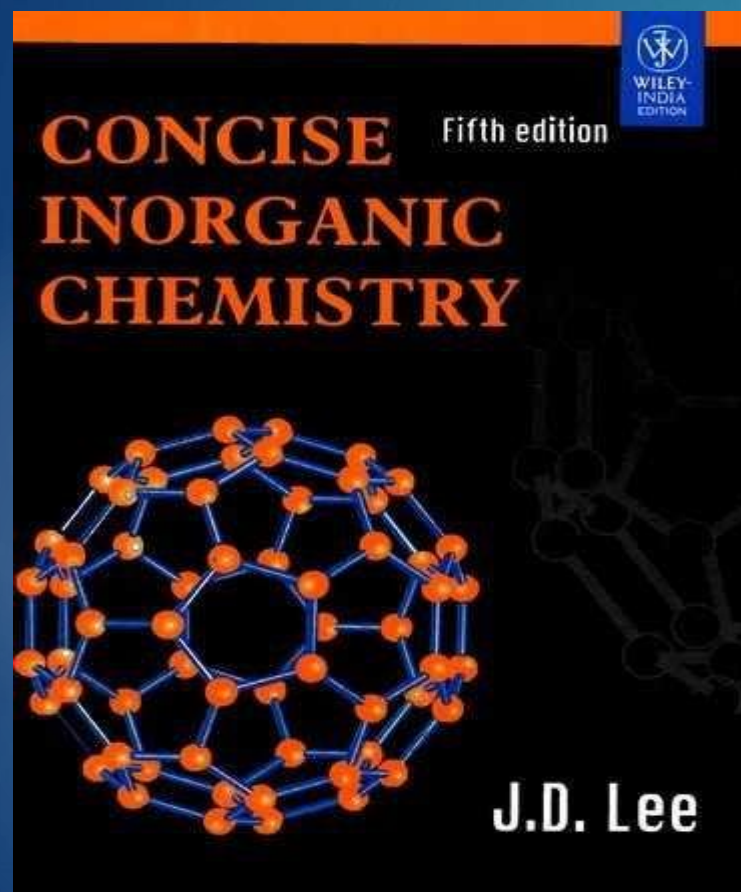


CHE2415: Basic Inorganic Chemistry



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Periodic Patterns in the Main-Group Elements

Periodic Patterns in the Main-Group Elements

1. **Hydrogen, the Simplest Atom**
2. **Trends Across the Periodic Table: The Period 2 Elements**
3. **Group 1A(1): The Alkali Metals**
4. **Group 2A(2): The Alkaline Earth Metals**
5. **Group 3A(13): The Boron Family**

Group Trends

Hydrogen

- ❖ Hydrogen has a very simple structure:
 - ▶ the nucleus has a single positive charge, and has 1 electron.
- ❖ Hydrogen is the most abundant element in the universe.
- ❖ Hydrogen exists as a diatomic gas, H_2 .
 - ▶ H_2 is colorless and odorless with very low melting and boiling points.
- ❖ H is abundant in combination with oxygen as H_2O .

Where does hydrogen belong?

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	1A	2A	3A	4A	5A	6A	7A	8A
	(1)	(2)	(13)	(14)	(15)	(16)	(17)	(18)
1	H			H			H	
2								
3								
4								
5								
6								
7								

Hydrogen and the Alkali Metals

- ❖ Like the Group 1A(1) elements, hydrogen
 - ▶ has an outer electron configuration of ns^1 ,
 - ▶ has a single valence electron, and
 - ▶ has a common +1 oxidation state.
- ❖ Unlike the alkali metals, hydrogen
 - ▶ **shares** electrons with nonmetals rather than transferring e^- to them.
 - ▶ has a much higher ionization energy than any alkali metal, due to its small size.

Hydrogen and Group 4A

- ❖ Like the Group 4A(1) elements, H has a half-filled valence level.
- ❖ H is similar to the other Group 4A elements in terms of
 - ▶ ionization energy,
 - ▶ electron affinity,
 - ▶ electronegativity, and
 - ▶ bond energies.

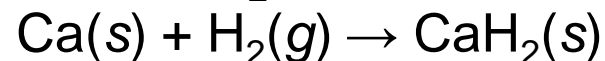
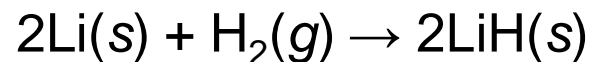
Hydrogen and the Halogens

- ❖ Like the halogens or Group 7A(17), hydrogen
 - ▶ exists as a diatomic molecule and
 - ▶ needs only 1 electron to fill its valence shell.
- ❖ Unlike the halogens
 - ▶ H has a much lower electronegativity than any halogen,
 - ▶ H lacks the three valence e^- pairs that halogens have, and
 - ▶ halide ions (X^-) are common and stable, but the hydride ion (H^-) is rare and reactive.

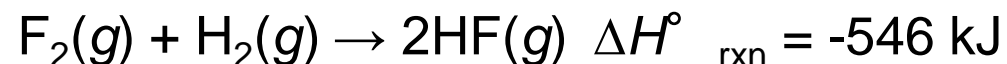
Highlights of Hydrogen Chemistry

Ionic (saltlike) hydrides form when hydrogen reacts with very reactive metals.

These hydrides are white, crystalline solids.



Covalent (molecular) hydrides form when hydrogen reacts with nonmetals. In most covalent hydrides, hydrogen has an oxidation number of +1.



Highlights of Hydrogen Chemistry

Many transition metals form ***metallic (interstitial) hydrides***, in which H_2 molecules and H atoms occupy the holes in the crystal structure of the metal.

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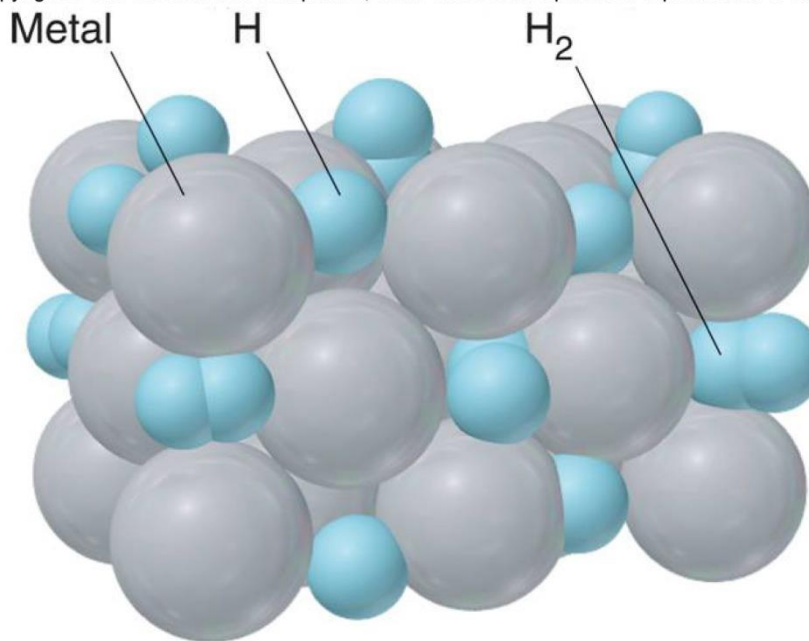


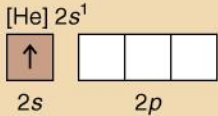
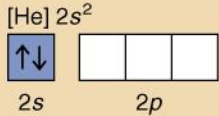
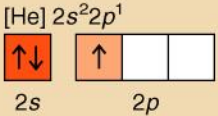
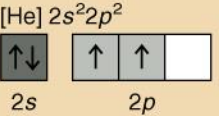




Figure 14.2 A metallic (interstitial) hydride.

Trends for the Period 2 Elements

- ❖ Atomic size generally decreases across the period.
- ❖ Ionization energy and electronegativity decrease across the period.
- ❖ Metallic character decreases across the period.
 - The type of bonding exhibited changes with metallic character.
- ❖ Oxides of the elements become more acidic across the period.
- ❖ Reducing strength decreases through the metals, and oxidizing strength increases through the nonmetals.

Trends in Atomic, Physical, and Chemical Properties of the Period 2 Elements.

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Group: Element/At. No.:	1A(1) Lithium (Li) Z = 3	2A(2) Beryllium (Be) Z = 4	3A(13) Boron (B) Z = 5	4A(14) Carbon (C) Z = 6
Atomic Properties				
Condensed electron configuration; partial orbital diagram	[He] 2s ¹ 	[He] 2s ² 	[He] 2s ² 2p ¹ 	[He] 2s ² 2p ² 
Physical Properties				
Appearance				
Metallic character	Metal	Metal	Metalloid	Nonmetal
Hardness	Soft	Hard	Very hard	Graphite: soft Diamond: extremely hard
Melting point/ boiling point	Low mp for a metal	High mp	Extremely high mp	Extremely high mp

Trends in Atomic, Physical, and Chemical Properties of the Period 2 Elements.

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Group: Element/At. No.:	1A(1) Lithium (Li) Z = 3	2A(2) Beryllium (Be) Z = 4	3A(13) Boron (B) Z = 5	4A(14) Carbon (C) Z = 6
Chemical Properties				
General reactivity	Reactive	Low reactivity at room temperature	Low reactivity at room temperature	Low reactivity at room temperature; graphite more reactive
Bonding among atoms of element	Metallic	Metallic	Network covalent	Network covalent
Bonding with nonmetals	Ionic	Polar covalent	Polar covalent	Covalent (π bonds common)
Bonding with metals	Metallic	Metallic	Polar covalent	Polar covalent
Acid-base behavior of common oxide	Strongly basic	Amphoteric	Very weakly acidic	Very weakly acidic
Redox behavior (O.N.)	Strong reducing agent (+1)	Moderately strong reducing agent (+2)	Complex hydrides good reducing agents (+3, -3)	Every oxidation state from +4 to -4
Relevance/Uses of Element and Compounds				
	Li soaps for auto grease; thermonuclear bombs; high-voltage, low-weight batteries; treatment of bipolar disorders (Li_2CO_3)	Rocket nose cones; alloys for springs and gears; nuclear reactor parts; x-ray tubes	Cleaning agent (borax); eyewash, antiseptic (boric acid); armor (B_4C); borosilicate glass; plant nutrient	Graphite: lubricant, structural fiber Diamond: jewelry, cutting tools, protective films Limestone (CaCO_3) Organic compounds: drugs, fuels, textiles, biomolecules, etc.

Trends in Atomic, Physical, and Chemical Properties of the Period 2 Elements.

15

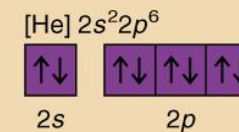
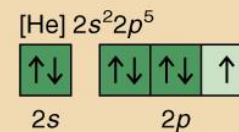
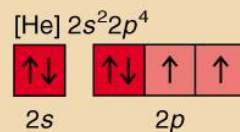
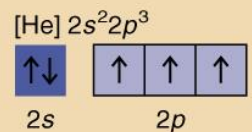
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5A(15)
Nitrogen (N) Z = 7

6A(16)
Oxygen (O) Z = 8

7A(17)
Fluorine (F) Z = 9

8A(18)
Neon (Ne) Z = 10



Nonmetal

—

Very low mp
and bp



Nonmetal

—

Very low mp
and bp



Nonmetal

—

Very low mp
and bp



Nonmetal

—

Extremely low mp
and bp

Trends in Atomic, Physical, and Chemical Properties of the Period 2 Elements.

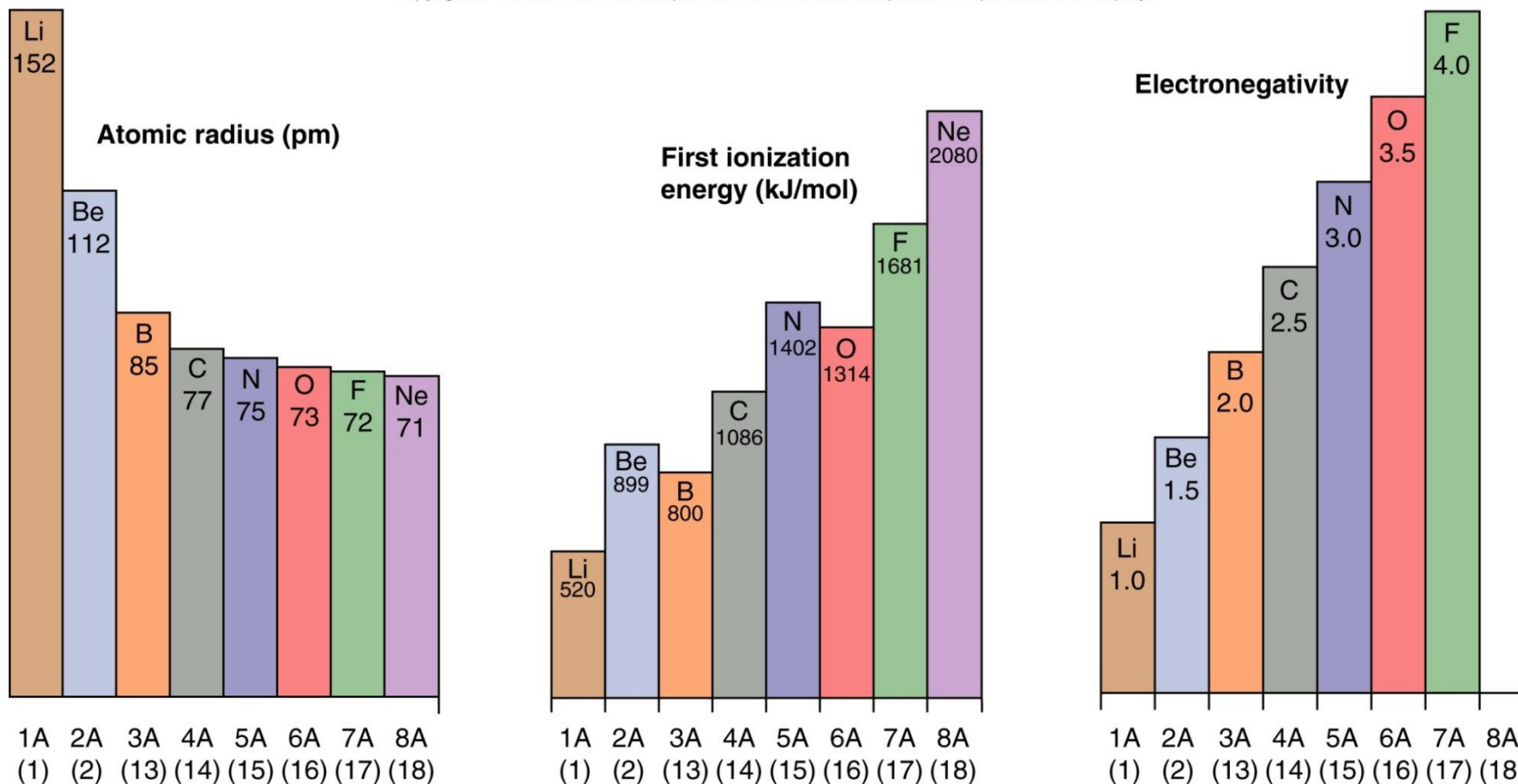
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5A(15) Nitrogen (N) Z = 7 **6A(16)** Oxygen (O) Z = 8 **7A(17)** Fluorine (F) Z = 9 **8A(18)** Neon (Ne) Z = 10

Inactive at room temperature	Very reactive	Extremely reactive	Chemically inert
Covalent N ₂ molecules	Covalent O ₂ (or O ₃) molecules	Covalent F ₂ molecules	None; separate atoms
Covalent (π bonds common)	Covalent (π bonds common)	Covalent	None
Ionic/polar covalent; anions with active metals	Ionic	Ionic	None
Strongly acidic (NO ₂)	—	Acidic	None
Every oxidation state from +5 to -3	O ₂ (and O ₃) very strong oxidizing agents (-2)	Strongest oxidizing agent (-1)	None
Component of proteins, nucleic acids; ammonia for fertilizers, explosives; oxides involved in manufacturing and air pollution (smog, acid rain)	Component of biological macromolecules; final oxidizer in residential, industrial, and biological energy production	Manufacture of coatings (Teflon); glass etching (HF); refrigerants involved in ozone depletion (CFCs); dental protection (NaF, SnF ₂)	Electrified gas in advertising signs

Trends in Atomic, Physical, and Chemical Properties of the Period 2 Elements.

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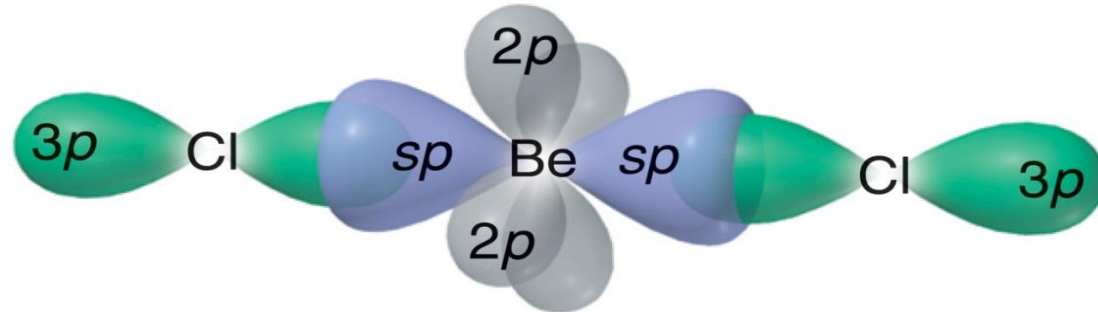
Trends in atomic radius, ionization energy, and electronegativity across Period 2.

Anomalous Behavior in Period 2

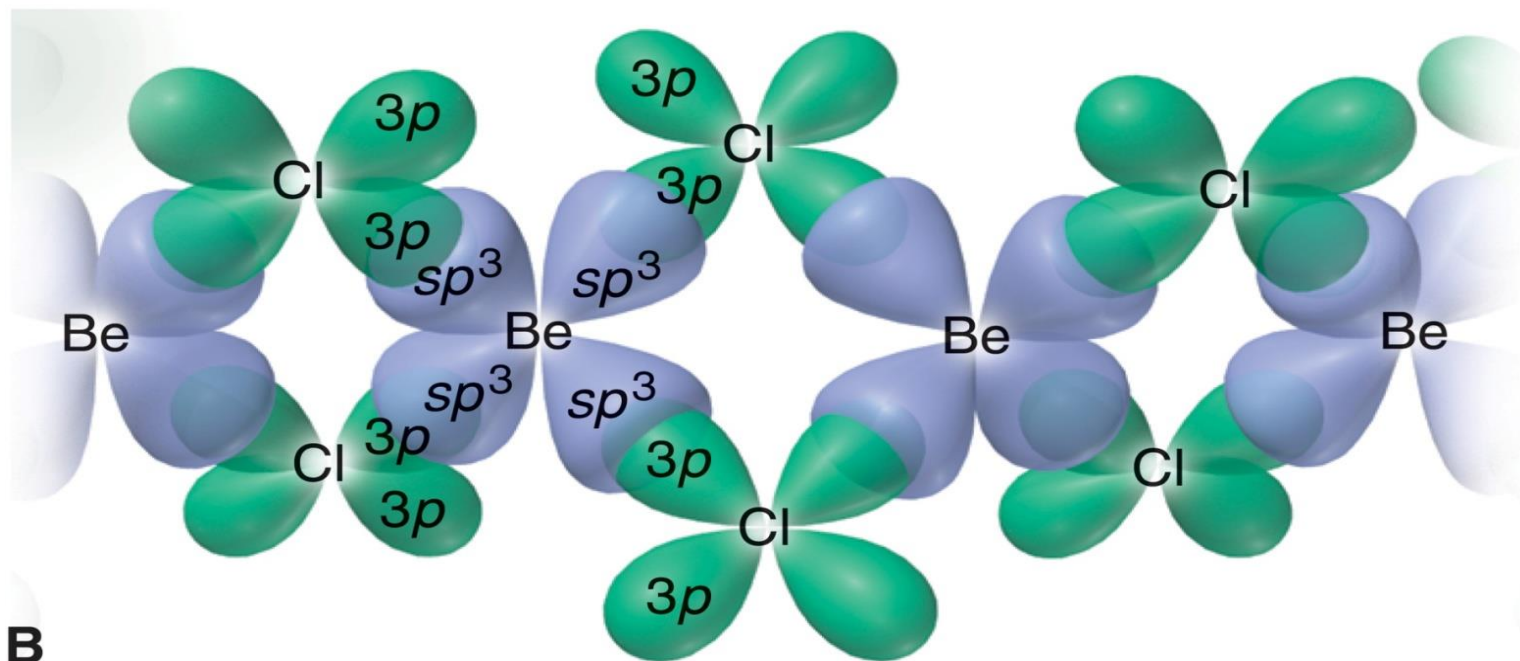
- ❖ Anomalous behavior in some Period 2 elements is due to their relatively small size and small number of valence orbitals.
- ❖ **Lithium** is the only element in Period 2 that forms a simple oxide and nitride.
- ❖ All **beryllium** compounds exhibit **covalent** bonding. This is due to the high charge density of Be^{2+} .
- ❖ **Boron** forms a complex family of compounds with metals, and covalent compounds with hydrogen called **boranes**

Overcoming electron deficiency in beryllium chloride.

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A



B

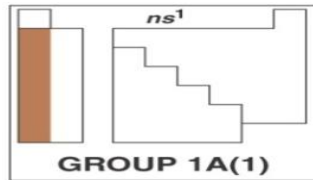
Anomalous Behavior in Period 2

- ❖ **Carbon** bonds to itself extensively and gives rise to organic compounds.
- ❖ **Nitrogen** is a triple-bonded, unreactive gas and is very different from the other Group 5A elements, which are reactive solids.
- ❖ **Oxygen** is the only gas in Group 6A and is much more reactive than the other members of its group.
- ❖ **Fluorine** is much more electronegative than the other halogens. It reacts violently with water, and HF is a **weak** acid where other hydrohalic acids are strong.

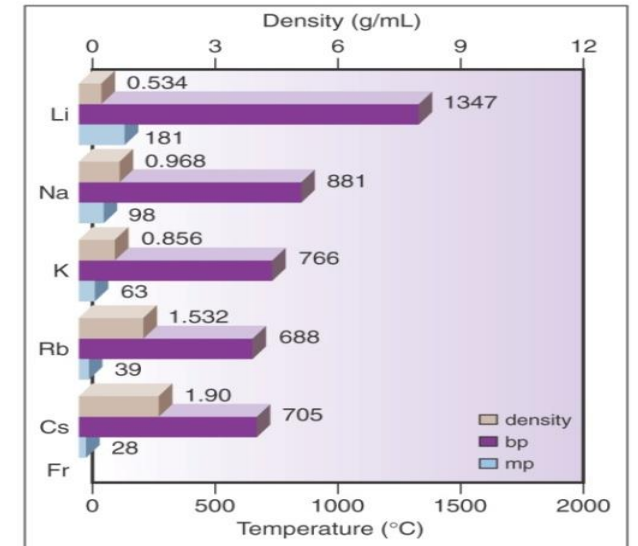
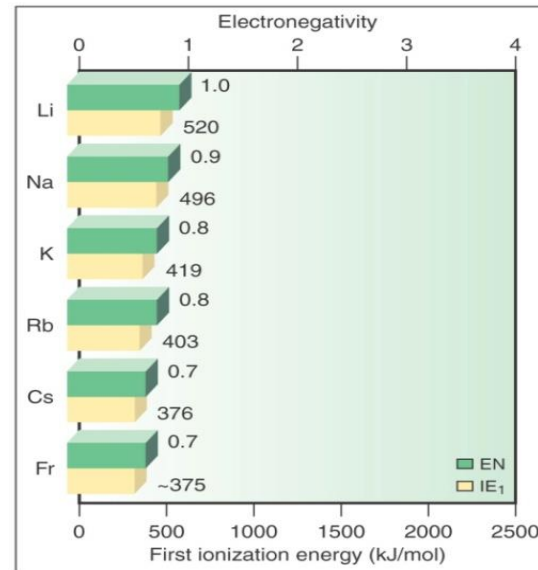
Group 1A(1): The Alkali Metals

KEY ATOMIC PROPERTIES and PHYSICAL PROPERTIES

KEY	Atomic No.	Symbol	Atomic mass	Valence e ⁻ configuration (Common oxidation states)	Image
	3	Li	6.941	2s ¹ (+1)	
	11	Na	22.99	3s ¹ (+1)	
	19	K	39.10	4s ¹ (+1)	
	37	Rb	85.47	5s ¹ (+1)	
	55	Cs	132.9	6s ¹ (+1)	
	87	Fr	(223)	7s ¹ (+1)	No sample available



Atomic radius (pm)		Ionic radius (pm)
Li		Li ⁺ 76
Na		Na ⁺ 102
K		K ⁺ 138
Rb		Rb ⁺ 152
Cs		Cs ⁺ 167
Fr		Fr ⁺ 180



GROUP 1A(1): REACTIONS

- ❖ Alkali metals are ***powerful reducing agents***.
 - ▶ They always occur in nature as +1 cations rather than as free metals.
- ❖ Alkali metals reduce halogens to form ionic solids:
 - ▶ $2E(s) + X_2 \rightarrow 2EX(s)$ (X = F, Cl, Br, I and E is the alkali metal).
- ❖ Alkali metals react vigorously with H₂O:
 - ▶ $2E(s) + H_2O(l) \rightarrow 2E^+(aq) + 2OH^-(aq) + H_2(g)$
- ❖ Alkali metals reduce H₂ to form ionic hydrides.
 - ▶ $2E(s) + H_2(g) \rightarrow 2EH(s)$
- ❖ Alkali metals reduce O₂ in air, and tarnish rapidly.

Properties of the Alkali Metals

- ❖ Alkali metals are the largest elements in their respective periods and their valence electron configuration is ns^1 .
 - The valence e^- is relatively far from the nucleus, resulting in weak metallic bonding.
- ❖ Alkali metals are unusually soft for metals. They can be cut easily with a knife.
- ❖ Alkali metals have lower melting and boiling points than any other group of metals.
- ❖ Alkali metals have lower densities than most metals.

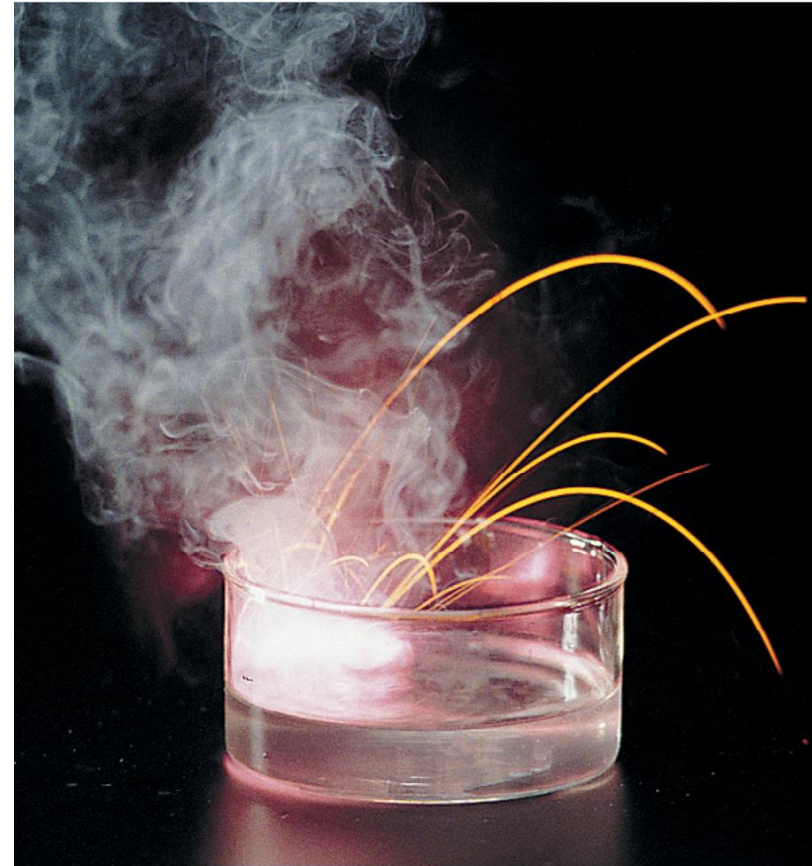
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Lithium floating in oil floating on water. Alkali metals have low densities.

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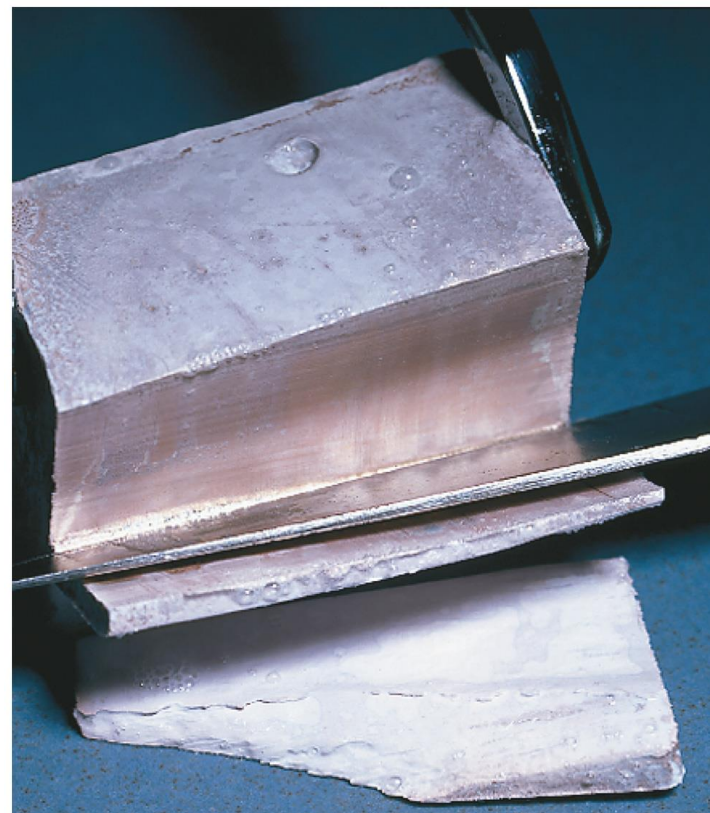


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Potassium reacting with water. Alkali metals are very reactive.

Alkali Metals

- ❖ Soft, metallic solids.
- ❖ Name comes from Arabic word for ashes.

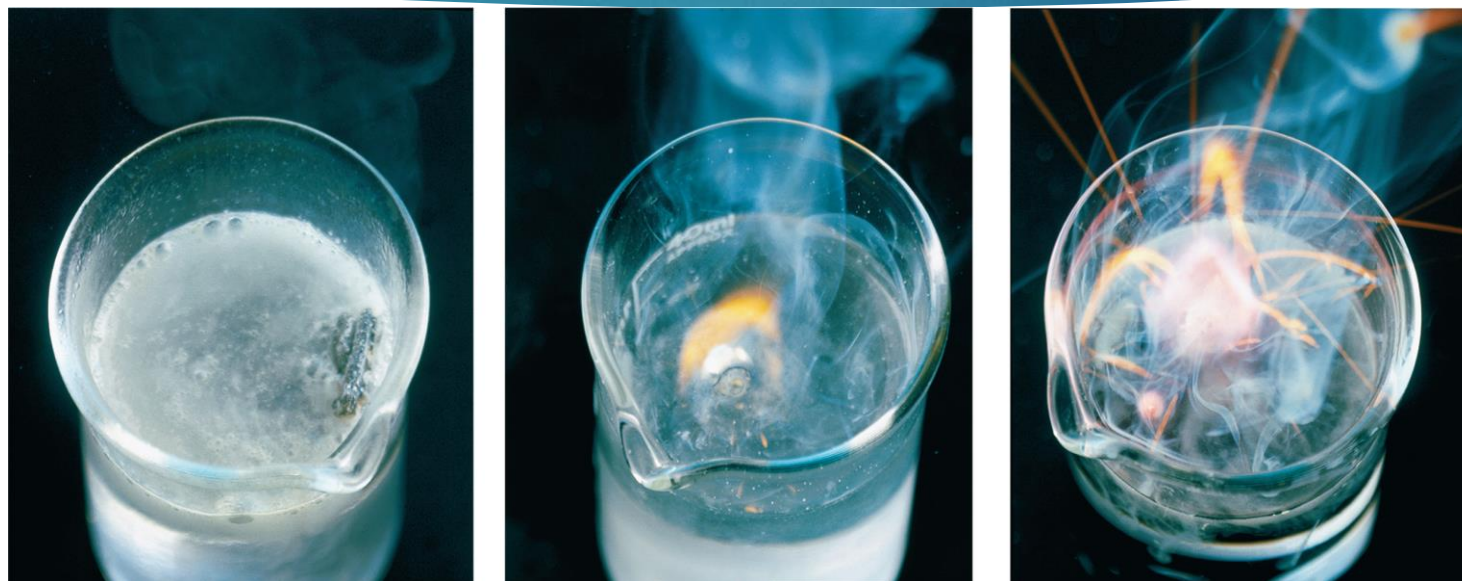


Alkali Metals

- ❖ Found only as compounds in nature.
- ❖ Have low densities and melting points.
- ❖ Also have low ionization energies.

Element	Electron Configuration	Melting Point (°C)	Density (g/cm ³)	Atomic Radius (Å)	I_1 (kJ/mol)
Lithium	[He]2s ¹	181	0.53	1.34	520
Sodium	[Ne]3s ¹	98	0.97	1.54	496
Potassium	[Ar]4s ¹	63	0.86	1.96	419
Rubidium	[Kr]5s ¹	39	1.53	2.11	403
Cesium	[Xe]6s ¹	28	1.88	2.25	376

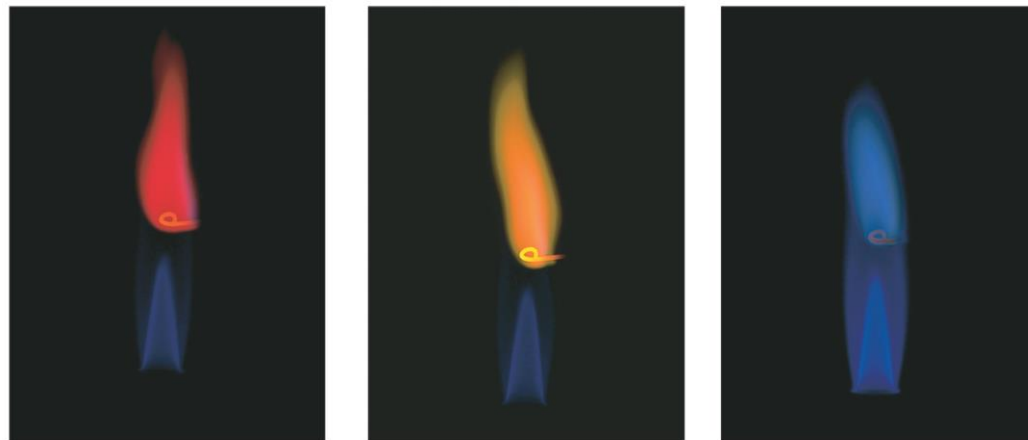
Alkali Metals



Their reactions with water are famously exothermic.

Alkali Metals

- ❖ Alkali metals (except Li) react with oxygen to form peroxides.
- ❖ K, Rb, and Cs also form superoxides:
$$K + O_2 \longrightarrow KO_2$$
- ❖ Produce bright colors when placed in flame.



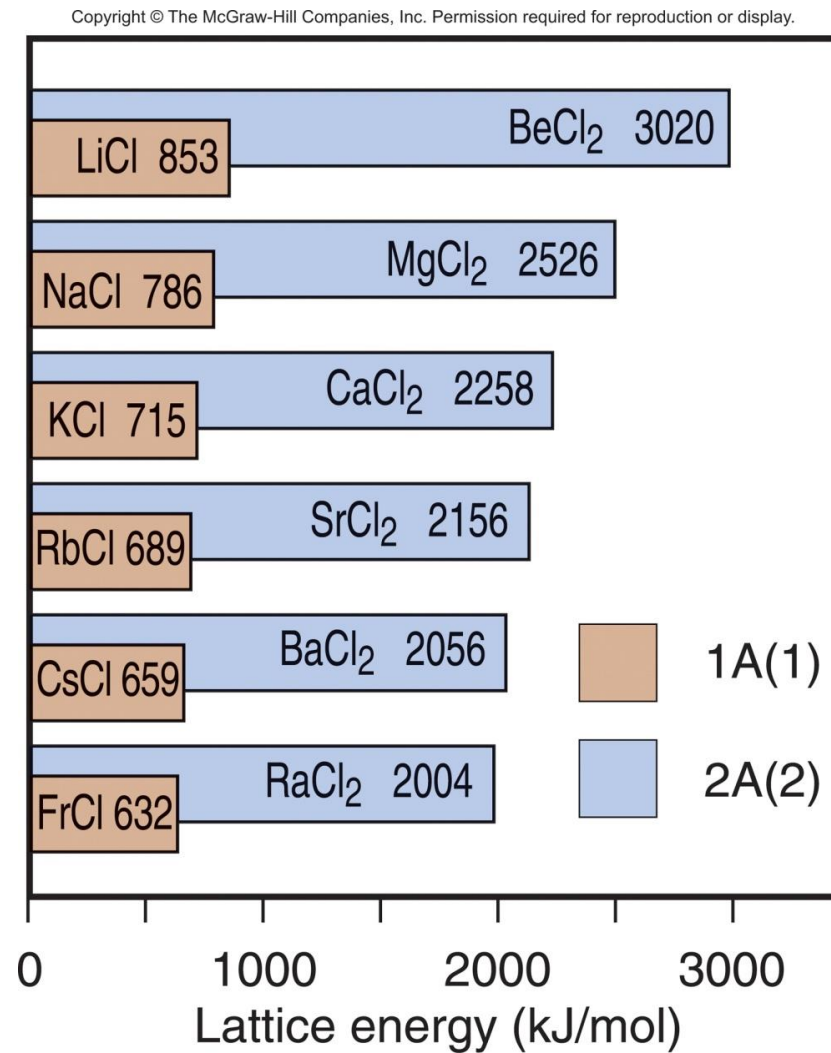
Alkaline Earth Metals

Element	Electron Configuration	Melting Point (°C)	Density (g/cm ³)	Atomic Radius (Å)	I_1 (kJ/mol)
Beryllium	[He]2s ²	1287	1.85	0.90	899
Magnesium	[Ne]3s ²	650	1.74	1.30	738
Calcium	[Ar]4s ²	842	1.55	1.74	590
Strontium	[Kr]5s ²	777	2.63	1.92	549
Barium	[Xe]6s ²	727	3.51	1.98	503

- ❖ Have higher densities and melting points than alkali metals.
- ❖ Have low ionization energies, but not as low as alkali metals.

Lattice energies of the Group 1A(1) and 2A(2) chlorides.

Lattice energy increases as the size of the cation decreases and its charge increases.



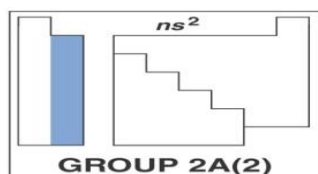
Group 2A(2): The Alkaline Earth Metals







- ❖ The oxides of Group 2A(2) elements form basic solutions and melt at extremely high temperatures.
- ❖ Group 2A(2) elements have higher ionization energies than Group 1A(1) elements
 - due to their higher effective nuclear charge and smaller size.
- ❖ Group 2A(2) elements are strong reducing agents.

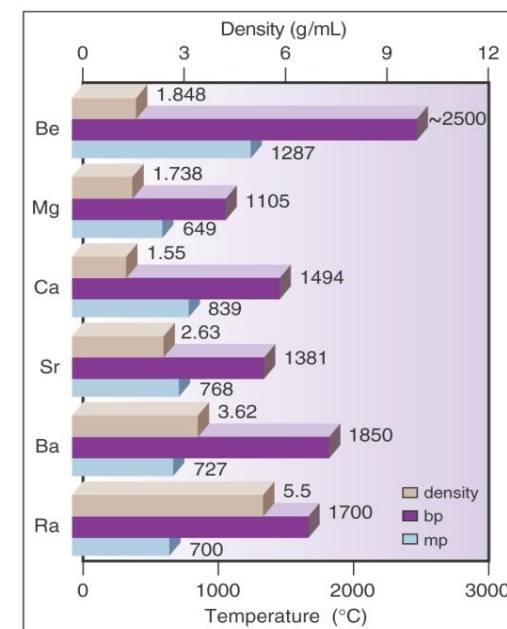
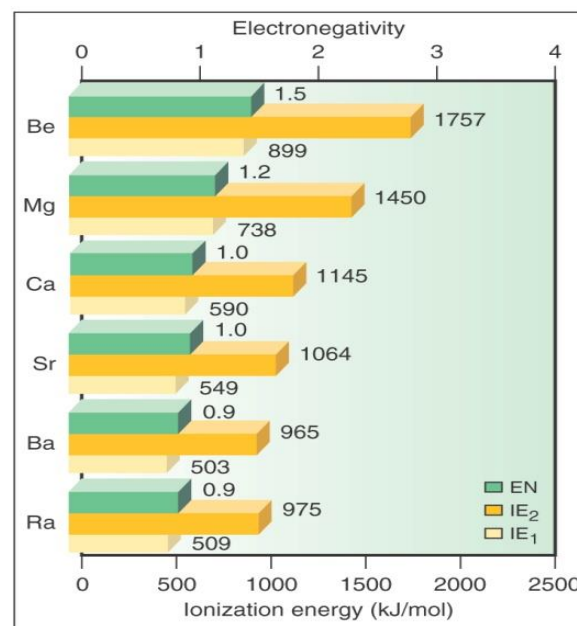
Group 2A(2): The Alkaline Earth Metals

KEY ATOMIC PROPERTIES, and PHYSICAL PROPERTIES

KEY	Atomic No. Symbol Atomic mass Valence e ⁻ configuration (Common oxidation states)	
4 Be 9.012 2s ² (+2)		
12 Mg 24.30 3s ² (+2)		
20 Ca 40.08 4s ² (+2)		
38 Sr 87.62 5s ² (+2)		
56 Ba 137.3 6s ² (+2)		
88 Ra (226) 7s ² (+2)		No sample available



Atomic radius (pm)		Ionic radius (pm)
Be 112		
Mg 160		Mg ²⁺ 72
Ca 197		Ca ²⁺ 100
Sr 215		Sr ²⁺ 118
Ba 222		Ba ²⁺ 135
Ra (~220)		Ra ²⁺ 148



GROUP 2A(2) REACTIONS

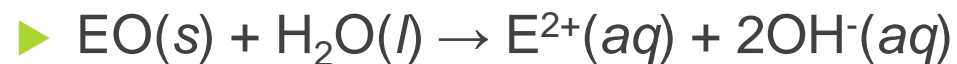
- ❖ The metals reduce O_2 to form oxides:
 - ▶ $3E(s) + O_2(g) \rightarrow 3EO(s)$
- ❖ The larger metals reduce water to form H_2 gas:
 - ▶ $2E(s) + H_2O(l) \rightarrow 2E^{2+}(aq) + 2OH^-(aq) + H_2(g)$ (E = Ca, Sr, Ba)
- ❖ The metals reduce halogens to form ionic halides:
 - ▶ $E(s) + X_2 \rightarrow EX_2(s)$ [X = F (not with Be), Cl, Br, I]
- ❖ Most of the elements reduce H_2 to form ionic hydrides:
 - ▶ $E(s) + H_2(g) \rightarrow EH_2(s)$ (E = all except Be)

GROUP 2A(2) REACTIONS

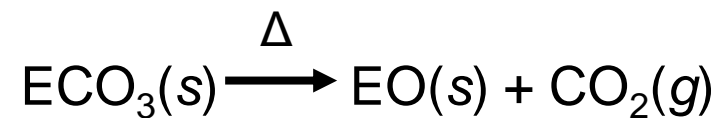
❖ The elements reduce nitrogen to form ionic nitrides:



❖ Except for BeO, the element oxides are basic:



❖ All carbonates undergo thermal decomposition:








Alkaline Earth Metals

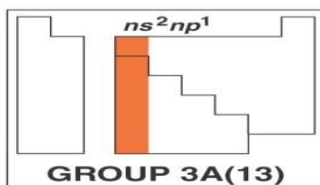
- ❖ Be does not react with water, Mg reacts only with steam, but others react readily with water.
- ❖ Reactivity tends to increase as go down group.








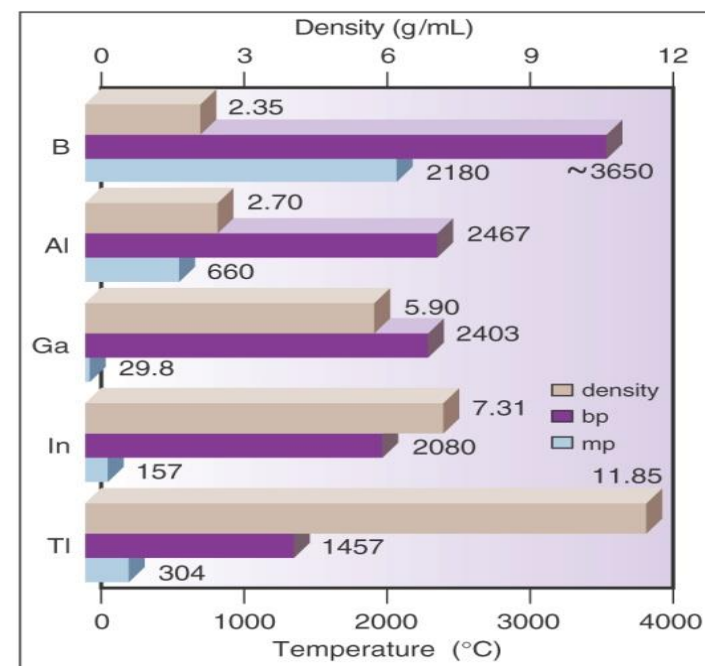
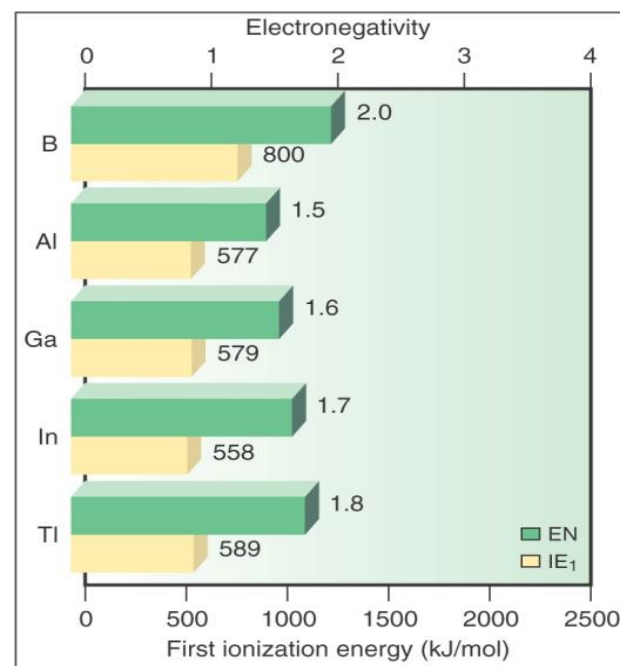
Group 3A(13): The Boron Family

KEY ATOMIC PROPERTIES and PHYSICAL PROPERTIES

KEY	Atomic No. Symbol Atomic mass Valence e ⁻ configuration (Common oxidation states)	
5 B 10.81 2s ² 2p ¹ (+3)		
13 Al 26.98 3s ² 3p ¹ (+3)		
31 Ga 69.72 4s ² 4p ¹ (+3, +1)		
49 In 114.8 5s ² 5p ¹ (+3, +1)		
81 Tl 204.4 6s ² 6p ¹ (+1)		
113 (284) 7s ² 7p ¹	Observed in experiments at Dubna, Russia, in 2003	



Atomic radius (pm)		Ionic radius (pm)
B 85		
Al 143		Al ³⁺ 54
Ga 135		Ga ³⁺ 62
In 167		In ³⁺ 80
Tl 170		Tl ⁺ 150

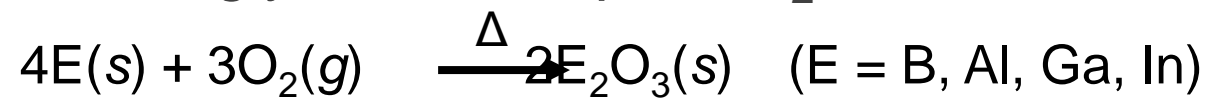


GROUP 3A(13) REACTIONS

❖ The elements react sluggishly, if at all, with water:



❖ When strongly heated in pure O_2 , all members form oxides:



❖ All members reduce halogens (X_2)



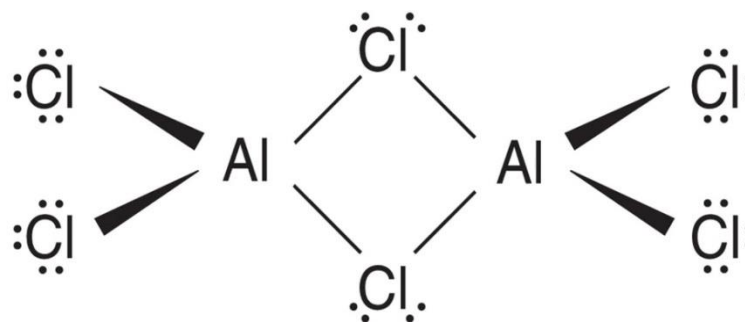
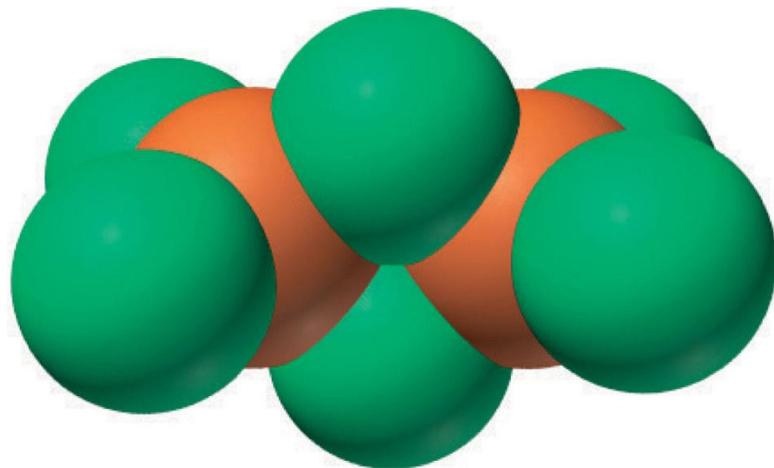
Influence of Transition Elements on Group 3A(13)

- ❖ Z_{eff} **increases** for the larger 3A elements due to poor shielding by d and f electrons.
- ❖ The larger 3A elements have **smaller** atomic radii and **larger** ionization energies than electronegativities than expected.
- ❖ These properties influence the physical and chemical behavior of these elements.

Features of Group 3A(13) Elements

- ❖ Larger Group 3A elements exhibit **multiple oxidation states**. They may lose either the np electron only, or both the np and ns electrons.
- ❖ The **lower** oxidation state becomes increasingly prominent down the group, since the ns^2 electrons form an **inert pair**.
- ❖ Oxides of the element in the **lower** oxidation state are **more basic** than oxides in the higher oxidation state.
- ❖ In_2O is more basic than In_2O_3 .

The dimeric structure of gaseous aluminum chloride.

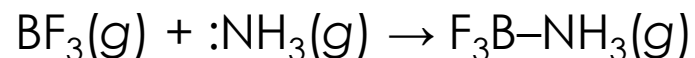


Compounds of 3A elements have more covalent character than similar 2A compounds.

Aluminum has the physical properties of a metal, but its halides exist as covalent ***dimers***.

Highlights of Boron Chemistry

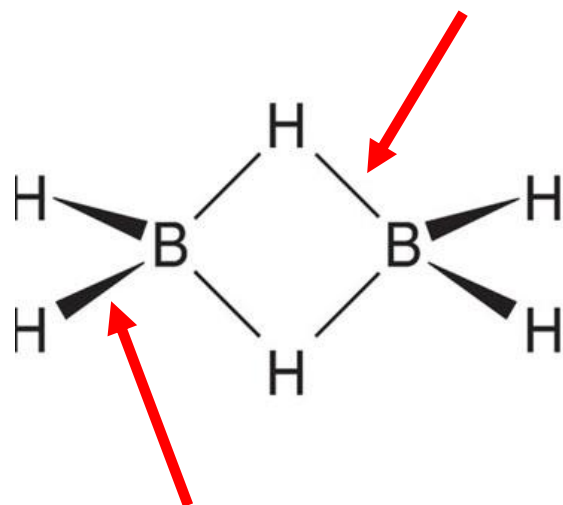
- ❖ All boron compounds are **covalent**, and B forms a variety of network covalent compounds with other elements.
- ❖ Boron is often electron-deficient in compounds, and acts effectively as a **Lewis acid** since it can accept an e⁻ pair.



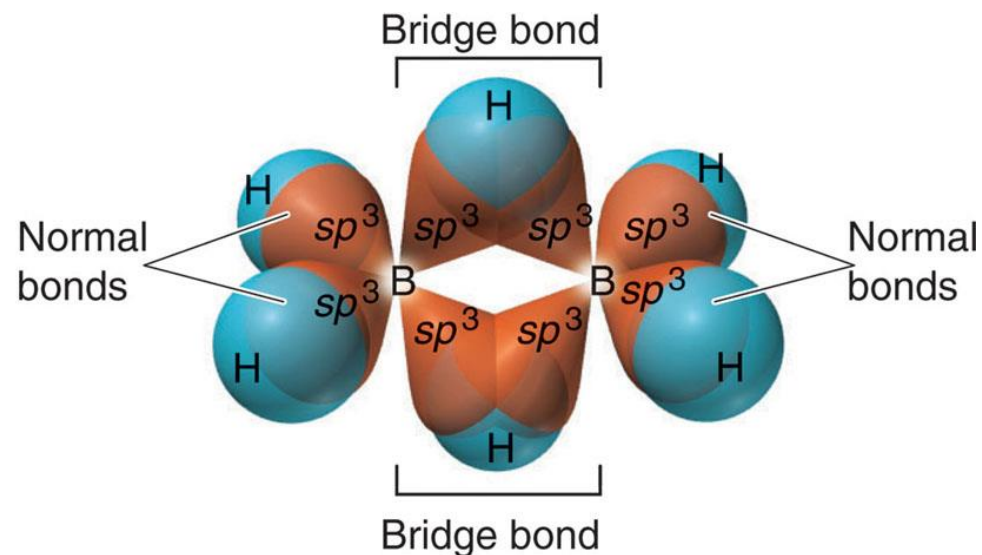
- ❖ Boron forms **bridge bonds**, in which **one pair** of electrons is shared between **three** atoms. This type of bonding is common between B and H.

The two types of covalent bonding in diborane.

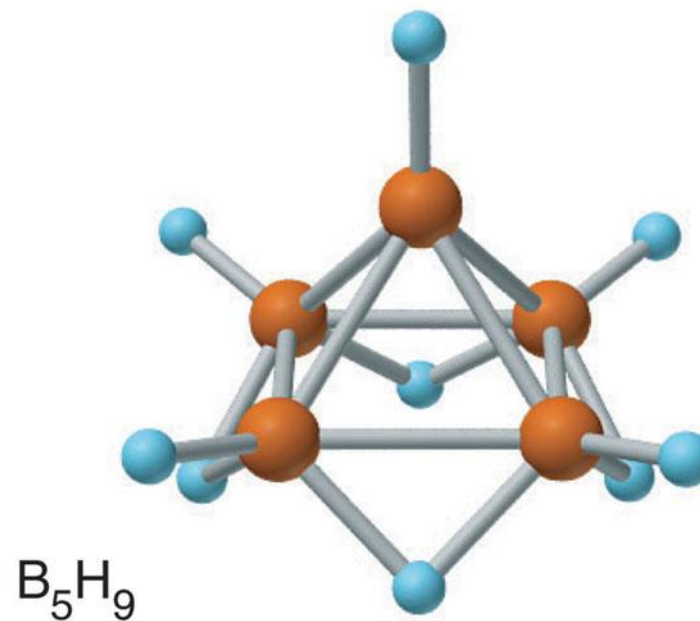
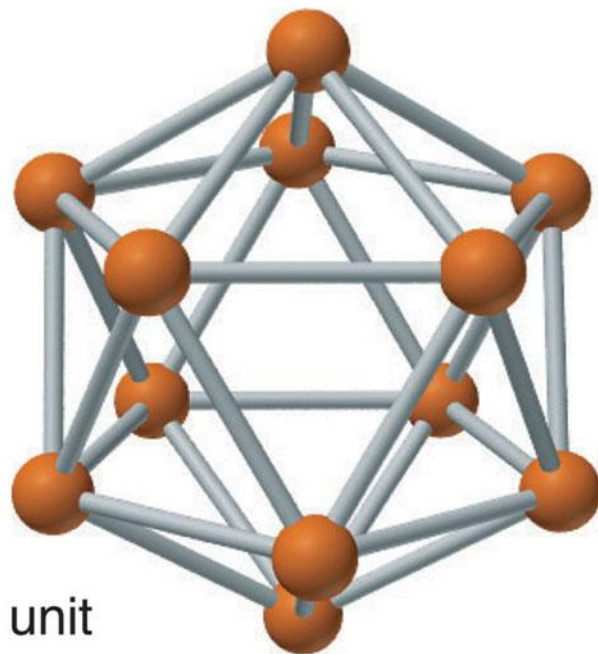
Hydride *bridge bond* , or three-center, two-electron bond.



Normal covalent bond formed by overlap of sp^3 hybrid orbital from B with s orbital from H.



The boron icosahedron and one of the boranes.



Beryllium and Aluminum

- ❖ There is a *diagonal relationship* between Be and Al.
- ❖ Both form oxoanions in strong base:
 - ▶ beryllate, $\text{Be}(\text{OH})_4^{2-}$ and aluminate, $\text{Al}(\text{OH})_4^-$.
- ❖ Both have bridge bonds in their hydrides and chlorides.
- ❖ Their oxides are
 - ▶ coatings that are impervious to water,
 - ▶ amphoteric, and
 - ▶ extremely hard with high melting points.
- ❖ **Some** Al and **all** Be compounds have significant covalent character.

Three diagonal relationships in the periodic table.

	1A (1)	2A (2)	3A (13)	4A (14)
2	Li	Be	B	
3		Mg	Al	Si