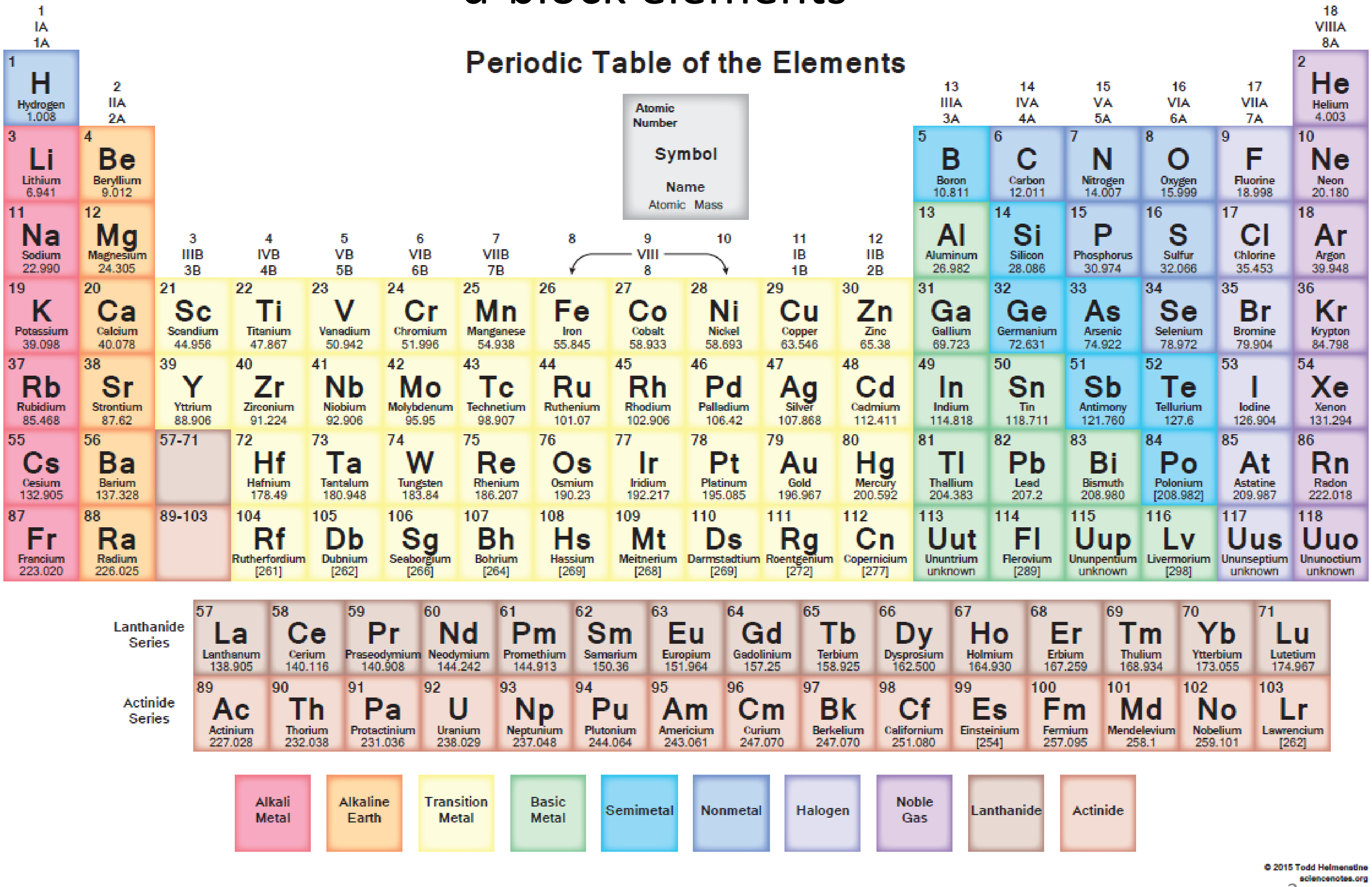
Focus 8
Elemental Chemistry

- Main group elements
- d-block elements



Hydrogen

Hydrogen is widely considered to be the fuel of our future.

Commonly found as +1 valence.

Hydrogen's **physical properties** are similar to the halogens, in that it needs one electron to fill its valence shell.

Chemically, hydrogen is very different from the halogens.

Therefore, we do not assign a group number to hydrogen.

Hydrogen

Hydrogen is the most abundant element in the universe: it accounts for 89% of all atoms.

On the other hand, due to it’s light mass, and high average speed, the Earth’s gravitational field is not strong enough to hold to the surface.

Most hydrogen atoms are trapped in water, minerals, clays, or petroleum.

Hydrogen

Its only combustion product is water, so it contributes zero to pollution.

Highly sought after as a fuel, the oceans have enough hydrogen for all of our energy needs.

One source of hydrogen is electrolysis

Another is sunlight or **photochemical decomposition**:

Sunlight: $2\ H_2O(l) \rightarrow\ 2\ H_2(g)\ +\ O_2(g) \quad \Delta G = +474\ \text{kJ}$

Hydrogen

Hydrogen has the **highest specific enthalpy** of any known fuel (the highest enthalpy of combustion per gram), and so liquid hydrogen is used with liquid oxygen to power the space shuttle's main rocket engines.

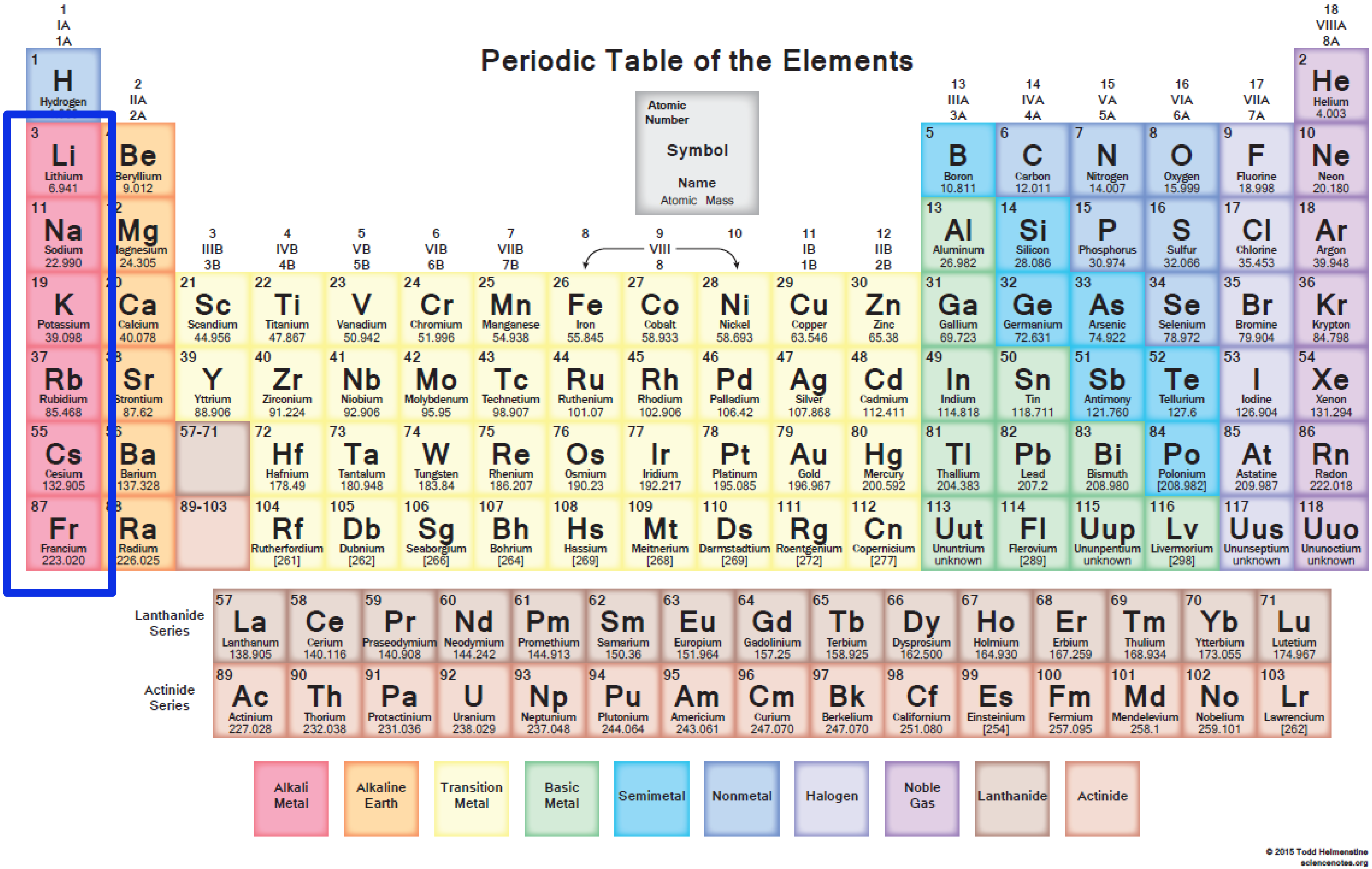
Each year, about **half** the 3×10^8 kg of hydrogen used in industry is converted into ammonia by the Haber process

Hydrogen

Hydrogen has an intermediate electronegativity of 2.2, so it is common to find both the anion, H^-, and cation, H^+.

A hydride, H^-, radius is large, 154 pm, the single proton has a hard time holding both electrons, so the second electron is easily lost.

In a hydrogen bond, O-H----X (X = N, O, F), the hydrogen bond is 5% of a covalent bond for the same H-X bond.



Periodic Table of the Elements
1 IA 1A
2 IIA 2A
3 IIIB 3B
4 IVB 4B
5 VB 5B
6 VIB 6B
7 VIIB 7B
8 VIII 8 9 10
11 IB 1B
12 IIB 2B
13 IIIA 3A
14 IVA 4A
15 VA 5A
16 VIA 6A
17 VIIA 7A
18 VIIIA 8A
Atomic Number
Symbol
Name
Atomic Mass
1 H Hydrogen
2 He Helium 4.003
3 Li Lithium 6.941
4 Be Beryllium 9.012
5 B Boron 10.811
6 C Carbon 12.011
7 N Nitrogen 14.007
8 O Oxygen 15.999
9 F Fluorine 18.998
10 Ne Neon 20.180
11 Na Sodium 22.990
12 Mg Magnesium 24.305
13 Al Aluminum 26.982
14 Si Silicon 28.086
15 P Phosphorus 30.974
16 S Sulfur 32.066
17 Cl Chlorine 35.453
18 Ar Argon 39.948
19 K Potassium 39.098
20 Ca Calcium 40.078
21 Sc Scandium 44.956
22 Ti Titanium 47.867
23 V Vanadium 50.942
24 Cr Chromium 51.996
25 Mn Manganese 54.938
26 Fe Iron 55.845
27 Co Cobalt 58.933
28 Ni Nickel 58.693
29 Cu Copper 63.546
30 Zn Zinc 65.38
31 Ga Gallium 69.723
32 Ge Germanium 72.631
33 As Arsenic 74.922
34 Se Selenium 78.972
35 Br Bromine 79.904
36 Kr Krypton 84.798
37 Rb Rubidium 85.468
38 Sr Strontium 87.62
39 Y Yttrium 88.906
40 Zr Zirconium 91.224
41 Nb Niobium 92.906
42 Mo Molybdenum 95.95
43 Tc Technetium 98.907
44 Ru Ruthenium 101.07
45 Rh Rhodium 102.906
46 Pd Palladium 106.42
47 Ag Silver 107.868
48 Cd Cadmium 112.411
49 In Indium 114.818
50 Sn Tin 118.711
51 Sb Antimony 121.760
52 Te Tellurium 127.6
53 I Iodine 126.904
54 Xe Xenon 131.294
55 Cs Cesium 132.905
56 Ba Barium 137.328
57-71
72 Hf Hafnium 178.49
73 Ta Tantalum 180.948
74 W Tungsten 183.84
75 Re Rhenium 186.207
76 Os Osmium 190.23
77 Ir Iridium 192.217
78 Pt Platinum 195.085
79 Au Gold 196.967
80 Hg Mercury 200.592
81 Tl Thallium 204.383
82 Pb Lead 207.2
83 Bi Bismuth 208.980
84 Po Polonium [208.982]
85 At Astatine 209.987
86 Rn Radon 222.018
87 Fr Francium 223.020
88 Ra Radium 226.025
89-103
104 Rf Rutherfordium [261]
105 Db Dubnium [262]
106 Sg Seaborgium [266]
107 Bh Bohrium [264]
108 Hs Hassium [269]
109 Mt Meitnerium [268]
110 Ds Darmstadtium [269]
111 Rg Roentgenium [272]
112 Cn Copernicium [277]
113 Uut Ununtrium unknown
114 Fl Flerovium [289]
115 Uup Ununpentium unknown
116 Lv Livermorium [298]
117 Uus Ununseptium unknown
118 Uuo Ununoctium unknown
Lanthanide Series
57 La Lanthanum 138.905
58 Ce Cerium 140.116
59 Pr Praseodymium 140.908
60 Nd Neodymium 144.242
61 Pm Promethium 144.913
62 Sm Samarium 150.36
63 Eu Europium 151.964
64 Gd Gadolinium 157.25
65 Tb Terbium 158.925
66 Dy Dysprosium 162.500
67 Ho Holmium 164.930
68 Er Erbium 167.259
69 Tm Thulium 168.934
70 Yb Ytterbium 173.055
71 Lu Lutetium 174.967
Actinide Series
89 Ac Actinium 227.028
90 Th Thorium 232.038
91 Pa Protactinium 231.036
92 U Uranium 238.029
93 Np Neptunium 237.048
94 Pu Plutonium 244.064
95 Am Americium 243.061
96 Cm Curium 247.070
97 Bk Berkelium 247.070
98 Cf Californium 251.080
99 Es Einsteinium [254]
100 Fm Fermium 257.095
101 Md Mendelevium 258.1
102 No Nobelium 259.101
103 Lr Lawrencium [262]
Alkali Metal
Alkaline Earth
Transition Metal
Basic Metal
Semimetal
Nonmetal
Halogen
Noble Gas
Lanthanide
Actinide
© 2015 Todd Helmenstine
sciencenotes.org

Group 1: Alkali Metals

The chemical properties of alkali metals are strikingly similar.

Sodium and potassium ions are used to transmit electrical signals throughout our brain and nervous system.

One valence electron dominates their chemical and physical properties.

TABLE 8C.1 The Group 1 Elements

Common name: alkali metals
Valence configuration: ns^1
Normal form*: soft, silver-gray metals

Z	Name	Symbol	Molar mass/ $(g\cdot mol^{-1})$	Melting point/°C	Boiling point/°C	Density/ $(g\cdot cm^{-3})$
3	lithium	Li	6.94	181	1347	0.53
11	sodium	Na	22.99	98	883	0.97
19	potassium	K	39.10	64	774	0.86
37	rubidium	Rb	85.47	39	688	1.53
55	cesium	Cs	132.91	28	678	1.87
87	francium	Fr	(223)	27	677	—

**Normal form* means the state and appearance of the element at 25 °C and 1 atm.

Table 8C.1
Atkins, *Chemical Principles: The Quest for Insight*, 7e

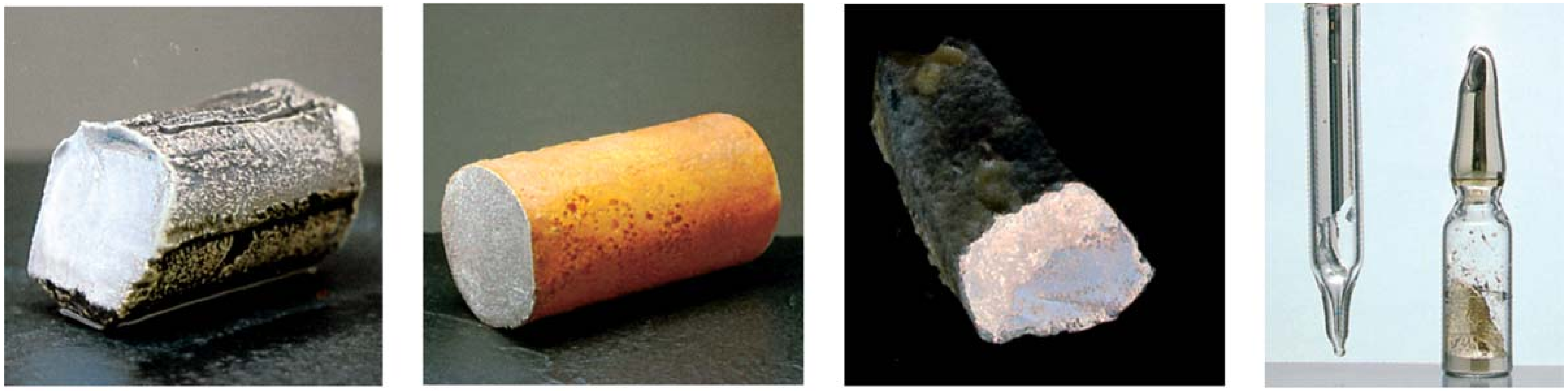
Group 1: Alkali Metals

The alkali metals **react most violently** of all metals.

To make pure metal, oxygen is completely removed and molten salts are electrolytic exposed to sodium vapor in the **Downs process**:

$$KCl(l) + Na\ (g) \xrightarrow{750\ °C} NaCl(s) + K(g)$$

Group 1: Alkali Metals



(a) (b) (c) (d)

Figure 8C.1
Atkins, *Chemical Principles: The Quest for Insight*, 7e
W. H. Freeman photos by Ken Karp.

(a) lithium; (b) sodium; (c) potassium; (d) rubidium and cesium. Francium has *never been isolated* in visible quantities. These *rapidly corrode* in moist air; rubidium and cesium *must be stored* in sealed, *airless containers*.

Group 1: Alkali Metals

Figure 8C.4
Atkins, *Chemical Principles: The Quest for Insight*, 7e

Solvated electrons commonly used for reducing organic compounds. Increasing the metal ion concentration will turn the blue into a **metallic bronze**.

Liquid NH_3 forms clusters around dissolved alkali metals producing the **ink-blue** metal-ammonia solutions.

Group 1: Alkali Metals

All alkali metals react directly with most nonmetals except noble gases.

$$6\,Li(s) + N_2(g) \rightarrow 2\,Li_3N(s)$$

Larger cation, forms predominantly the very pale yellow sodium peroxide, Na_2O_2. Potassium, with an even bigger cation, forms mainly the superoxide, KO_2, which contains the superoxide ion, O_2^- .

Group 2: Alkaline Earth Metals

Calcium, strontium, and barium are called the alkaline earth metals, because their “earths”—the old name for oxides—are basic (alkaline).

Magnesium and calcium are by far the most important members. **Magnesium** is, in effect, the **doorway to life**.

Chlorophyll

The Group 2 Elements

The ns^2 valence electron configuration means the second ionization energy is low with a typical +2 oxidation number.

These are very reactive elements.

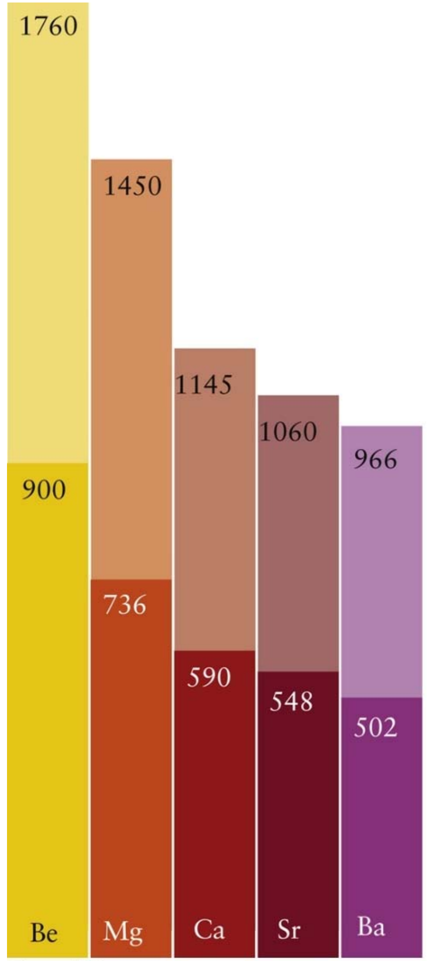


Figure 8D.1
Atkins, *Chemical Principles: The Quest for Insight*, 7e

First and second ionization energies

The Group 2 Elements

Beryllium is found mainly as beryl, $3BeO \cdot Al_2O_3 \cdot 6SiO_2$. These crystals can weigh several tons. Green beryl, Cr^{3+} impurities, are emeralds.

Magnesium occurs in seawater and as the mineral dolomite, $CaCO_3 \cdot MgCO_3$.

Figure 8D.3
Atkins, *Chemical Principles: The Quest for Insight*, 7e
M. Claye/Science Source.

Calcium also occurs as $CaCO_3$ in compressed deposits of the sea shells including limestone, calcite, and chalk.

The Group 2 Elements

beryllium magnesium calcium strontium barium

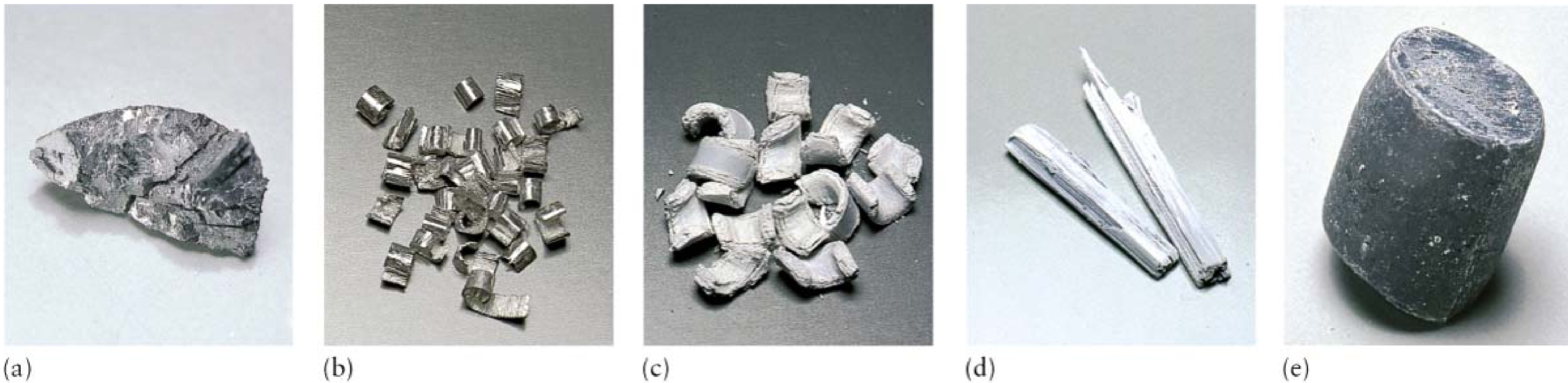


Figure 8D.2
Atkins, *Chemical Principles: The Quest for Insight*, 7e
W. H. Freeman photos by Ken Karp.

The Group 2 Elements

Calcium, strontium, and barium are obtained either by electrolysis or by reduction with aluminum in a version of the thermite process,

$$3\ BaO(s) + 2\ Al(s) \xrightarrow{\Delta} Al_2O_3(s) + 3\ Ba(s)$$

Except beryllium, all Group 2 metals react with water to make a basic solution.

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

They react with an acid to produce hydrogen gas in a redox reaction.

$$Mg(s) + 2\ H^{+}(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$$

Compounds of Calcium

Calcium carbonate decomposes to make **quicklime** when heated:

$$CaCO_3(s) \xrightarrow{\Delta} \mathbf{CaO}(s) + CO_2(g)$$

Calcium oxide ("thirsts" for water) is called quicklime because it reacts so exothermically and rapidly with water.

Calcium hydroxide is commonly known as slaked lime because the thirst of quicklime for water has been quenched (slaked).

$$\mathbf{Ca(OH)_2}(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$$

Group 13: The Boron Family

Group 13 elements are not extremely electropositive or electronegative.

B and Al are typically +3, the heavier elements tend to keep their s-electrons (inert pairing effect) so are typically +1.

Physical Properties of Group 13 Elements

TABLE 8E.1 The Group 13 Elements

Valence configuration: ns^2np^1

Z	Name	Symbol	Molar mass/ $(g{\cdot}mol^{-1})$	Melting point/°C	Boiling point/°C	Density/ $(g{\cdot}cm^{-3})$	Normal form*
5	boron	B	10.81	2300	3931	2.47	powdery brown metalloid
13	aluminum	Al	26.98	660	2467	2.70	silver-white metal
31	gallium	Ga	69.72	30	2403	5.91	silver metal
49	indium	In	114.82	156	2080	7.29	silver-white metal
81	thallium	Tl	204.38	304	1457	11.87	soft metal

**Normal form* means the state and appearance of the element at 25 °C and 1 atm.

Table 8E.1
Atkins, *Chemical Principles: The Quest for Insight*, 7e

Group 13 Elements

Boron forms perhaps the most extraordinary structures of all the elements.

With only three valence electrons and a small atomic radii, it tends to form only three covalent bonds with an incomplete octet.

Boron is mined in the Mojave Desert region of California as borax and kernite, $Na_2B_4O_7 \cdot xH_2O$, with $x = 10$ and 4.

It is converted to an amorphous boron using magnesium.

$$B_2O_3(s) + 3\,Mg(s) \xrightarrow{\Delta} 2\,B(s) + 3\,MgO(s)$$

Group 13 Oxides

Boric acid, $B(OH)_3$, **is toxic** to bacteria and many insects as well as humans.

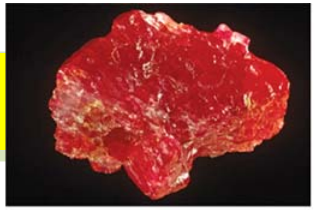
The incomplete octet means it can act as a Lewis acid:

$$(OH)_3B + :OH_2 \rightarrow (OH)_3B—OH_2 + H_2O(l) \rightarrow H_3O^+ (aq) + B(OH)_4^- (aq)$$

Boric acid, $(OH)_3B—OH_2$, is a starting material for B_2O_3 used for flux or fiberglass and borosilicate's glass like Pyrex, because it has a low thermal expansion.

Group 13 Oxides

Ruby, alumina with Cr^{3+}



(a)

Sapphire, alumina with Fe^{3+} and Ti^{4+}

(b)

Alumina is aluminum oxide, Al_2O_3.

α-alumina is very hard and stable and is used as an abrasive known as emery.

γ-alumina is less dense and used in chromatography.

Topaz, alumina with Fe^{3+}

(c)

Figure 8E.4
Atkins, *Chemical Principles: The Q*
Part (a) Jacana/Science Source;
part (b) ©Boltin PictureLibrary/B
part (c) Roberto de Gugliemo/Sci

Group 14 Elements

The ns^2np^2 valence electron configuration are why carbon and silicon typically make four bonds.

Inert-pair effect is common for the heavier elements and why lead is commonly in a +2 oxidation state.

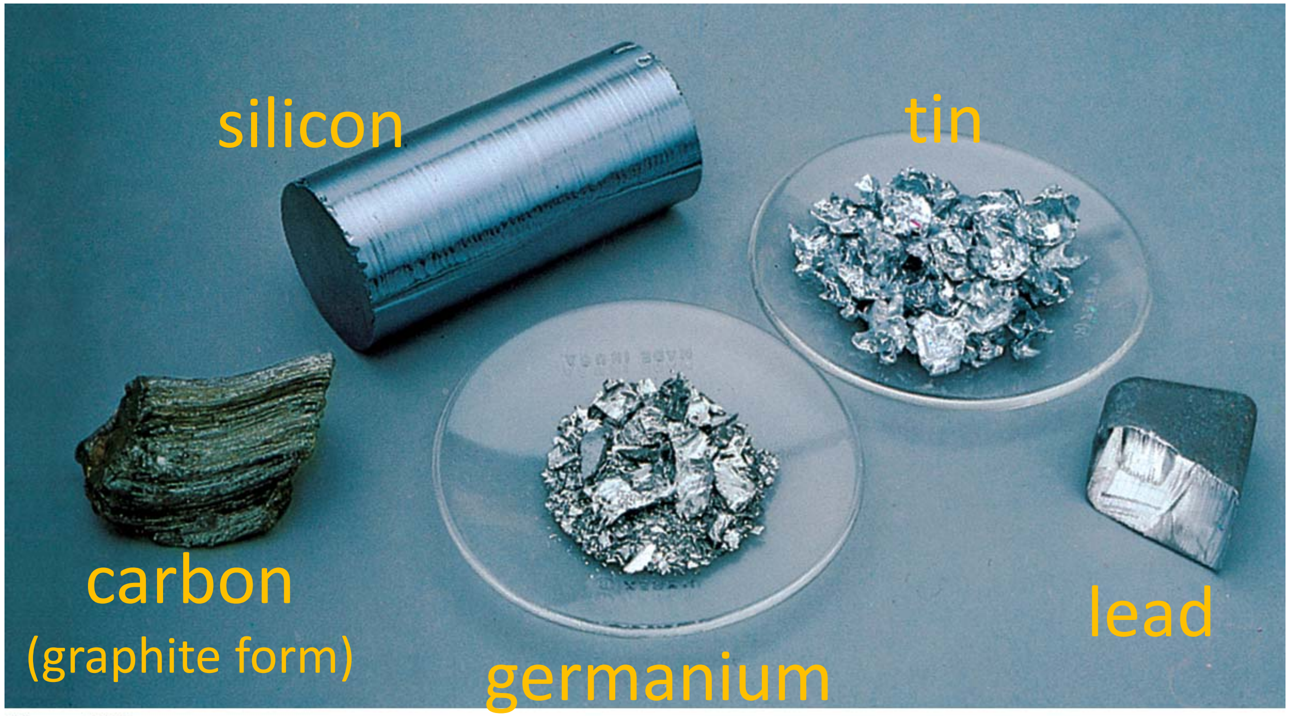


Figure 8F.1
Atkins, *Chemical Principles: The Quest for Insight*, 7e

Group 14 Elements

Carbon is nonmetallic, forming covalent compounds.

Carbon and silicon oxides are acidic.

The **metallic character** increases down the group.

Germanium is a typical **metalloid**.

Tin and lead have definite metallic properties.

Tin a metalloids has some **amphoteric properties**.

$Sn(s) + 2\,H_3O^+(aq) \rightarrow Sn^{2+}(aq) + H_2(g) + 2\,H_2O(l)$

$Sn(s) + 2\,OH^-(aq) + 2\,H_2O(l) \rightarrow Sn(OH)_2^{2-}(aq) + H_2(g)$

Group 14 Elements

Carbon is smaller than silicon, so carbon's p-orbitals get closer together forming π-bonds like C=C and C=O, whereas silicon double bonds are rare.

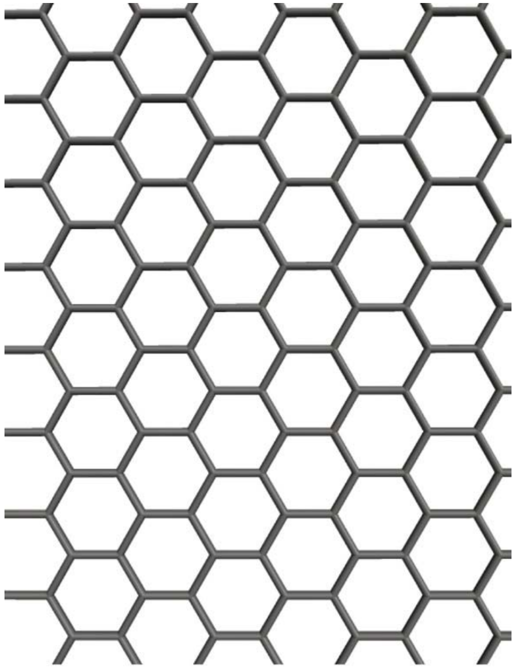
Carbon forms discrete molecules, O=C=O. Silicon dioxide (silica) forms networks of -O-Si-O- groups.

Silicon is bigger so it expands its valence shells using d-orbitals and acts as a Lewis acid.

A carbon atom is smaller with no available d-orbitals so it cannot act as Lewis acid.

The Different Forms of Carbon

Graphite is the most stable solid allotrope.



2 Graphene

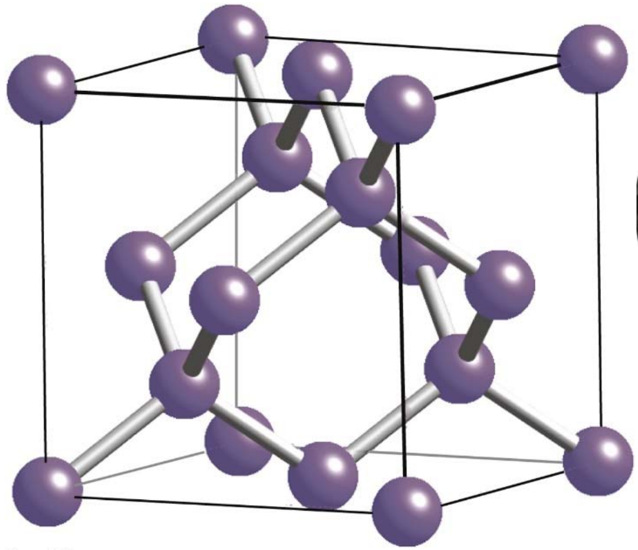
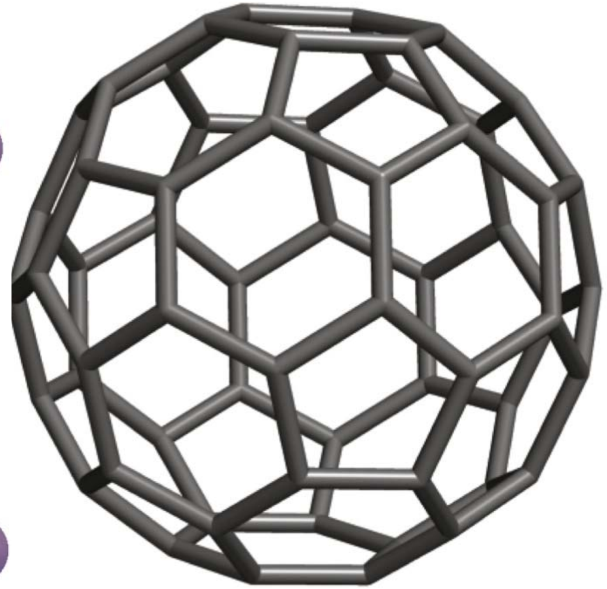


Figure 3H.6



3 Buckminsterfullerene, C_{60}

Graphite Diamond Fullerene

Silicon, Germanium, Tin, and Lead

Germanium was predicted by Mendeleev and finally found 1886. It's mainly used as a semiconductor.

Tin and **lead** are obtained very easily from their ores and have been known since antiquity by the reduction of the mineral cassiterite, SnO_2 and carbon at 1200 °C.

$$SnO_2(s) + C(s) \xrightarrow{\Delta} Sn(l) + CO_2(g)$$

Lead ore is called galena, PbS, and converted to the oxide first, then to the metal.

$$2\ PbS(s) + 3\ O_2(g) \xrightarrow{\Delta} 2\ PbO(s) + 2\ SO_2(g)$$

$$PbO(s) + C(s) \rightarrow Pb(s) + CO(g)$$