

General Chemistry – Week 7

Materials

Dr. Arne Seitz

BioImaging & Optics Platform (BIOP)
Research Core Facilities, School of Life Sciences
École Polytechnique Fédérale de Lausanne



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Recap

- Entropy
 - Measure of disorder of a system
 - The entropy of the system and the surroundings needs to be considered
- Gibbs free Energy
 - $\Delta G = \Delta H - T\Delta S$

Gibbs Free Energy and Nonexpansion Work: Applied

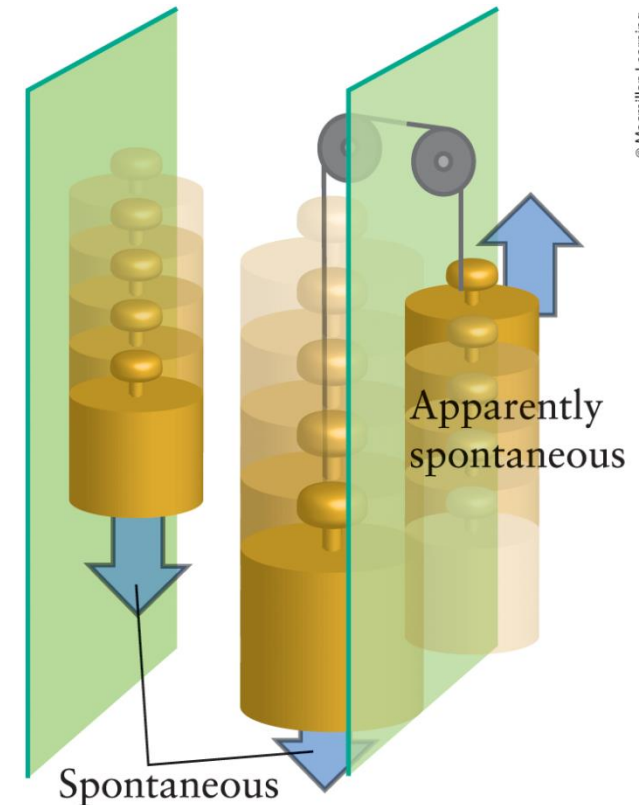
- How much nonexpansion work is done in our body in the oxidation of glucose, $\text{C}_6\text{H}_{12}\text{O}_6(\text{s, glucose}) + 6 \text{O}_2(\text{g}) \rightarrow 6 \text{CO}_2(\text{g}) + 6 \text{H}_2\text{O}(\text{l})$ to make peptide links (a link between amino acids) in a protein?
- We calculated the Gibbs free energy of reaction to be -2879 kJ per mol or 180.0 g of glucose.
- It takes 17 kJ of work to build 1 mol of peptide links in a protein.
- So 1 mole of glucose or $180. \text{ g}$ of glucose can build about $(2879 \text{ kJ})/(17 \text{ kJ}) = 170$ moles of peptide links.
- A typical protein has several hundred peptide links, and so several glucose molecules must be sacrificed to build one protein molecule.

Free Energy and Life

- Many biological reactions, such as the construction of a protein from amino acids or the construction of a DNA molecule, are not spontaneous and are driven by an external source of energy.
- That energy comes from sunlight and the chemicals in food that have stored solar energy.
- Many biological chemical reactions are nonspontaneous reactions. To make these reactions work, we must use entropy to drive a reaction forward.

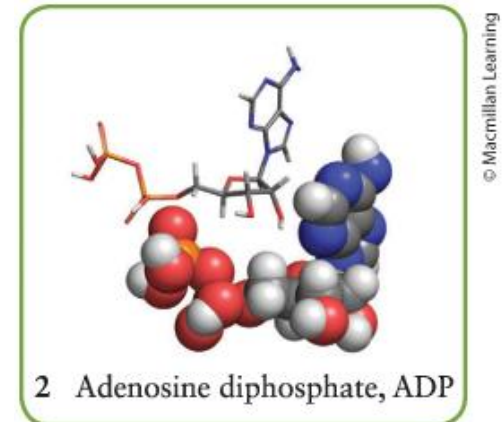
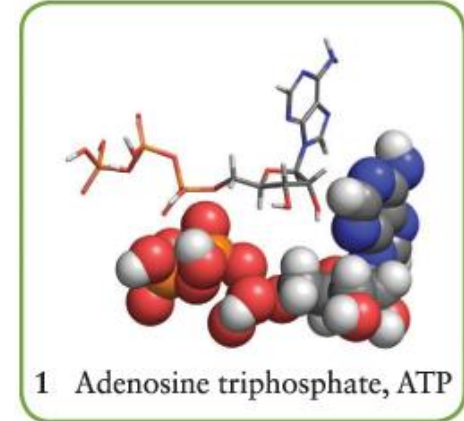
Free Energy and Life

- Staying alive is very much like using weights tied to each other over a pulley.
- The lighter weight can not move on its own.
- However, by connecting a lighter weight to a heavier weight falling, then dropping the heavy weight, the light weight can soar upward.



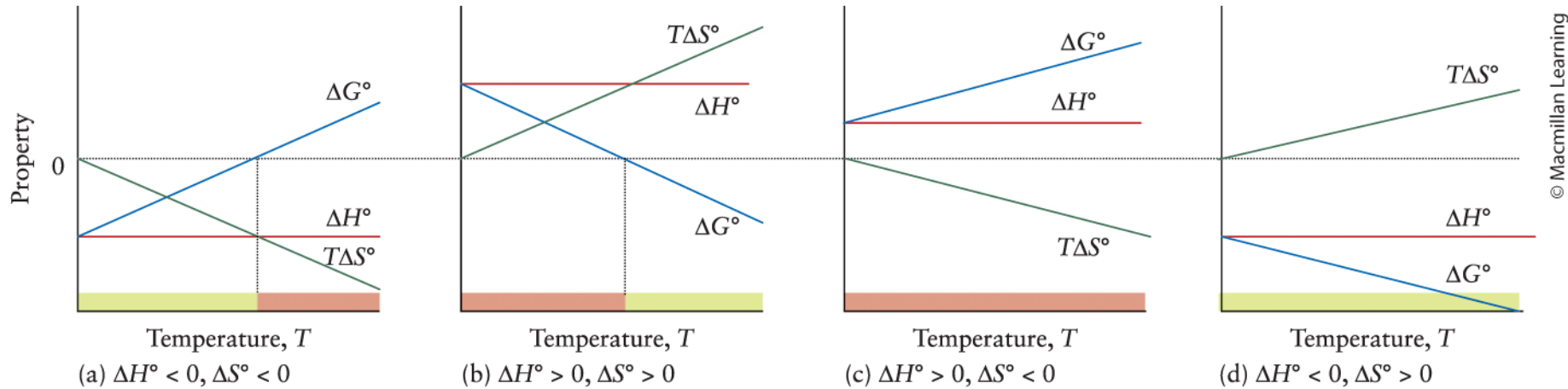
Free Energy and Life

- The hydrolysis of adenosine triphosphate, ATP, to adenosine diphosphate, ADP, is frequently how biological organisms couple and drive nonspontaneous reactions.
- To restore ADP with 2 phosphates to ATP with 3 takes +30 kJ of energy.
- We eat food in a combustion reaction that releases 2500 kJ per mole of energy per mole of glucose. Eating glucose is our heavy weight, enough to “recharge” 80 moles of ADP.
- Once we stop eating, decay begins; entropy continues forward.



The Effect of Temperature

- ΔG° does depend on temperature: $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$



Spontaneous if:

- (a) T is low (b) T is high (c) never (d) always

- Exothermic, $\Delta H^\circ < 0$ and $\Delta S^\circ < 0$, as long as T remains low, ΔG° is “–”
- Endothermic, $\Delta H^\circ > 0$ and $\Delta S^\circ > 0$, if T is high enough, ΔG° will be “–”
- Endothermic, $\Delta H^\circ > 0$ and $\Delta S^\circ < 0$, this is never spontaneous at any T
- Exothermic, $\Delta H^\circ < 0$ and $\Delta S^\circ > 0$, spontaneous at any T

EPFL The Pressure-Dependence of Gibbs Free Energy

- The Gibbs free energy of a solid or a liquid changes very little with pressure.
- However, the pressure dependence of the Gibbs free energy of a gas is significant.

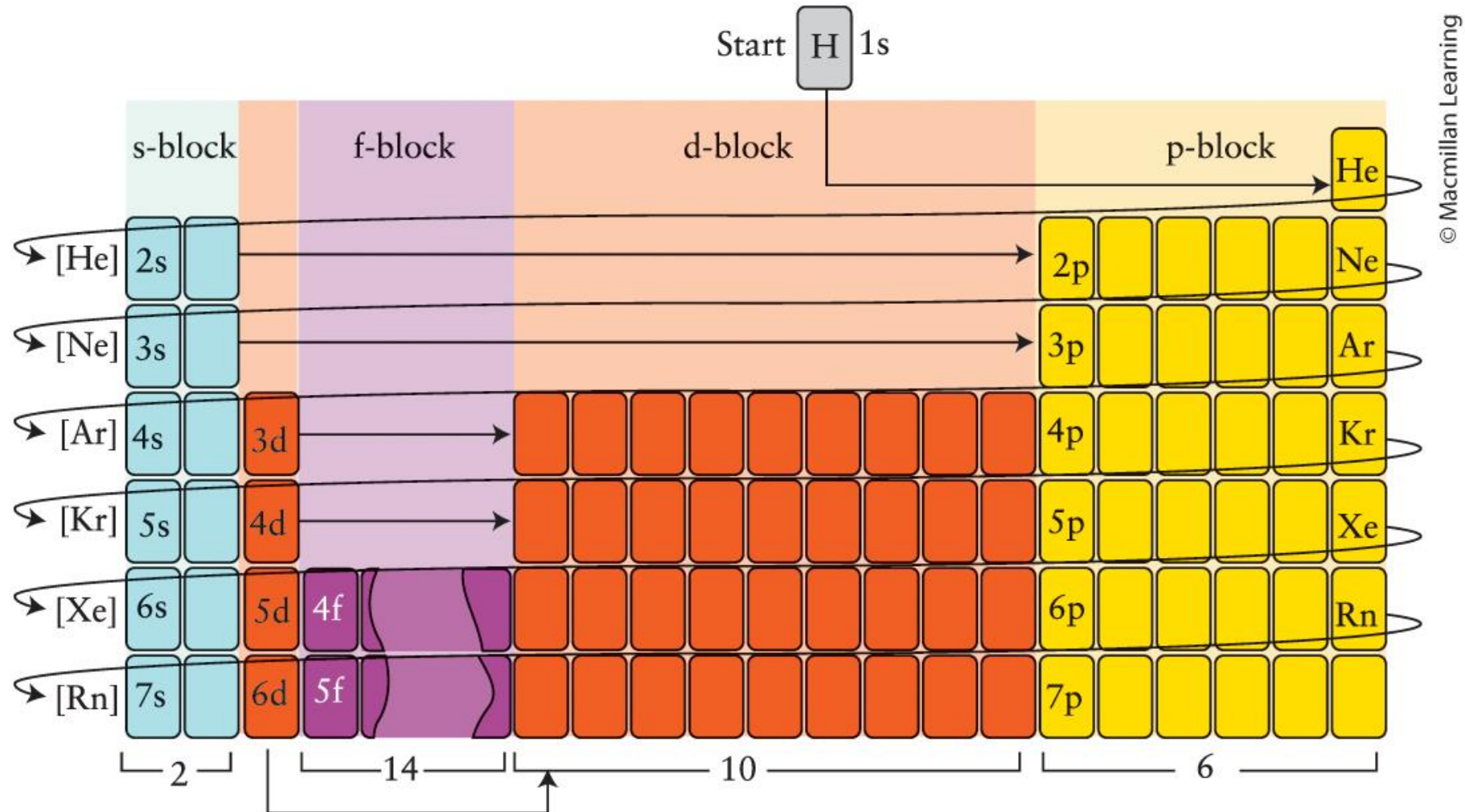
Periodic Table of Elements

1 H Hydrogen	2 He Helium	3 Li Lithium	4 Be Beryllium	5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium	13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon	19 K Potassium	20 Ca Calcium
21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc
31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton	37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium
41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin
51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon	55 Cs Cesium	56 Ba Barium	57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium
61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium
71 Lu Lutetium	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury
81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon	87 Fr Francium	88 Ra Radium	89 Ac Actinium	90 Th Thorium
91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium
101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium
111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson	119 Uu Ununennium	120 Uub Unbibium

Learning objectives

- The following lectures survey the properties of the elements.
- We recall the principles of the periodic table of the Elements
 - Building principle of atoms
 - Electronic configuration
 - Periodicity
- We understand that an atom's property is related to its location in the periodic table.
- We explore descriptive chemistry: how to prepare and the properties and applications of elements and their compounds.

Filling Order for Orbitals



The periodic table

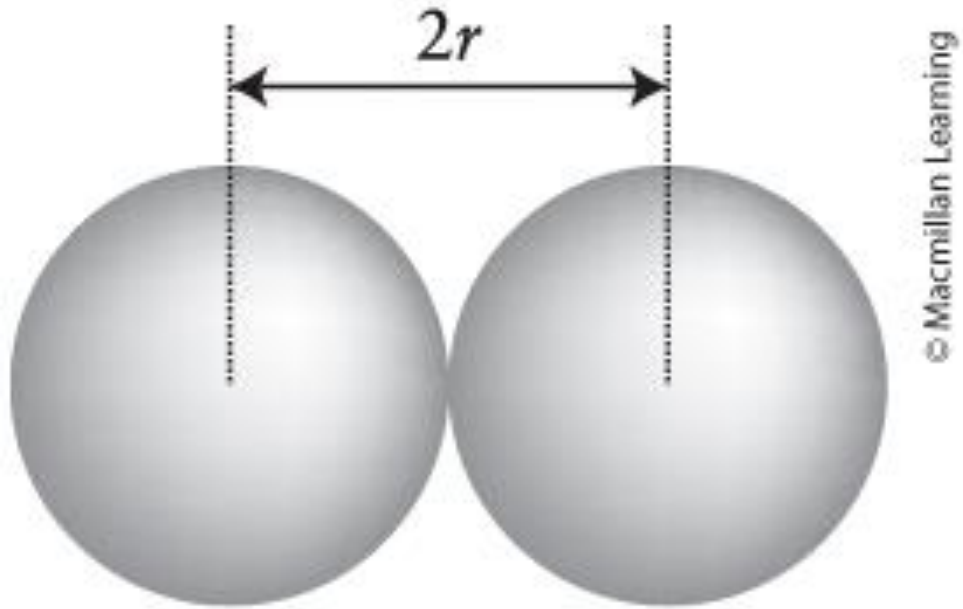
Periodic Table of the Elements

Periodic Table of the Elements																						
		Period 1																18				
		<div>H1 hydrogen 1.0080 1s¹</div>																<div>He2 helium 4.00 1s²</div>				
Group	1	2											13	14	15	16	17					
Period	2	<div>Li3 lithium 6.94 2s¹</div>	<div>Be4 beryllium 9.01 2s²</div>											<div>B5 boron 10.81 2s²2p¹</div>	<div>C6 carbon 12.01 2s²2p²</div>	<div>N7 nitrogen 14.01 2s²2p³</div>	<div>O8 oxygen 16.00 2s²2p⁴</div>	<div>F9 fluorine 19.00 2s²2p⁵</div>	<div>Ne10 neon 20.18 2s²2p⁶</div>			
	3	<div>Na11 sodium 22.99 3s¹</div>	<div>Mg12 magnesium 24.31 3s²</div>											<div>Al13 aluminum 26.98 3s²3p¹</div>	<div>Si14 silicon 28.09 3s²3p²</div>	<div>P15 phosphorus 30.97 3s²3p³</div>	<div>S16 sulfur 32.06 3s²3p⁴</div>	<div>Cl17 chlorine 35.45 3s²3p⁵</div>	<div>Ar18 argon 39.95 3s²3p⁶</div>			
	4	<div>K19 potassium 39.10 4s¹</div>	<div>Ca20 calcium 40.08 4s²</div>	<div>Sc21 scandium 44.96 3d¹4s²</div>	<div>Ti22 titanium 47.87 3d²4s²</div>	<div>V23 vanadium 50.94 3d³4s²</div>	<div>Cr24 chromium 52.00 3d⁵4s¹</div>	<div>Mn25 manganese 54.94 3d⁵4s²</div>	<div>Fe26 iron 55.84 3d⁶4s²</div>	<div>Co27 cobalt 58.93 3d⁷4s²</div>				<div>Ni28 nickel 58.69 3d⁸4s²</div>	<div>Cu29 copper 63.55 3d¹⁰4s¹</div>	<div>Zn30 zinc 65.38 3d¹⁰4s²</div>	<div>Ga31 gallium 69.72 4s²4p¹</div>	<div>Ge32 germanium 72.63 4s²4p²</div>	<div>As33 arsenic 74.92 4s²4p³</div>	<div>Se34 selenium 78.97 4s²4p⁴</div>	<div>Br35 bromine 79.90 4s²4p⁵</div>	<div>Kr36 krypton 83.80 4s²4p⁶</div>
	5	<div>Rb37 rubidium 85.47 5s¹</div>	<div>Sr38 strontium 87.62 5s²</div>	<div>Y39 yttrium 88.91 4d¹5s²</div>	<div>Zr40 zirconium 91.22 4d²5s²</div>	<div>Nb41 niobium 92.91 4d⁴5s¹</div>	<div>Mo42 molybdenum 95.95 4d⁵5s¹</div>	<div>Tc43 technetium (98) 4d⁵5s²</div>	<div>Ru44 ruthenium 101.07 4d⁷5s¹</div>	<div>Rh45 rhodium 102.91 4d⁸5s¹</div>				<div>Pd46 palladium 106.42 4d¹⁰</div>	<div>Ag47 silver 107.87 4d¹⁰5s¹</div>	<div>Cd48 cadmium 112.41 4d¹⁰5s²</div>	<div>In49 indium 114.82 5s²5p¹</div>	<div>Sn50 tin 118.71 5s²5p²</div>	<div>Sb51 antimony 121.76 5s²5p³</div>	<div>Te52 tellurium 127.60 5s²5p⁴</div>	<div>I53 iodine 126.90 5s²5p⁵</div>	<div>Xe54 xenon 131.29 5s²5p⁶</div>
	6	<div>Cs55 cesium 132.91 6s¹</div>	<div>Ba56 barium 137.33 6s²</div>	<div>La57 lanthanum 138.91 5d¹6s²</div>	<div>Hf72 hafnium 178.49 5d²6s²</div>	<div>Ta73 tantalum 180.95 5d³6s²</div>	<div>W74 tungsten 183.84 5d⁴6s²</div>	<div>Re75 rhenium 186.21 5d⁵6s²</div>	<div>Os76 osmium 190.23 5d⁶6s²</div>	<div>Ir77 iridium 192.22 5d⁷6s²</div>				<div>Pt78 platinum 195.08 5d⁹6s¹</div>	<div>Au79 gold 196.97 5d¹⁰6s¹</div>	<div>Hg80 mercury 200.59 5d¹⁰6s²</div>	<div>Tl81 thallium 204.38 6s²6p¹</div>	<div>Pb82 lead 207.2 6s²6p²</div>	<div>Bi83 bismuth 208.98 6s²6p³</div>	<div>Po84 polonium (209) 6s²6p⁴</div>	<div>At85 astatine (210) 6s²6p⁵</div>	<div>Rn86 radon (222) 6s²6p⁶</div>
	7	<div>Fr87 francium (223) 7s¹</div>	<div>Ra88 radium (226) 7s²</div>	<div>Ac89 actinium (227) 6d¹7s²</div>	<div>Rf104 rutherfordium (265) 6d²7s²</div>	<div>Db105 dubnium (268) 6d³7s²</div>	<div>Sg106 seaborgium (271) 6d⁴7s²</div>	<div>Bh107 bohrium (272) 6d⁵7s²</div>	<div>Hs108 hassium (270) 6d⁶7s²</div>	<div>Mt109 meitnerium (276) 6d⁷7s²</div>												
			Lanthanoids (lanthanides)		6	<div>Ce58 cerium 140.12 4f¹5d¹6s²</div>	<div>Pr59 praseodymium 140.91 4f³6s²</div>	<div>Nd60 neodymium 144.24 4f⁴6s²</div>	<div>Pm61 promethium (145) 4f⁵6s²</div>	<div>Sm62 samarium 150.36 4f⁶6s²</div>												
			Actinoids (actinides)		7	<div>Th90 thorium 232.04 6d²7s²</div>	<div>Pa91 protactinium 231.04 5f²6d¹7s²</div>	<div>U92 uranium 238.03 5f³6d¹7s²</div>	<div>Np93 neptunium (237) 5f⁴6d¹7s²</div>	<div>Pu94 plutonium (244) 5f⁶7s²</div>												
						<div>Eu63 europium 151.96 4f⁷6s²</div>	<div>Gd64 gadolinium 157.25 4f⁷5d¹6s²</div>	<div>Tb65 terbium 158.93 4f⁹6s²</div>	<div>Dy66 dysprosium 162.50 4f¹⁰6s²</div>	<div>Ho67 holmium 164.93 4f¹¹6s²</div>	<div>Er68 erbium 167.26 4f¹²6s²</div>	<div>Tm69 thulium 168.93 4f¹³6s²</div>	<div>Yb70 ytterbium 173.05 4f¹⁴6s²</div>	<div>Lu71 lutetium 174.97 5d¹6s²</div>								
						<div>Am95 americium (243) 5f⁷7s²</div>	<div>Cm96 curium (247) 5f⁷6d¹7s²</div>	<div>Bk97 berkelium (247) 5f⁹7s²</div>	<div>Cf98 californium (251) 5f¹⁰7s²</div>	<div>Es99 einsteinium (252) 5f¹¹7s²</div>	<div>Fm100 fermium (257) 5f¹²7s²</div>	<div>Md101 mendelevium (258) 5f¹³7s²</div>	<div>No102 nobelium (259) 5f¹⁴7s²</div>	<div>Lr103 lawrencium (262) 6d¹7s²</div>								

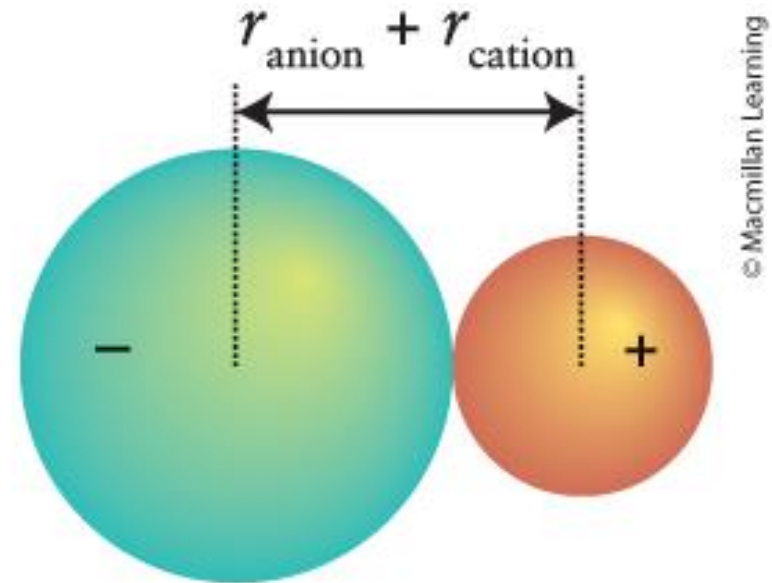
Molar masses (atomic weights) quoted to the number of significant figures given here can be regarded as typical of most naturally occurring samples.

- Valence electrons experience increasing effective nuclear charge going across a period from left to right. Valence electrons experience decreasing effective nuclear charge going down a group because the valence electrons in those shells are farther from the nucleus.
- Five atomic properties are related to effective nuclear charge.
 - atomic radius,
 - ionization energy,
 - electron affinity,
 - electronegativity, and
 - polarizability.

Atomic Radius and Ionic Radius

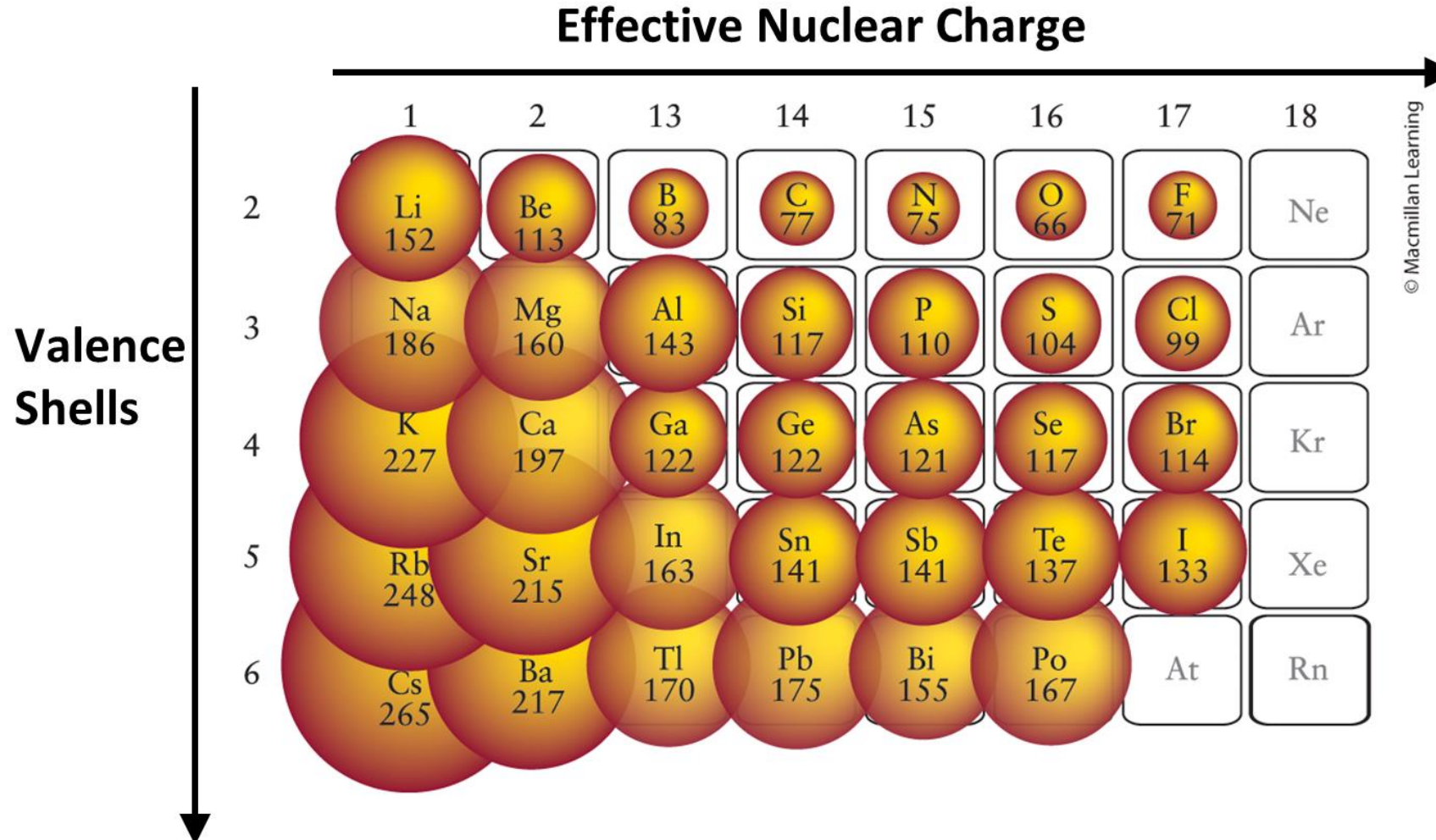


1 Atomic radius

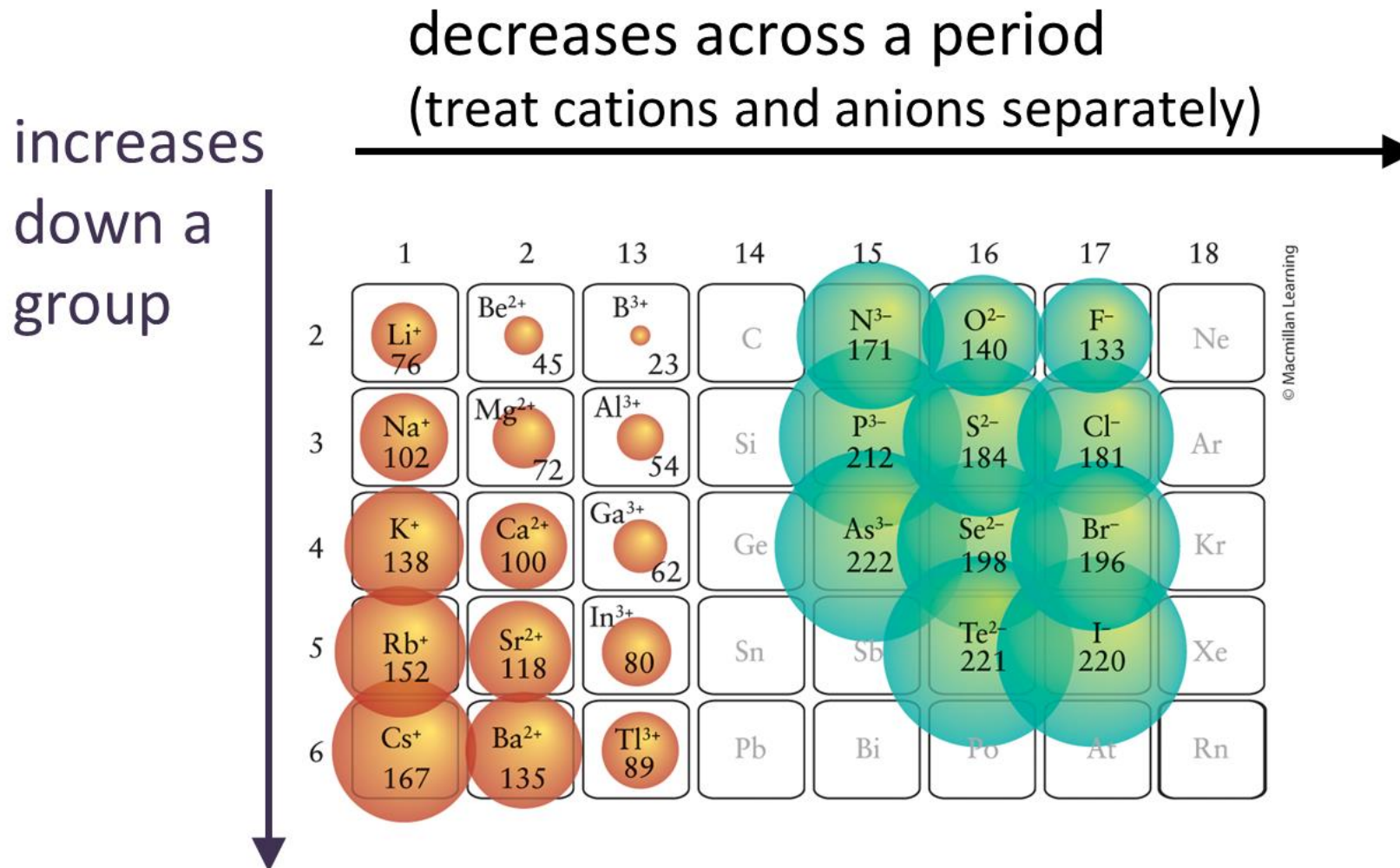


2 Ionic radius

Periodic Trend of Atomic Radius



Periodic Trend of Ionic Radius



Blocks on the Periodic Table

Blocks on the Periodic Table

- Groups 1-2 are the s-block, and groups 13-18 are the p-block. The s-block and the p-block are called main group elements.
- Groups 3-12 are the d-block.
- Within the d-block, groups 3-11 are called the transition metals representing a transition from the highly reactive s-block metals to the p-block metals.

The diagram illustrates the periodic table with the following blocks highlighted:

- s-Block:** Groups 1 and 2 (colored blue).
- d-Block:** Groups 3 through 10 (colored orange). This block is also labeled "Transition metals".
- p-Block:** Groups 13 through 18 (colored yellow).
- f-Block:** Lanthanoids (lanthanides) and Actinoids (actinides) (colored purple).

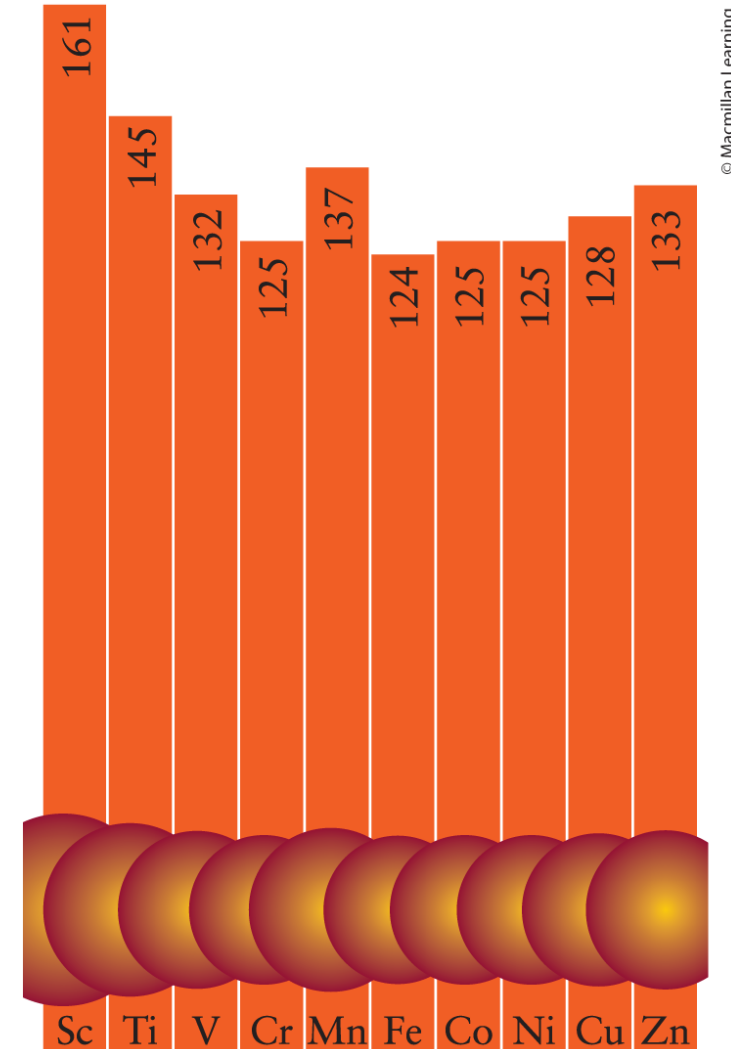
	d-Block										
	3	4	5	6	7	8	9	10	11	12	
Mg	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Al
Ca	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	Ga
Sr	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	In
Ba	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Tl
Ra											Nh

f-Block			
Ce			Lu
Th			Lr

Lanthanoids (lanthanides)
Actinoids (actinides)

Trends in Atomic Radii of d-Block Elements

- Additional d-electrons increase electron-electron repulsions more rapidly, than nuclear charge increases, so the radii increase
- Moving across a period from left to right, atomic radii of d-block elements *decrease*, then *increase* due to lack of shielding from d-orbitals.



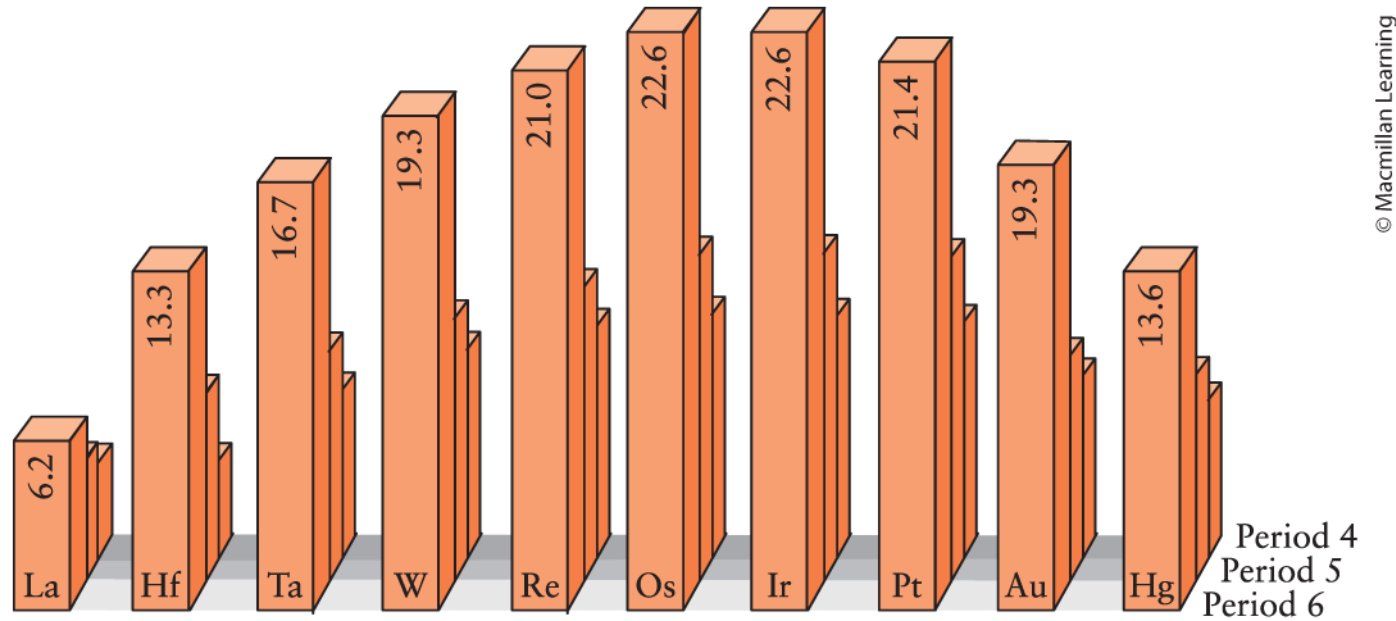
Trends in Atomic Radii of d-Block Elements

- The trends in atomic radii of d-block elements are slightly different from main-group elements.

		Group									
		3	4	5	6	7	8	9	10	11	12
Period	4	Sc 161	Ti 145	V 132	Cr 125	Mn 137	Fe 124	Co 125	Ni 125	Cu 128	Zn 133
	5	Y 181	Zr 160	Nb 143	Mo 136	Tc 136	Ru 134	Rh 134	Pd 138	Ag 144	Cd 149
	6	La 188	Hf 156	Ta 143	W 137	Re 137	Os 135	Ir 136	Pt 138	Au 144	Hg 160

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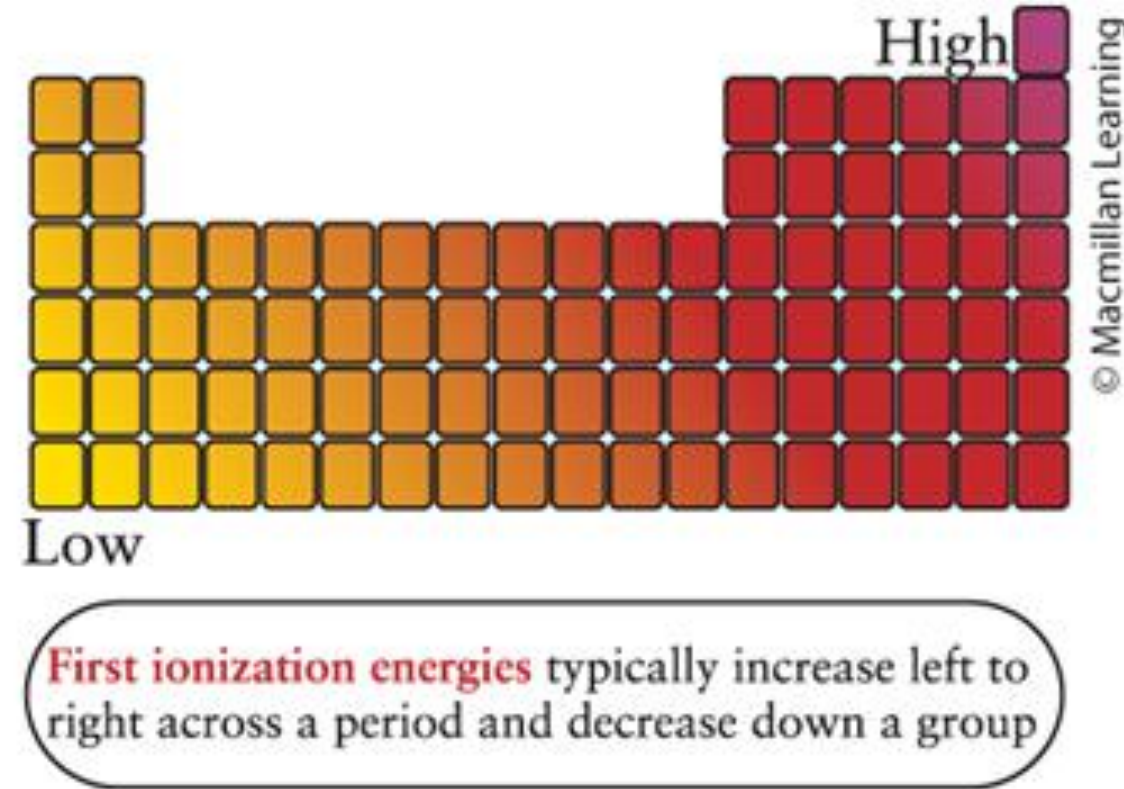
- The atomic radii of d-block elements increase from Period 4 to Period 5. However, as a result of lanthanide contraction, d-block elements in Periods 5 and 6 have similar atomic radii.



- Lanthanide contraction affects the densities of Period 6 elements.
- The atomic radii of Period 6 elements are similar to Period 5, but the atomic masses of Period 6 elements are much greater, resulting in higher densities.
- Lanthanide contraction is also the reason for the low reactivity, or “nobility,” of gold and silver.

Trends in First Ionization Energy

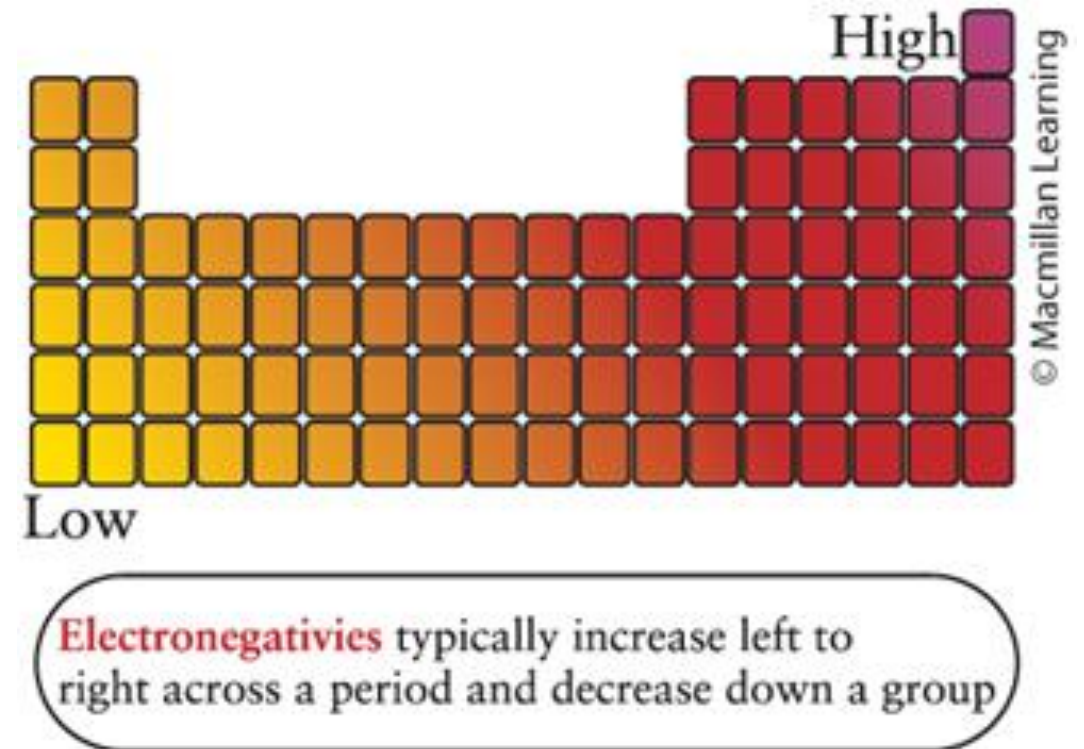
- First ionization energies typically increase from left to right across a period and decrease down a group.
- Moving across a period, the increasing effective nuclear charge grips electrons more tightly, resulting in greater first ionization energies.
- Moving down a group, the decreasing effective nuclear charge is due to additional atomic shells. The more shells, the more core electrons shield outer electrons from the nuclear charge, making it easier to remove valence electrons.



- Electron affinity is the energy released when an electron is added to a gaseous atom to form an anion.
- Periodic trends in electron affinity are not as clear as other atomic properties. However, the highest electron affinities are found at the top right of the periodic table.
- Atoms with a higher effective nuclear charge release more energy.

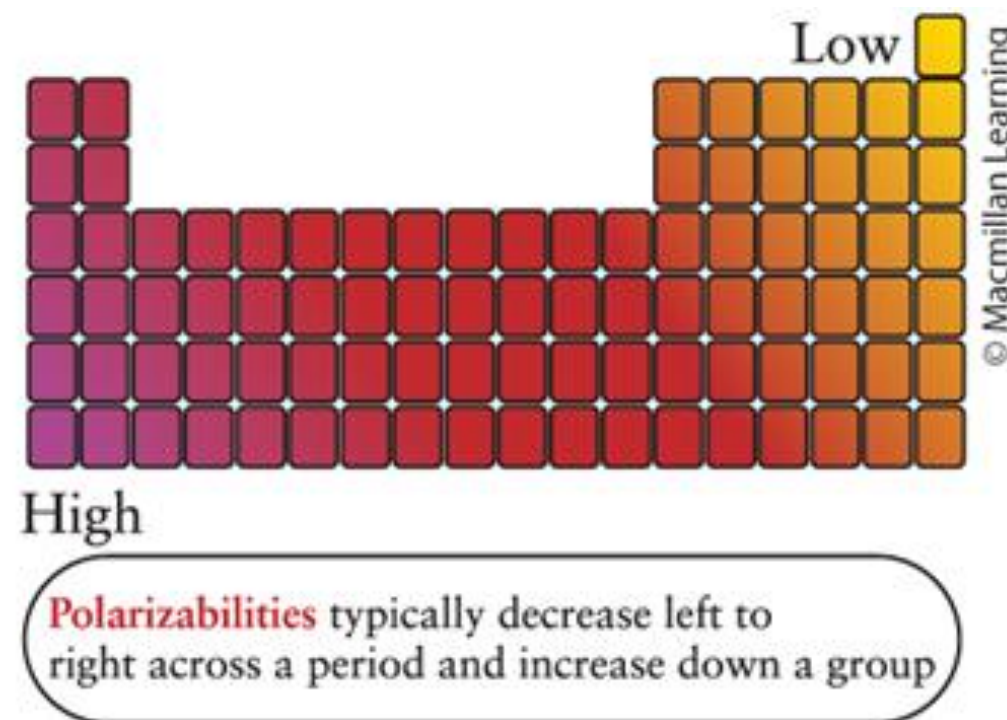
Trends in Electronegativity

- Electronegativities typically increase from left to right across a period and decrease down a group.
- Electronegativity is the tendency of an atom to attract electrons to itself.
- Atoms with a greater effective nuclear charge have a stronger pull on bonding electrons, resulting in higher electronegativities.

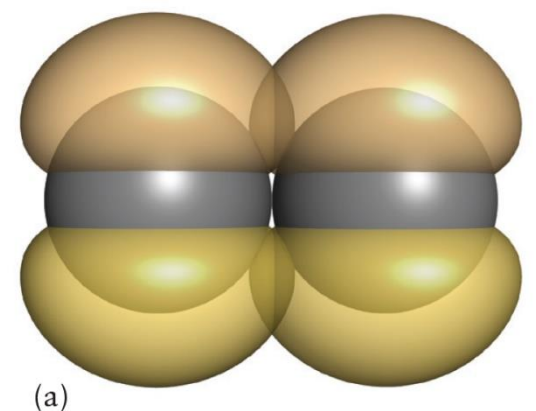


Trends in Polarizability

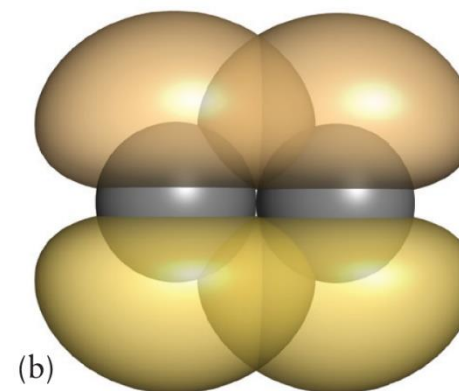
- Polarizabilities typically decrease from left to right across a period and increase down a group.
- Polarizability is the ease with which an electron cloud of an atom can be distorted.
- Electron-rich, heavier atoms are easily polarized.
- Atoms with a high polarizing ability are small-sized, highly-charged atoms.



- The small radii of Period 2 atoms account for bonding differences compared to their congeners, the other members of the group.
- Period 2 atoms are small so their p-orbitals overlap effectively; the reason for multiple π -bonds.
- Period 3 atoms are bigger, their p-orbitals are held apart so have very little overlap.

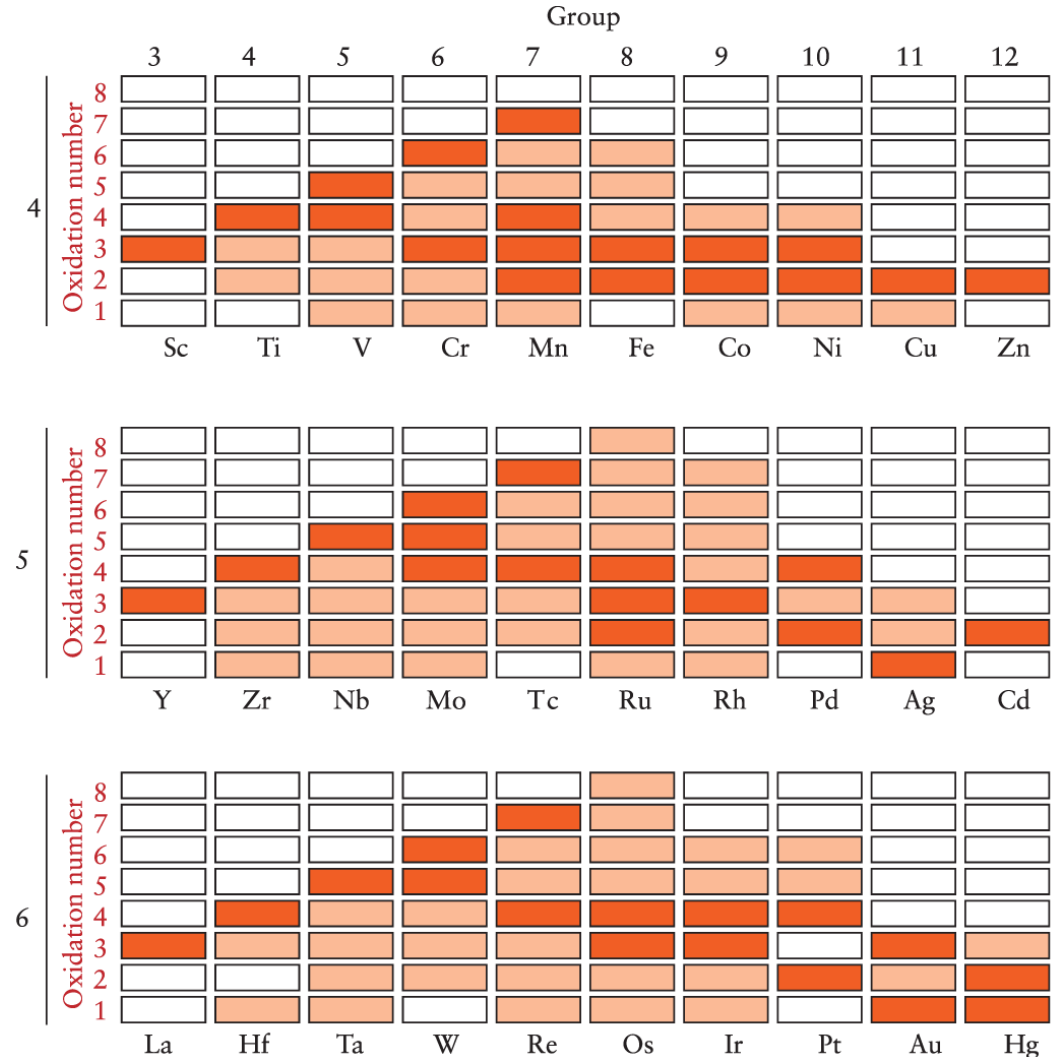


Period 2

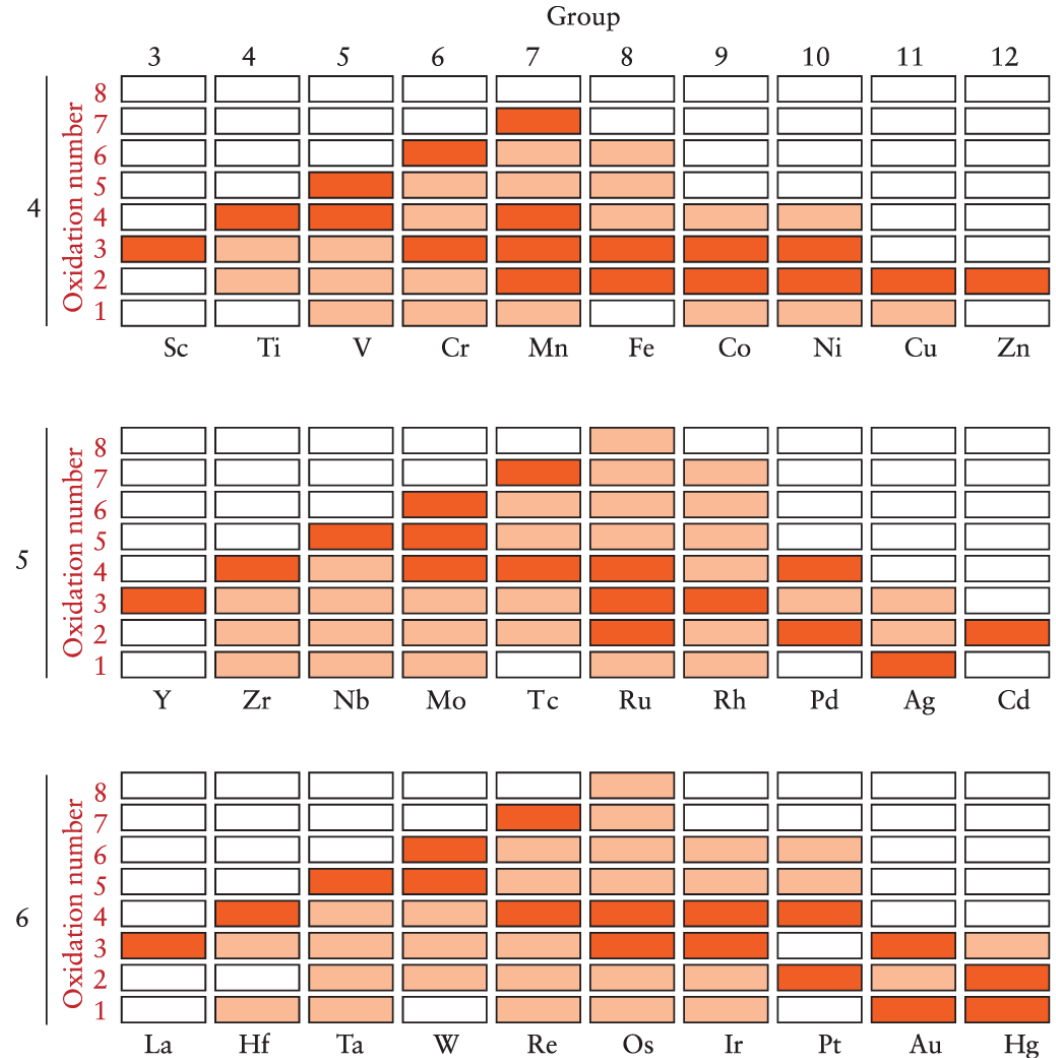


Period 3

- The d-block elements tend to lose their valence s-electrons first when forming compounds.
- Most lose a variable number of d-electrons and exist in a variety of oxidation states.



- Elements in the center of each row have the widest range of oxidation states.
- Elements in the second and third rows reach higher oxidation states.



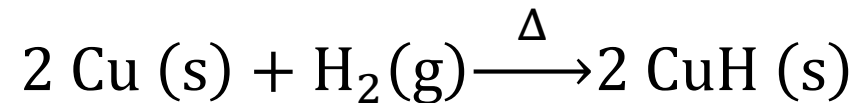
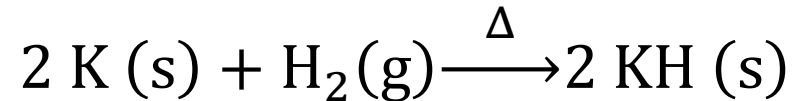
Trends in Chemical Properties: Hydrides

- All the main-group elements, except the noble gases, and possibly indium and thallium, form binary compounds with hydrogen called hydrides.
- Hydride formulas are related to group numbers.
- Carbon (Group 14/IV) forms CH_4 .
- Nitrogen (Group 15/V) forms NH_3 .
- Oxygen (Group 16/VI) forms H_2O .
- Fluorine (Group 17/VII) forms HF .

Trends in Chemical Properties: Hydrides

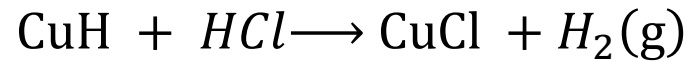
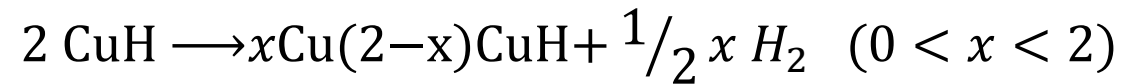
Saline Hydrides

- Most Group 1 and 2 elements, except for beryllium, form ionic compounds with hydrogen called saline hydrides or salt-like hydrides.
- They are formed by heating the metal in hydrogen gas.



Metallic Hydrides

- Metallic hydrides release their hydrogen (as H₂ gas) when heated or treated with acid. Metallic hydrides are being studied as a possible way to store and transport hydrogen.



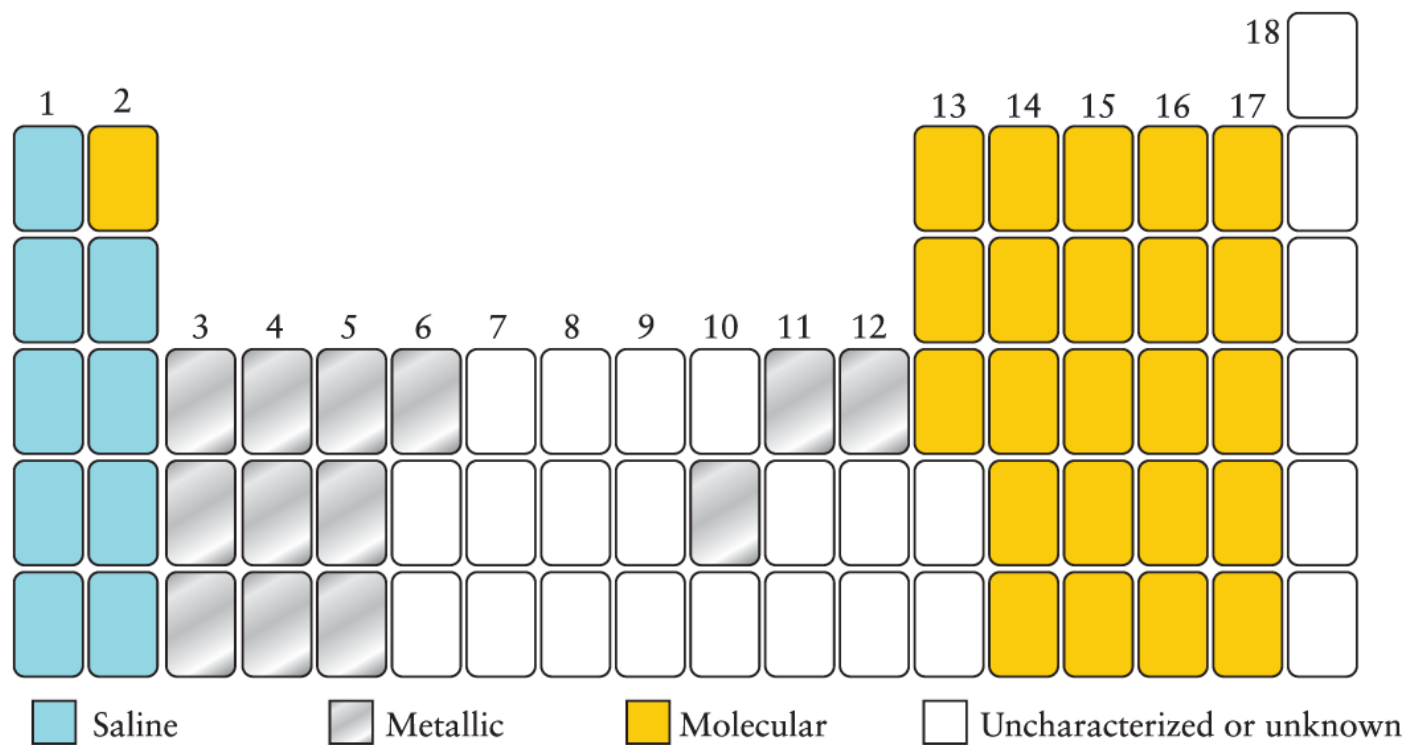
- Metallic hydrides are black, powdery, electrically conducting solids formed by heating certain d-block metals in hydrogen.

Molecular Hydrides

- Nonmetals form covalent molecular hydrides. Many are volatile, and some are Brønsted acids.
- Hydride gases include ammonia, the hydrogen halides (HF, HCl, HBr, HI), and lighter hydrocarbons such as methane, ethane, ethene, and ethyne.
- Liquid molecular hydrides include water and hydrocarbons such as octane and benzene.

The Pattern of Hydrides

Type: **s-block** **d-block** **p-block**
 saline metallic molecular



Trends in Chemical Properties: Oxides

- All main-group elements, except noble gases, react with oxygen to form oxides. Oxides demonstrate periodic trends in the chemical properties of elements.
- Ionic oxides on the left of the periodic table are soluble.
- Left side p-block oxides are insoluble, high-melting-point solids.
- Right side p-block oxides are low-melting-point, often gaseous, molecular oxides.

- Metallic elements with low ionization energies commonly form basic oxides.
- Elements with intermediate ionization energies like Be, B, Al, and the metalloids, form amphoteric oxides, meaning:
 - They do not react with or dissolve in water.
 - They do dissolve in both acidic and basic solutions.

- Many oxides of nonmetals, such as CO_2 , NO , SO_3 , are gaseous molecular compounds and can act as a Lewis acid.



Molecular Oxides

- Many oxides of nonmetals, such as CO_2 , NO , SO_3 , are gaseous molecular compounds and can act as a Lewis acid.



- Acid anhydrides form acidic solutions when in water. For example, SO_3 forms H_2SO_4 in water. Also, N_2O_5 forms HNO_3 in water.



- Formal anhydrides do not react with water. Although CO does not react with cold water, it is the formal anhydride of formic acid HCOOH , because it can be obtained by removing the elements of water from the molecular formula of the acid.

- The pattern of oxidation numbers underlies trends in the chemical properties of the d-block elements.
- An element with a high oxidation number is easily reduced, and probably a good oxidizing agent like MnO_4^- .
- An element with a low oxidation number is probably a good reducing agent like Cr^{2+} .

- The pattern of oxidation numbers correlates with the pattern of acid-base behavior. Most d-block metals are basic, but oxides of a given element shift toward acidic character as the oxidation number increases.

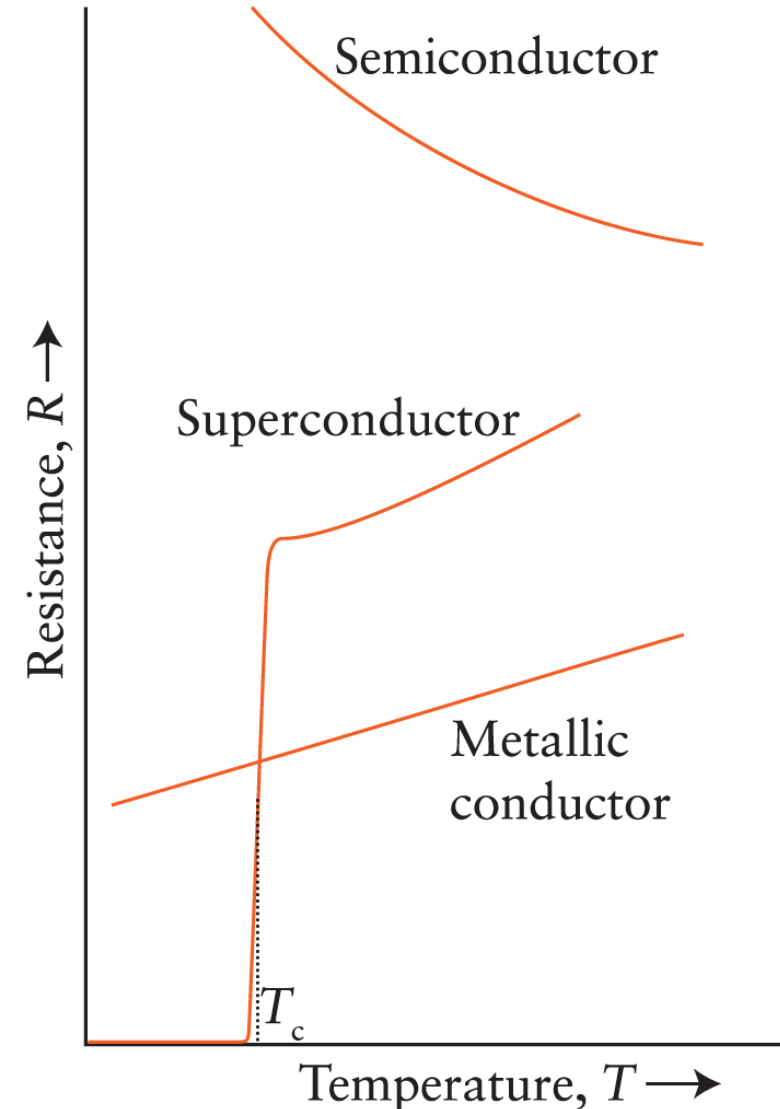
CrO	+2	basic
Cr ₂ O ₃	+3	amphoteric
CrO ₃	+6	acidic

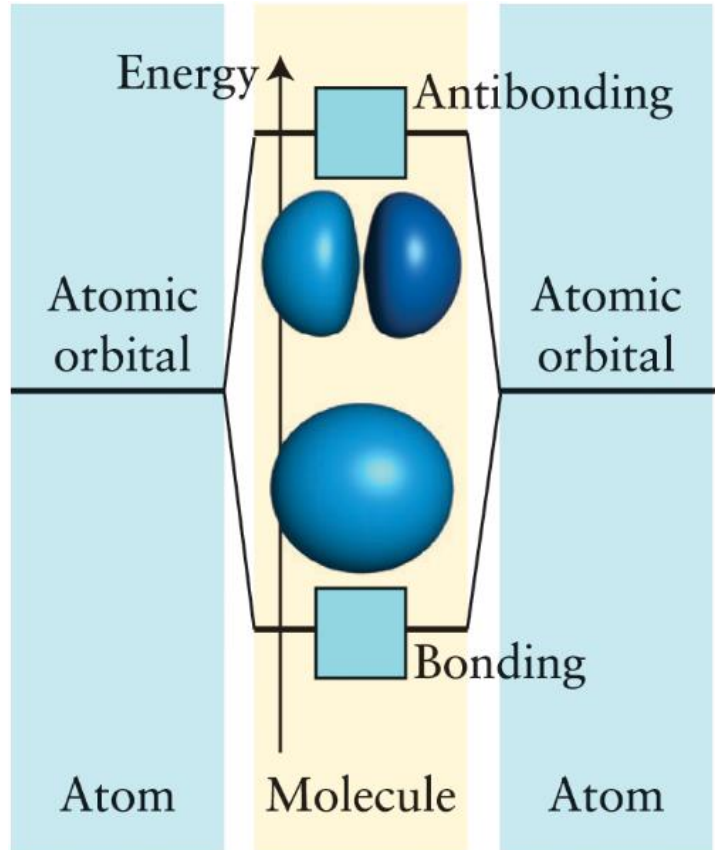
Classification of Solids Electrically

- An electric current is the flow of electric charge. The charge is carried by electrons in electronic conduction. Electronic conduction is the type of conduction in metals and graphite.
- In ionic conduction, the charge is carried by ions. Ionic conduction is the mode of electrical conduction in molten salts or electrolyte solutions. Most ions are too bulky to travel easily through most solids. However, solid electrolytes allow ions to move through their lattices.
- Solid electrolytes are important components of rechargeable batteries, like lithium-ion batteries.

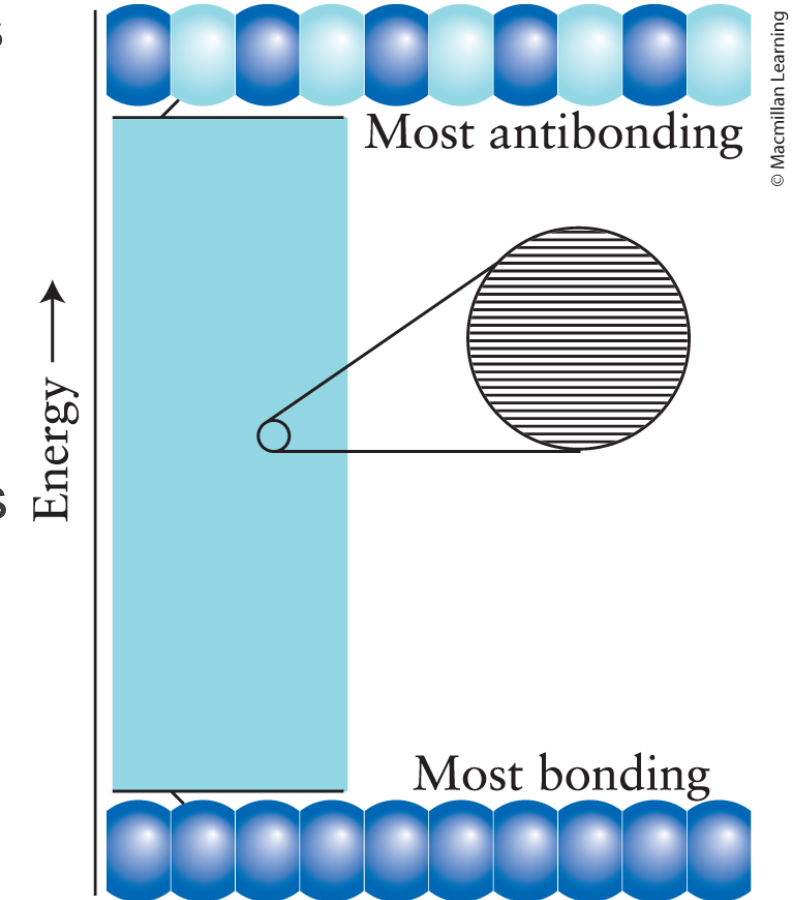
Classification of Solids Electrically

- Insulators have such a high resistance they do not conduct electricity.
- Solids can be classified according to how their resistance varies with temperature.
- Metallic conductor: resistance increases when temperature increases
- Semiconductor: resistance decreases when temperature increases
- Superconductor: conducts electricity with zero resistance at temperatures lower than a critical temperature, T_c (usually very low)

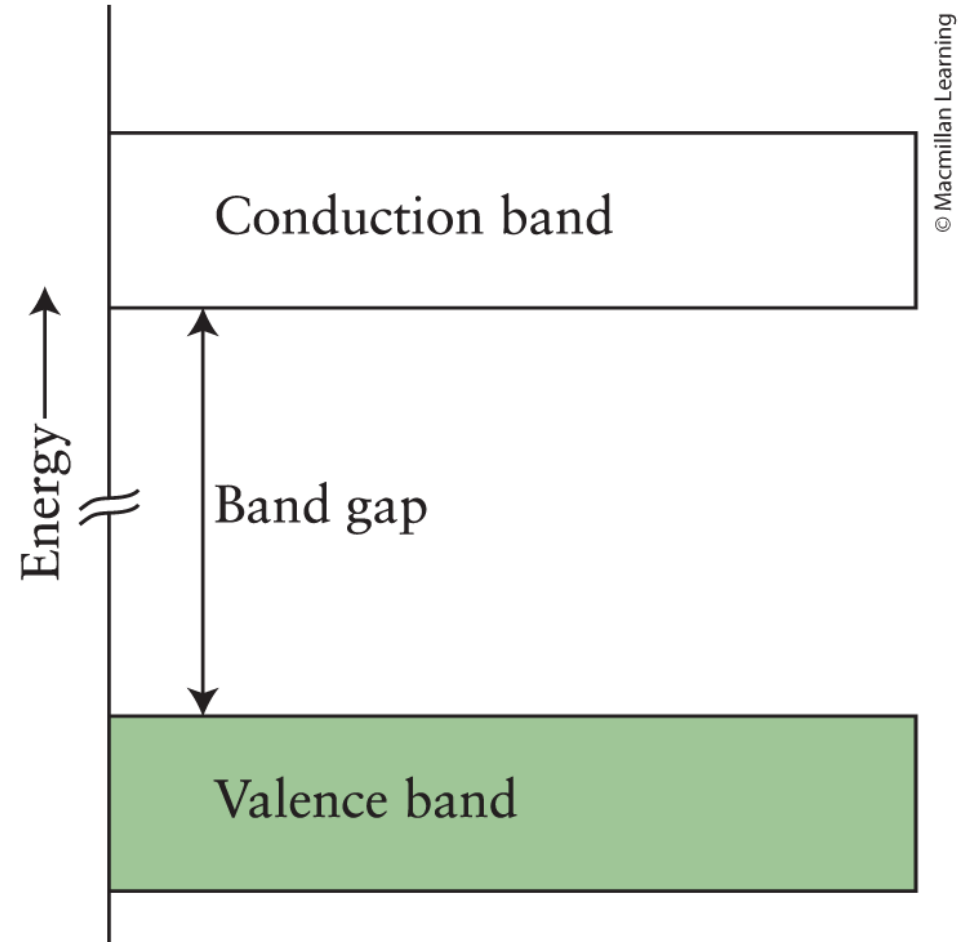




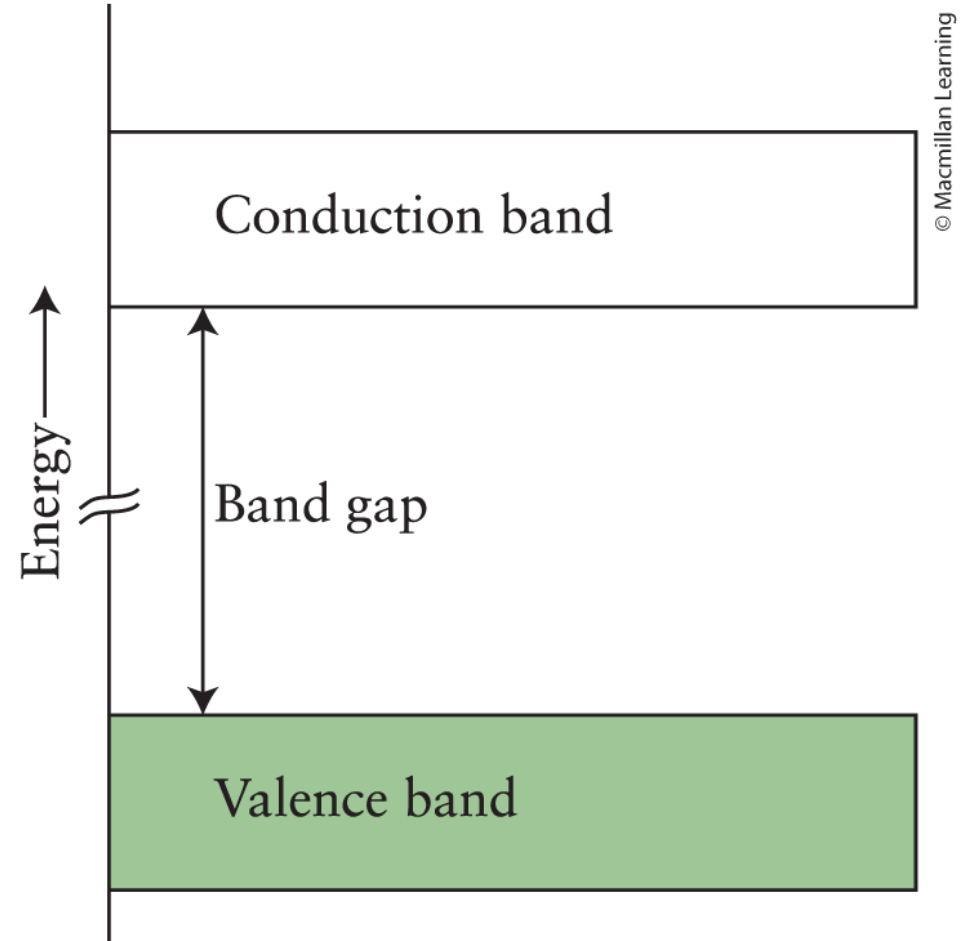
- When N atomic orbitals merge together, they form N molecular orbitals.
- The same thing happens in a solid, but N is enormous (for example, about 10^{23} for 10 g of copper). More molecular orbitals means MOs are closer together in energy, forming a nearly continuous band.
- In metals, half the MOs are bonding and half are antibonding.



- Neighboring orbitals are so close in energy that little additional energy is needed to excite metal electrons from the topmost filled MO to empty orbitals of the conduction band. Conduction band electrons move freely.
- When a metal is heated, atoms vibrate more vigorously, which impedes the migration of electrons, increasing the resistance.
- Conduction bands are empty or incompletely filled bands of molecular orbitals.



- In insulators, the valence electrons fill all available molecular orbitals to give a full band valence band. Here there is a substantial band gap, a range of energies for which there are no orbitals, before the next band, the conduction band composed of empty orbitals, begins.
- Electrons need a very large injection of energy to reach the conduction band.
- If the energy gap is too large, electrons are not mobile and the solid does not conduct electricity.

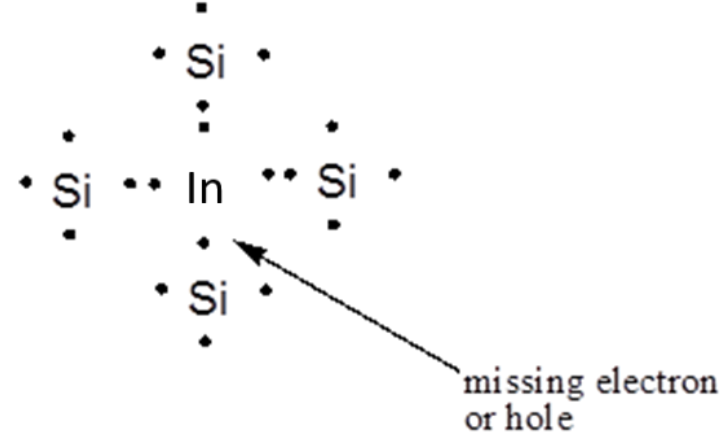
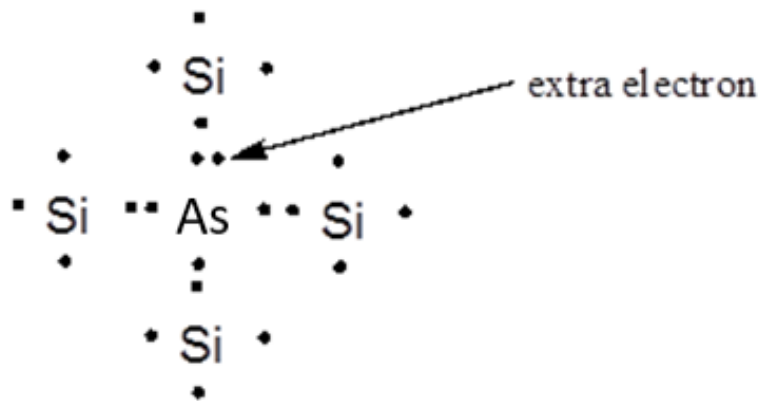


Intrinsic and Extrinsic Semiconductors

- In an intrinsic semiconductor, an empty conduction band lies close in energy to a full valence band.
- As the solid is warmed, electrons can be excited from the valence band into the conduction band; resistance in the semiconductor decreases as its temperature raises.
- Semiconductors are doped by spreading small impurities throughout a solid to modify their electrical carrying ability. This produces an extrinsic semiconductor.

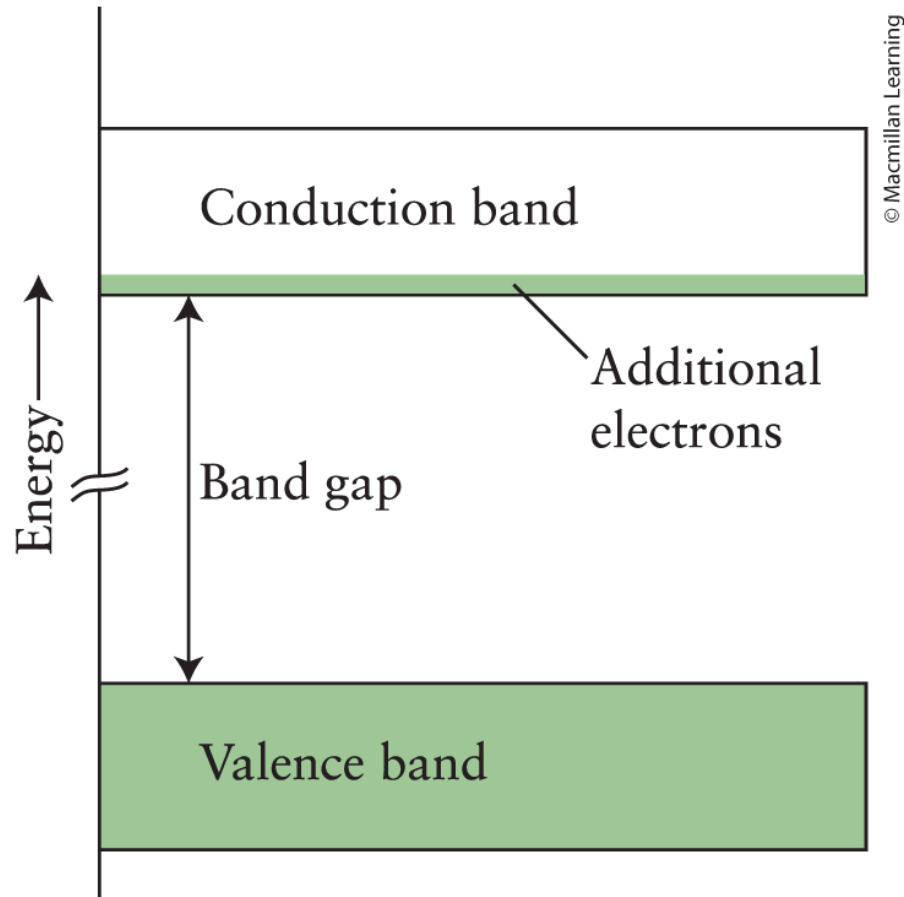
Doping Semiconductors

- Doping silicon with arsenic increases the number of electrons in the solid. This type of material is called an n-type semiconductor because it contains excess negatively charged electrons.

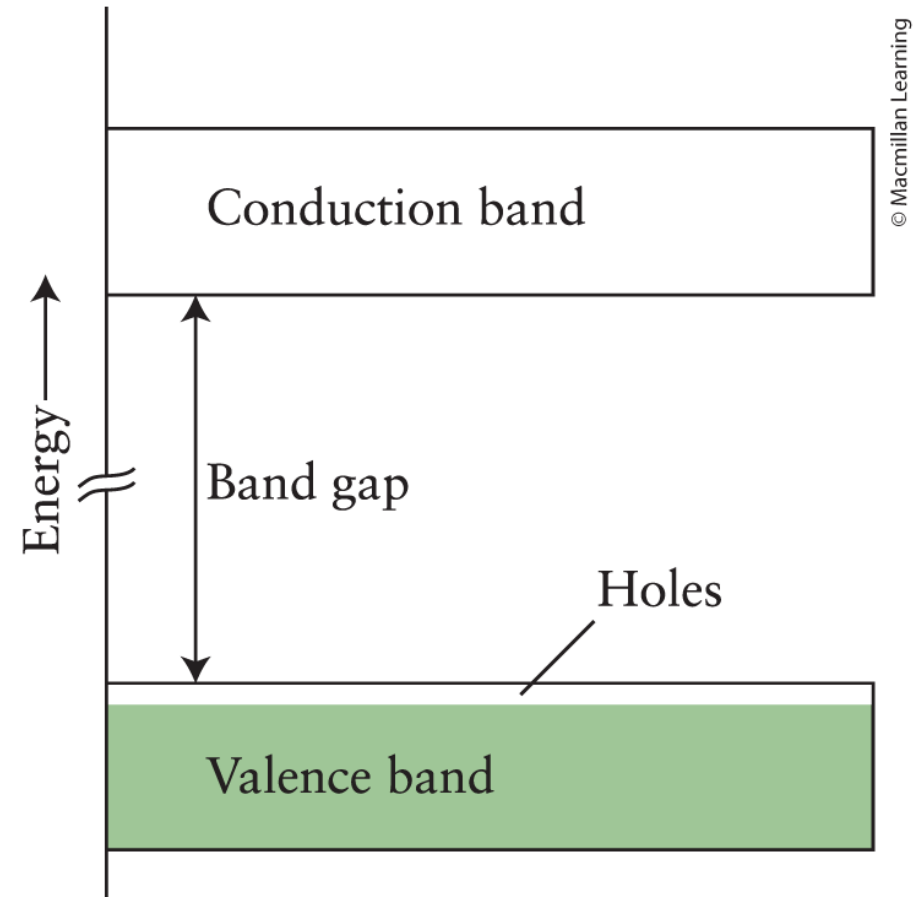


- Doping silicon with indium produces materials with “extra” holes. This type of material is called a p-type semiconductor because it contains positively charged holes.

Doping Semiconductors



■ n-type semiconductor

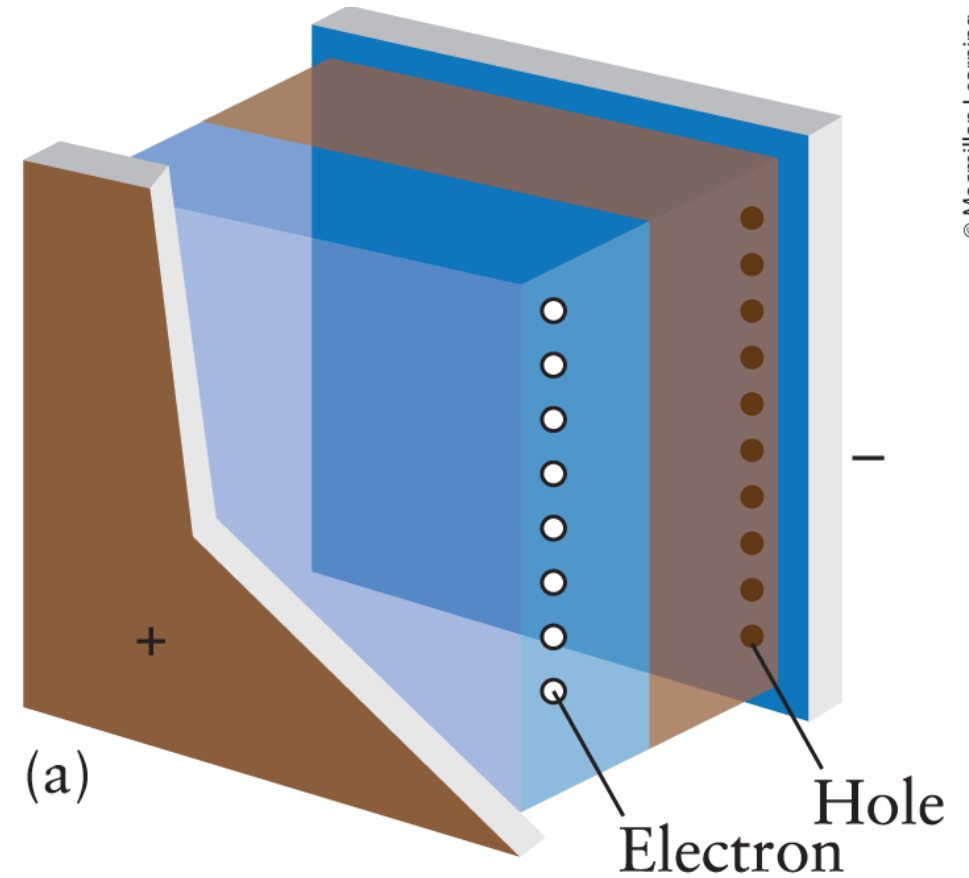


■ p-type semiconductor

- The region in the semiconductor where the n-type and p-type semiconductors meet is called the p–n junction.
- At a p–n junction, electric current can only flow in one direction.
- An interesting interaction occurs at the p–n junction when the n-type layer comes into contact with the p-type layer. Electrons will only flow in one direction (forward biased) but not in the other (reverse biased).
- One type of a p–n junction is a light-emitting diode, or LED.

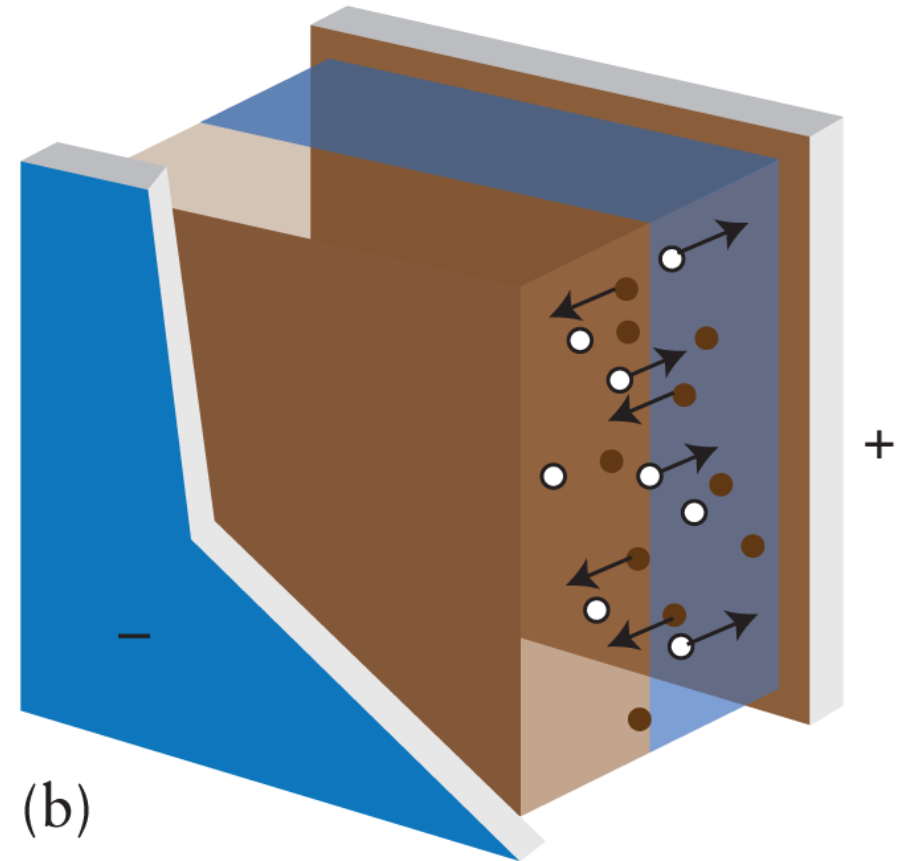
p-n Junction

- When the p-type and n-type semiconductors are sandwiched together, at the point at which they touch, a sudden, mad rush of extra free electrons in the n-type layer fall into holes on the p-type side.
- Electrons stop moving when a p-type has a negative charged applied: the holes move to the “-” side, preventing the electrons on the n-type side from jumping the band gap.



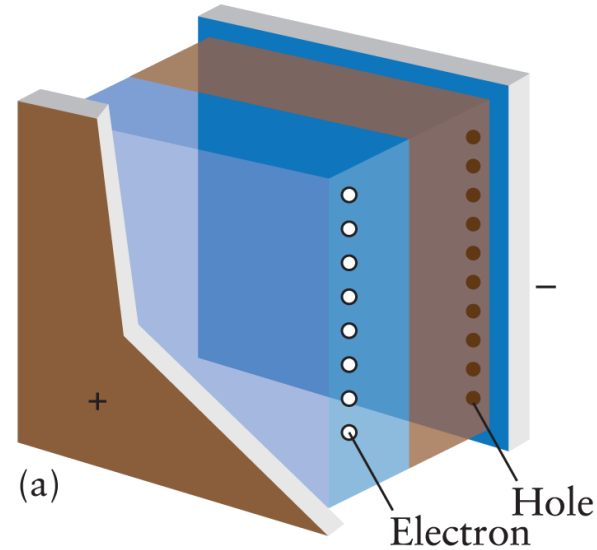
p–n Junction

- Switching the charge, making the n-type negatively charged, will draw the holes to the n-type side, and electrons begin jumping the “junction” or flowing to the p-type side; the added potential can be either electrical or a photon.

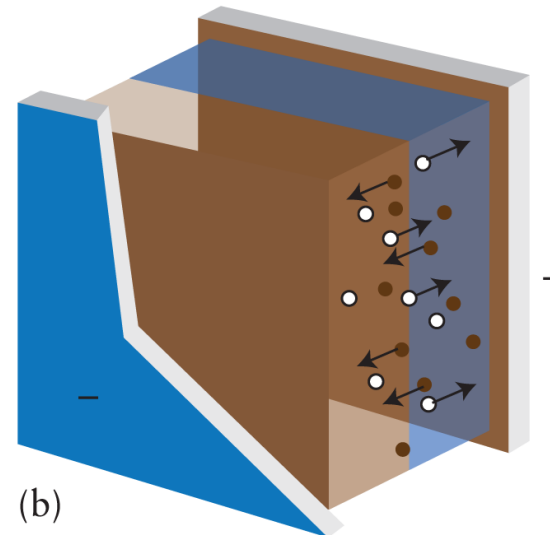


p–n Junction

- Doping determines the size of the band gap and hence the voltage of the semiconductor.
- This is called a bias because electrons can only flow once the n-type has an applied negative voltage.



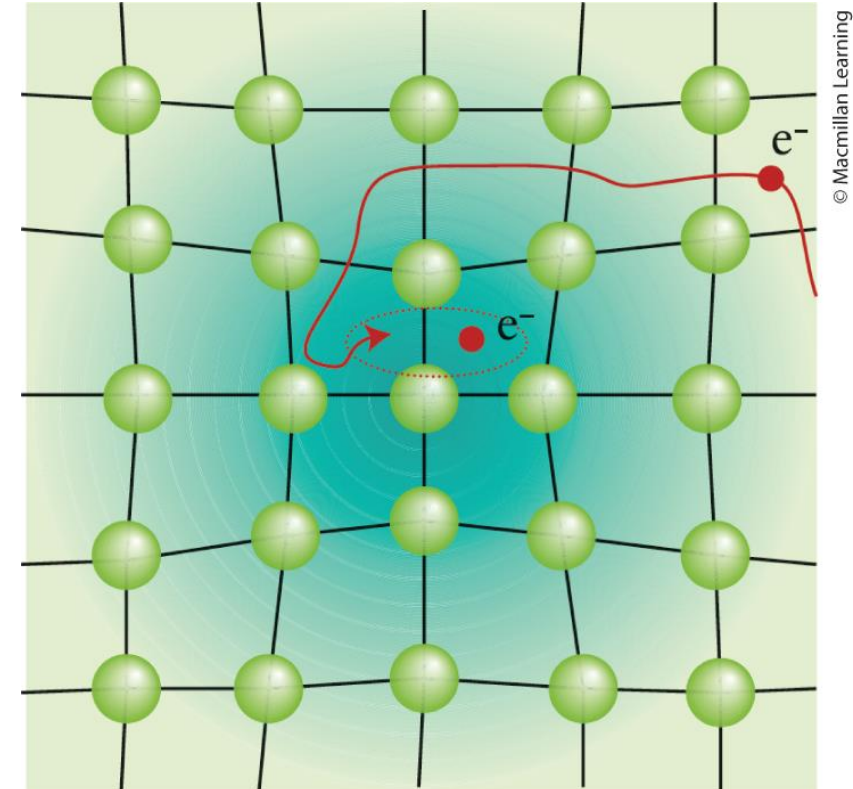
- (a) reverse bias, the current does not flow.



- (b) forward bias, charge carriers can be regenerated

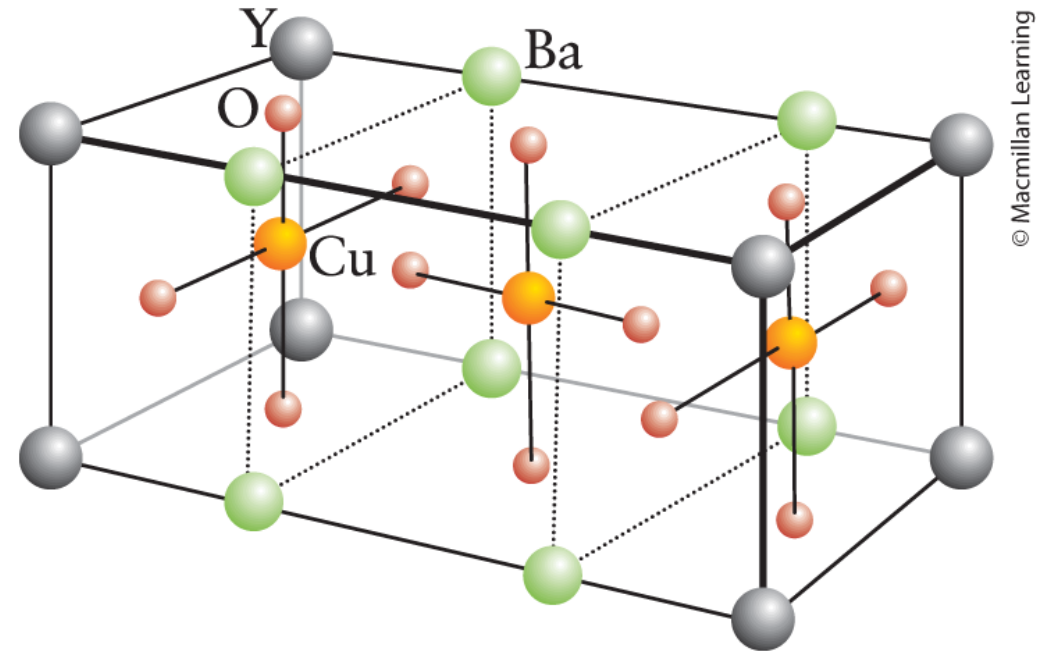
- In principle, superconductors have great potential to help reduce losses in power transmission.
- Superconductivity is the loss of all electrical resistance when a substance is cooled to its critical temperature (T_c).
- It is thought low temperatures reduce the effect of the vibrations of the atoms in their crystalline lattice. They do this by forming pairs of electrons called Cooper pairs.

- Cooper pairs form when one electron distorts the cationic lattice, drawing in a second electron.
- The two electrons are weakly attracted, and not shaken apart by the vibrations of the crystal lattice.



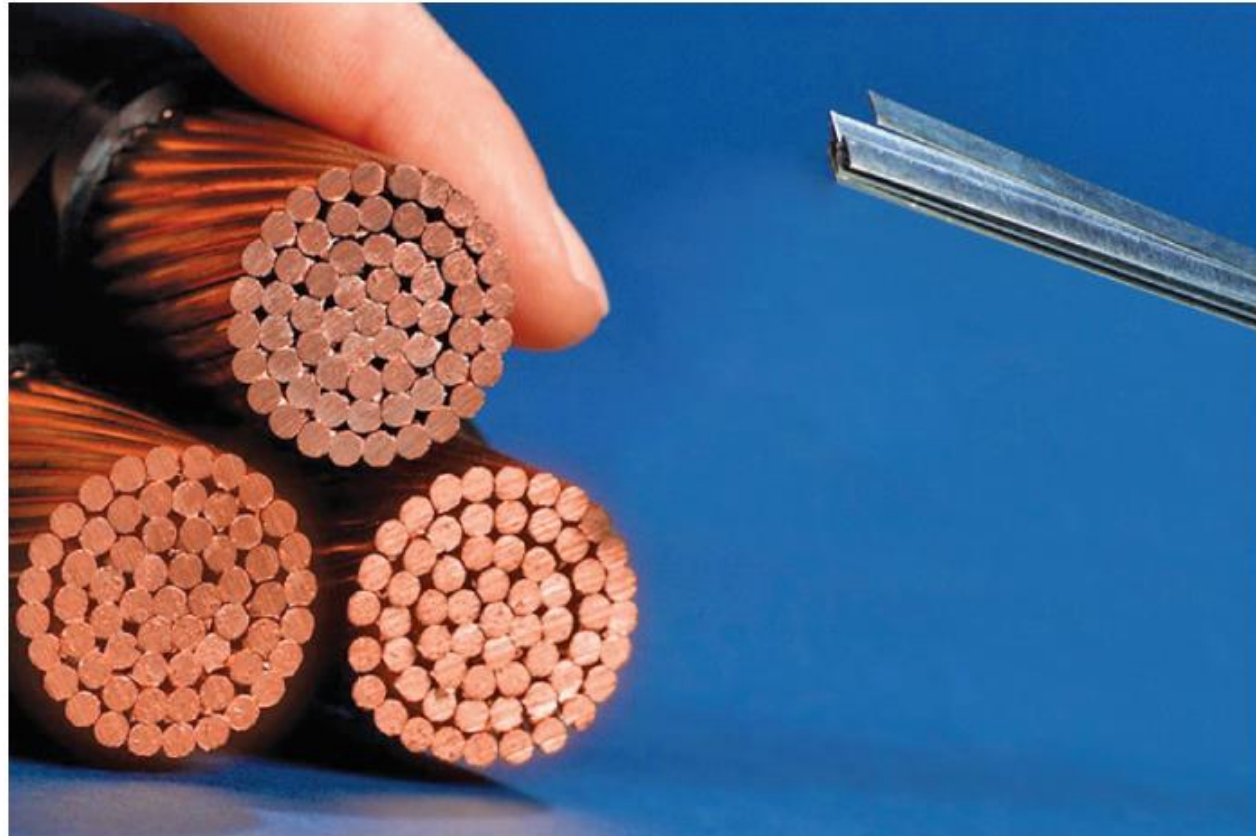
Superconductivity

- Superconductivity was first observed in 1911 in mercury, the $T_c = 4$ K and by 1988, materials were recording T_c of 125 K.
- By 2015, the highest transition temperature attained was 138 K.
- In 2020, a material was shown to have superconducting properties at 287 K, but it is unsuitable for practical applications because it requires very high pressures.



Superconducting Wire

- Twenty-five kilograms of the experimental conducting wire on the right can carry as much current as 1800 kg of the bulky copper wire on the left – a ratio of 72:1.



Courtesy American Superconductor (AMSC).

Summary

- The properties of elements are related to their location in the periodic table.
- The d-block elements have similar sizes.
- The lanthanide contraction leads to smaller atomic radii and higher densities than expected for elements in Period 6.
- The d-block elements can be found with a variety of oxidation numbers.
- The electrical conductivity can be explained in terms of the occupation of molecular orbitals.

