 pm

Ionic radius

181 pm

Atomic and Ionic Radii



9-4 Ionization Energy

$Mg(g) \rightarrow Mg^{+}(g) + e^{-}$ $\qquad I_1 = 738$ kJ

$Mg^{+}(g) \rightarrow Mg^{2+}(g) + e^{-}$ $\qquad I_2 = 1451$ kJ

$$I = R_H \frac{Z_{eff}^{\,2}}{n^2}$$

First Ionization Energy

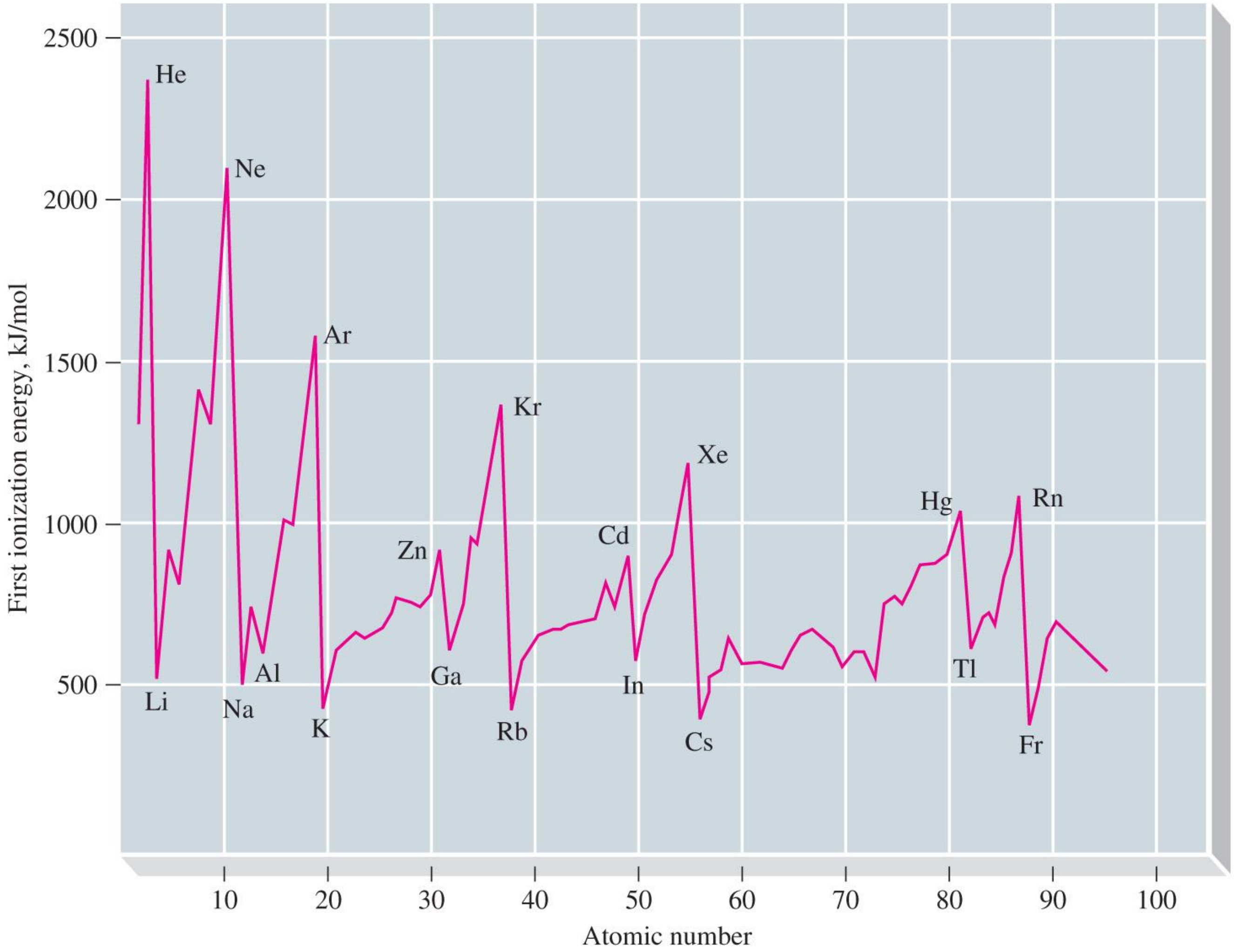


TABLE 9.4 Ionization Energies of the Third-Period Elements (in kJ/mol)								
	Na	Mg	Al	Si	P	S	Cl	Ar
I_1	495.8	**737.7**	**577.6**	786.5	**1012**	**999.6**	1251.1	1520.5
I_2	4562	**1451**	1817	1577	1903	2251	2297	2666
I_3		**7733**	2745	3232	2912	3361	3822	3931
I_4			11,580	4356	4957	4564	5158	5771
I_5				16,090	6274	7013	6542	7238
I_6					21,270	8496	9362	8781
I_7						27,110	11,020	12,000

I_2 (Mg) vs. I_3 (Mg) I_1 (Mg) vs. I_1 (Al) I_1 (P) vs. I_1 (S)

9-5 Electron Affinity

$F(g) + e^- \rightarrow F^-(g)$ EA = -328 kJ

$F(1s^2 2s^2 2p^5) + e^- \rightarrow F^-(1s^2 2s^2 2p^6)$

$Li(g) + e^- \rightarrow Li^-(g)$ EA = -59.6 kJ

First Electron Affinities

1	2	13	14	15	16	17	18
H −72.8							He >0
Li −59.6	Be >0	B −26.7	C −121.8	N +7	O −141.0	F −328.0	Ne >0
Na −52.9	Mg >0	Al −42.5	Si −133.6	P −72	S −200.4	Cl −349.0	Ar >0
K −48.4	Ca −2.37	Ga −28.9	Ge −119.0	As −78	Se −195.0	Br −324.6	Kr >0
Rb −46.9	Sr −5.03	In −28.9	Sn −107.3	Sb −103.2	Te −190.2	I −295.2	Xe >0
Cs −45.5	Ba −13.95	Tl −19.2	Pb −35.1	Bi −91.2	Po −186	At −270	Rn >0

Second Electron Affinities

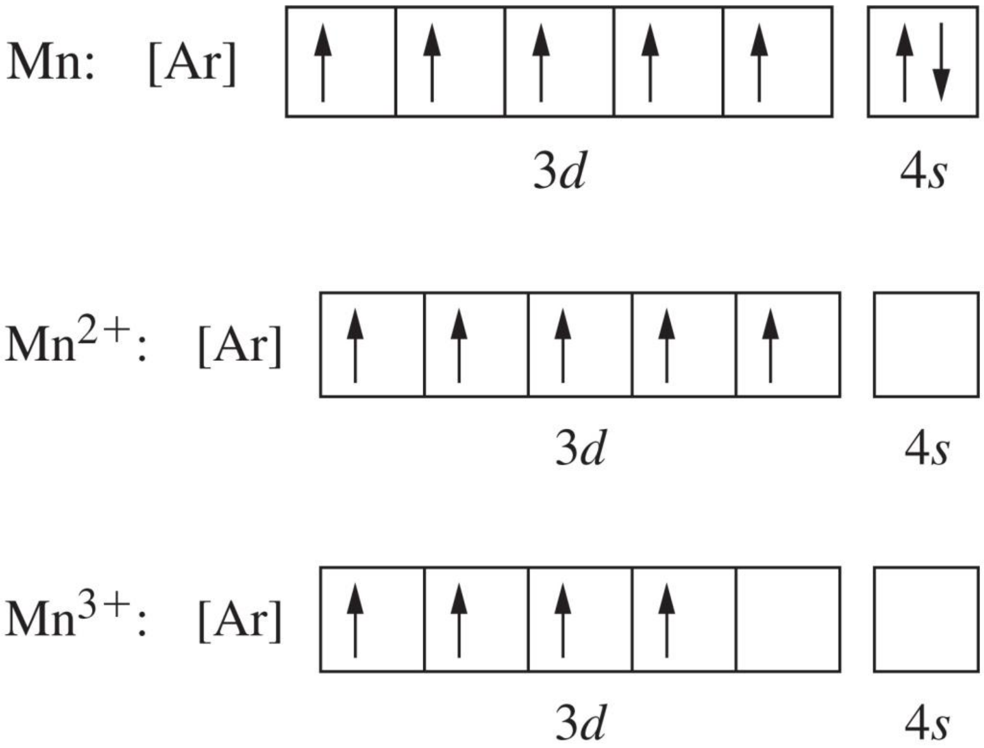
$O(g) + e^- \rightarrow O^-(g)$ EA = -141 kJ

$O^-(g) + e^- \rightarrow O^{2-}(g)$ EA = +744 kJ

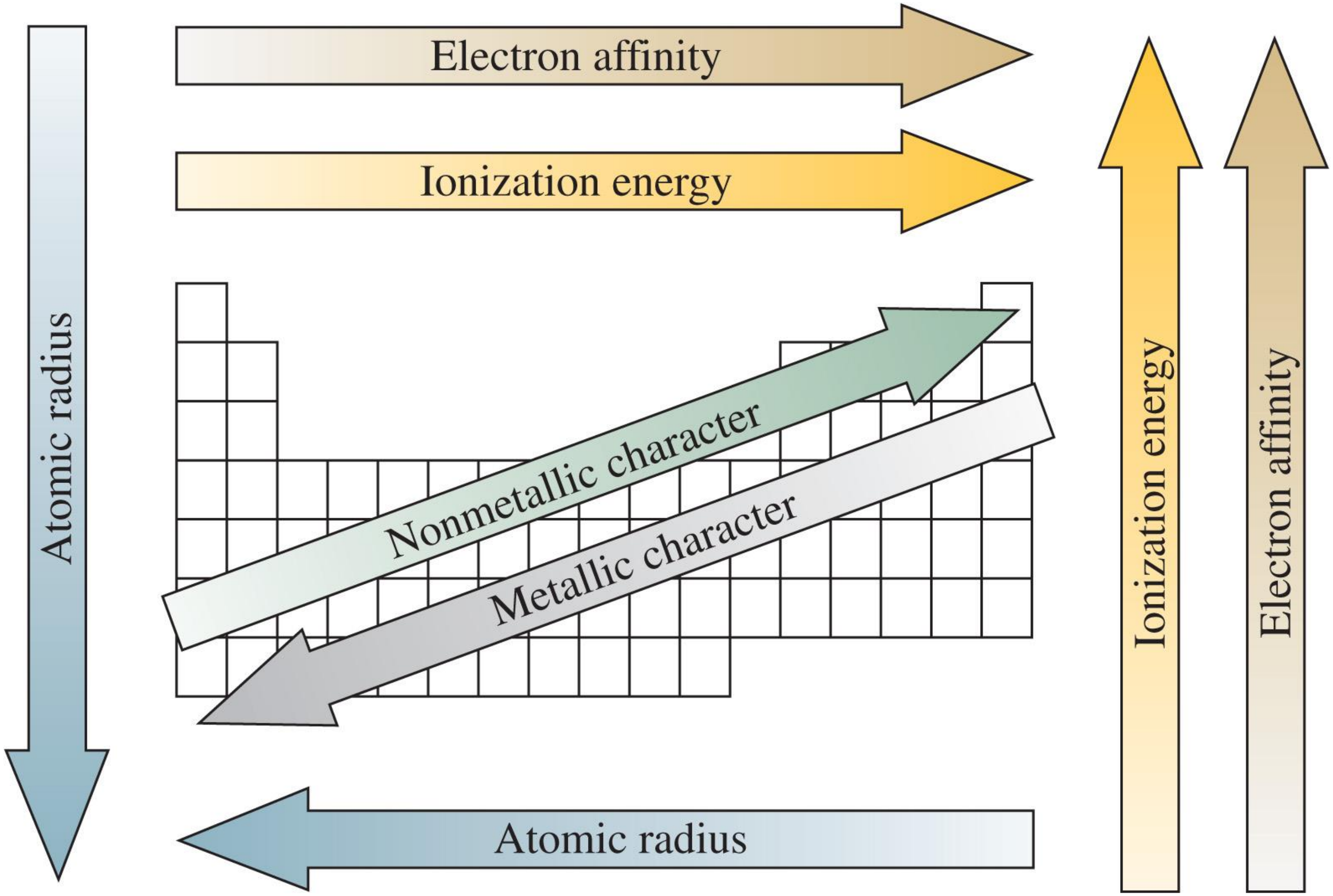
9-6 Magnetic Properties

- Diamagnetic atoms or ions:
  - All e^- are paired.
  - Weakly repelled by a magnetic field.
- Paramagnetic atoms or ions:
  - *Unpaired* e^-.
  - Attracted to an external magnetic field.

Paramagnetism



9-7 Periodic Properties of the Elements



Boiling Point

TABLE 9.5 Some Properties of Three Halogen (Group 17) Elements

	Atomic Number	Atomic Mass, u	Molecular Form	Melting Point, K	Boiling Point, K
Cl	17	35.45	Cl_2	172	239
Br	35	79.90	Br_2	?	?
I	53	126.90	I_2	387	458

Melting Points of Elements

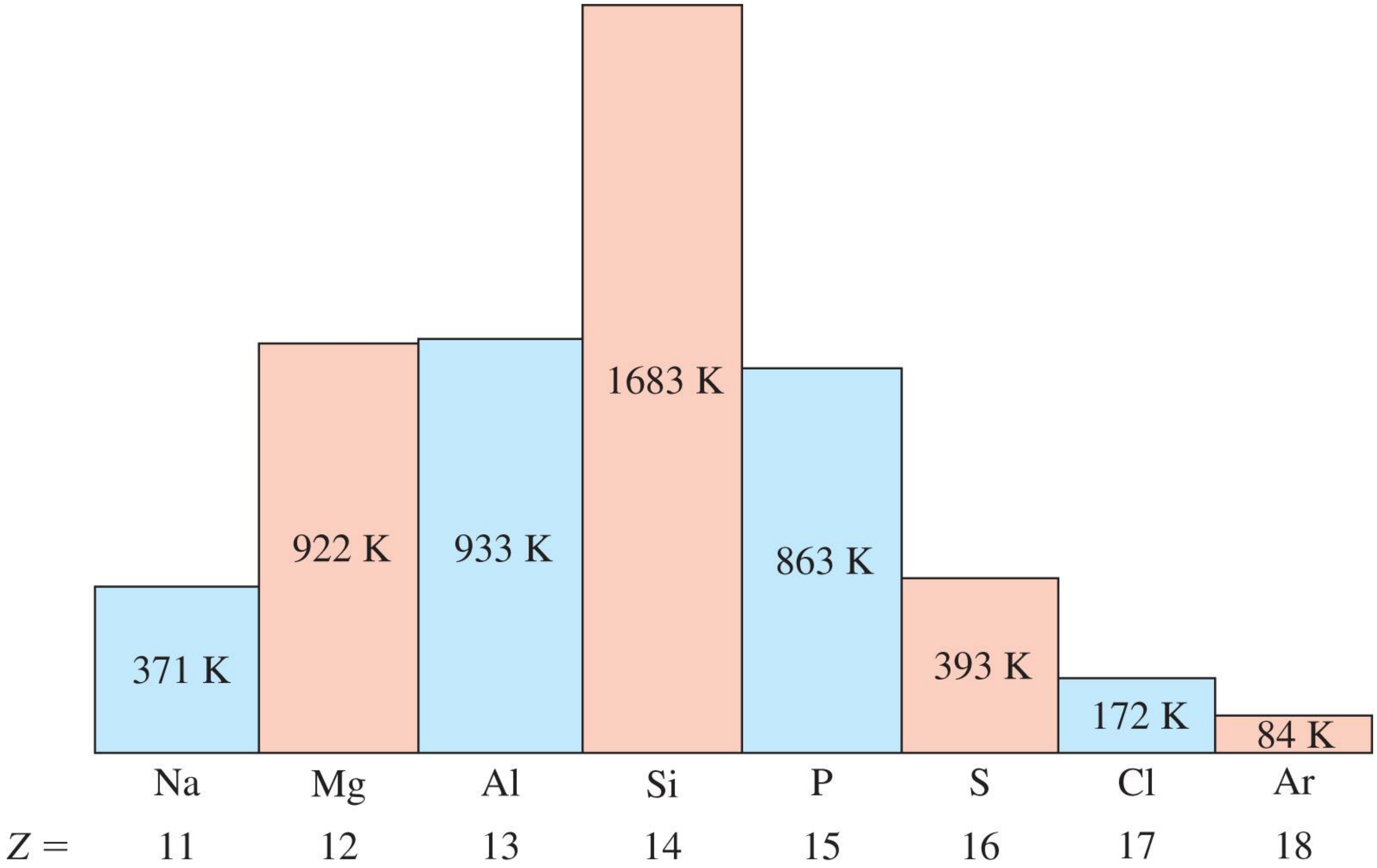
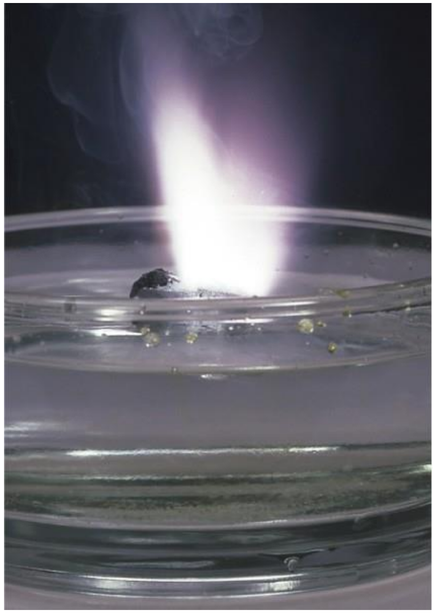


TABLE 9.6 Melting Points of Two Series of Compounds

	Molecular Mass, u	Melting Point, °C
CF_4	88.0	−183.7
CCl_4	153.8	−22.9
CBr_4	331.6	90.1
CI_4	519.6	171
HF	20.0	−83.6
HCl	36.5	−114.2
HBr	80.9	−86.8
HI	127.9	−50.8

Reducing Ability of Group 1 and 2 Metals



$$2\ K(s) + 2\ H_2O(l) \rightarrow 2\ K^+ + 2\ OH^- + H_2(g)$$

$I_1 = 419$ kJ

$I_1 = 590$ kJ

$I_2 = 1145$ kJ

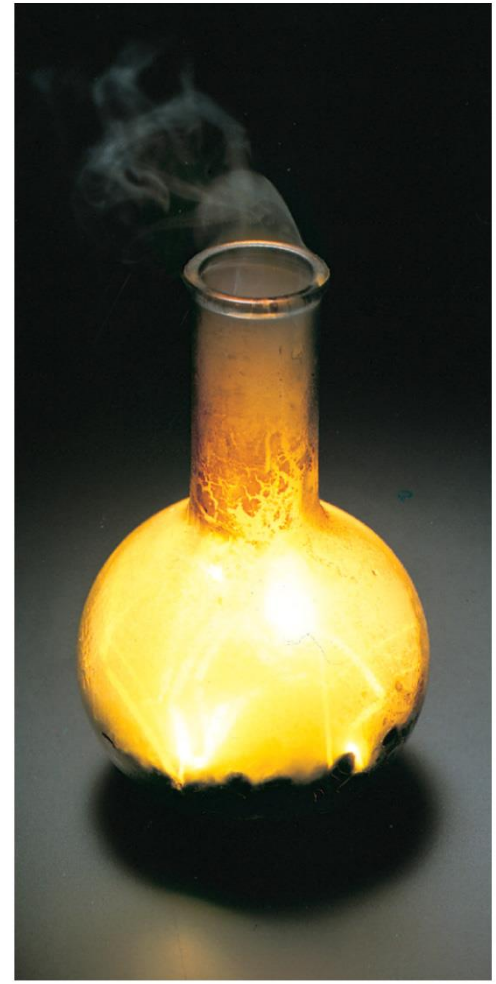
$$Ca(s) + 2\ H_2O(l) \rightarrow Ca^{2+} + 2\ OH^- + H_2(g)$$

Oxidizing Abilities of the Halogens

(a) (b)

$$2\,Na + Cl_2 \rightarrow 2\,NaCl$$

$$Cl_2 + 2\,I^- \rightarrow 2\,Cl^- + I_2$$



Acid Base Nature of Element Oxides

- Basic oxides or base anhydrides:

  $Li_2O(s) + H_2O(l) \rightarrow 2\ Li^+(aq) + 2\ OH^-(aq)$

- Acidic oxides or acid anhyhydrides:

  $SO_2\ (g) + H_2O(l) \rightarrow\ H_2SO_3(aq)$

- Na_2O and MgO yield basic solutions
- Cl_2O, SO_2 and P_4O_{10} yield acidic solutions
- SiO_2 dissolves in strong base, acidic oxide.

Focus on The Periodic Law and Mercury

- Should be a solid.
- Relativistic shrinking of s-orbitals affects all heavy metals but is maximum with Hg.

End of Chapter Questions

- Think of a problem like a root system:
  - Each branching is a decision.
  - The answer is at the tip of one of the rootlets.