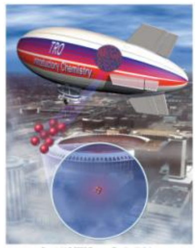
Introductory Chemistry, 2nd Edition
Nivaldo Tro

Chapter 9 Electrons in Atoms and the Periodic Table



Roy Kennedy
Massachusetts Bay Community College
Wellesley Hills, MA
2006, Prentice Hall

- hydrogen
- helium

May 6, 1937

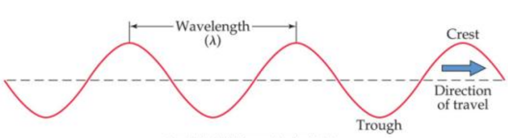
9.2 Atomic Emission (Line) Spectra

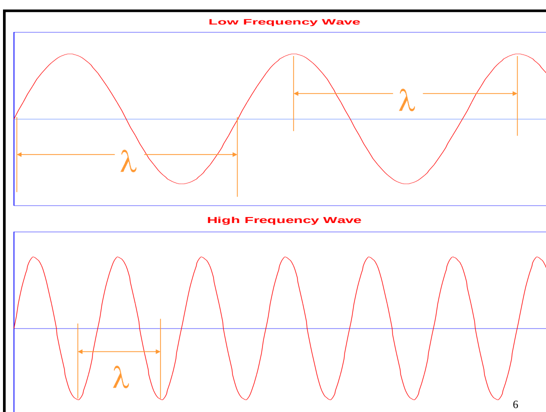
- Flame tests
- Lamps

Electromagnetic Radiation

- light is one of the forms of energy
- **electromagnetic radiation**

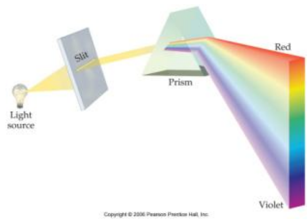
Electromagnetic Waves



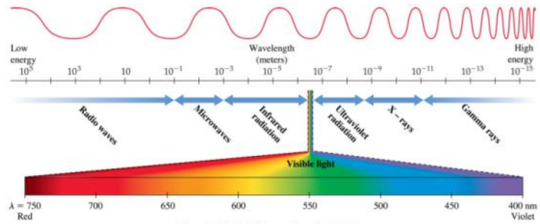


9.3 The Electromagnetic Spectrum

- light passed through a prism is separated into all its colors - this is called a **continuous spectrum**
- the color of the light is determined by its wavelength



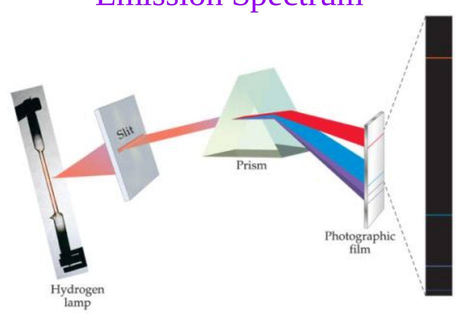
Electromagnetic Spectrum



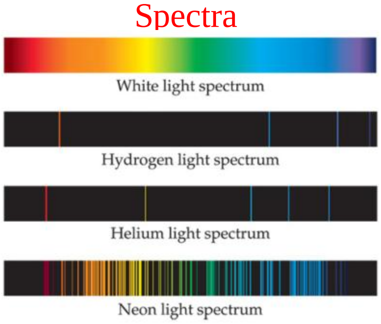
Energy and Light

- each wavelength of light has a different amount of energy

Emission Spectrum



Spectra

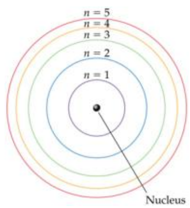


9.4 The Bohr Model of the Atom

- Bohr's major idea was that the energy of the atom was **quantized**
  - ✓quantized means specific amounts of energy
- The amount of energy was related to the electron's position in the atom

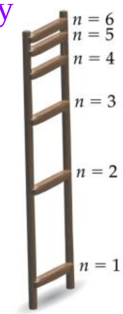
The Bohr Model of the Atom Electron Orbits

- in the Bohr Model, electrons travel in orbits around the nucleus

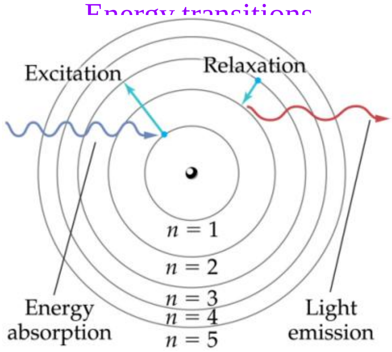


The Bohr Model of the Atom Orbits and Energy

- each orbit has a specific amount of energy
- the energy of each orbit is characterized by an integer - the integer, **n**, is called a **quantum number**

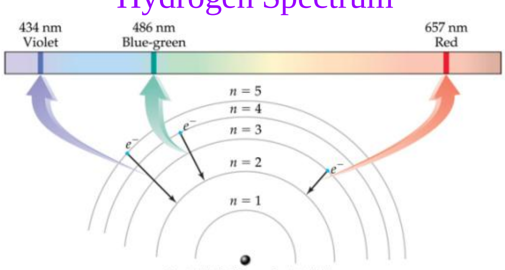


The Bohr Model of the Atom and Energy transitions



The Bohr Model of the Atom Ground and Excited States

The Bohr Model of the Atom Hydrogen Spectrum



The Bohr Model of the Atom Success and Failure

- the mathematics of the Bohr Model very accurately predicts the spectrum of hydrogen
- however its mathematics fails when applied to multi-electron atoms
  - ✓it cannot account for electron-electron interactions
- a better theory was needed

9.5 The Quantum-Mechanical Model of the Atom

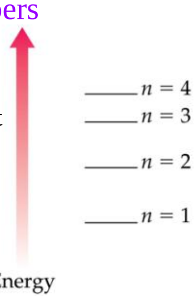
- Erwin Schrödinger
- Wave, particle, probability, quantized energy = Quantum mechanics model

The Quantum-Mechanical Model Orbitals

Not orbits!

The Quantum-Mechanical Model Quantum Numbers

- in Schrödinger's Wave Equation, there are 3 integers, called **quantum numbers**, that quantize the energy
- the **principal quantum number**, **n**, specifies the main energy level for the orbital



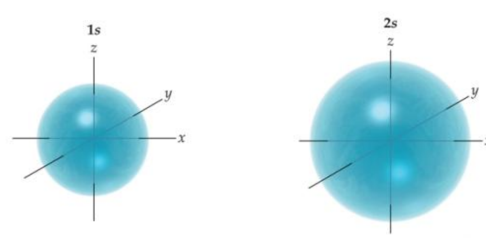
The Quantum-Mechanical Model Quantum Numbers

- each principal energy shell has one or more subshells
  - ✓ the number of subshells = the principal quantum number
- the quantum number that designates the subshell is often given a letter
  - ✓ *s*, *p*, *d*, *f*
- each kind of sublevel has orbitals with a particular shape
  - ✓ the shape represents the probability map
    - ➢ 90% probability of finding electron in that region

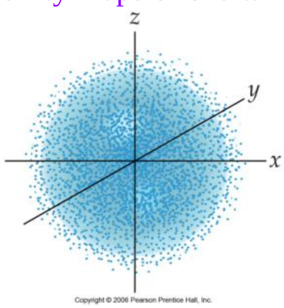
Shells & Subshells

Shell	# of subshells	Letters specifying subshells			
$n = 4$	4	*s*	*p*	*d*	*f*
$n = 3$	3	*s*	*p*	*d*	
$n = 2$	2	*s*	*p*		
$n = 1$	1	*s*			

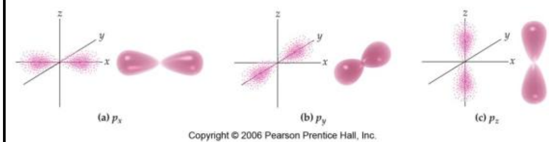
How does the 1*s* Subshell Differ from the 2*s* Subshell



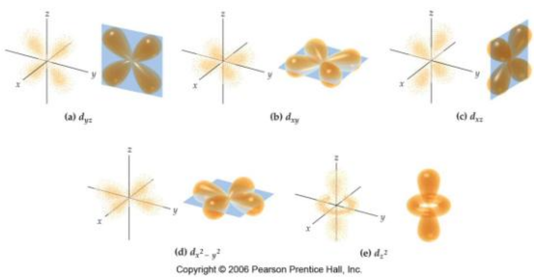
Probability Maps & Orbital Shape



Probability Maps & Orbital Shape
p Orbitals



Probability Maps & Orbital Shape
d Orbitals

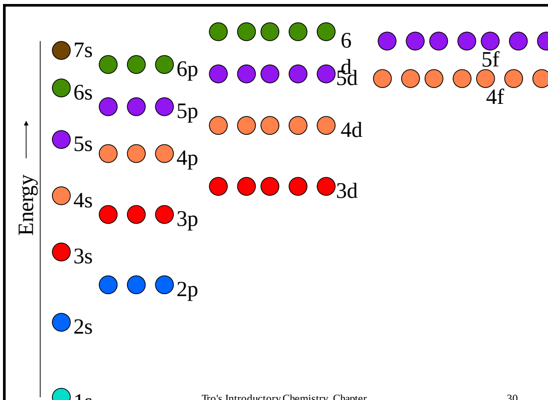


Subshells and Orbitals

- the subshells of a principal shell have slightly different energies
  - ✓ the subshells in a shell of H all have the same energy, but for multielectron atoms the subshells have different energies
  - ✓ $s < p < d < f$
- each subshell contains one or more orbitals
  - ✓ *s* subshells have 1 orbital
  - ✓ *p* subshells have 3 orbitals
  - ✓ *d* subshells have 5 orbitals
  - ✓ *f* subshells have 7 orbitals

Electron Configurations

- the distribution of electrons into the various energy shells and subshells in an atom in its ground state is called its **electron configuration**
- each energy shell and subshell has a maximum number of electrons it can hold
  - ✓ $s = 2$, $p = 6$, $d = 10$, $f = 14$
- we place electrons in the energy shells and subshells in order of energy, from low energy up
  - ✓ Aufbau Principal

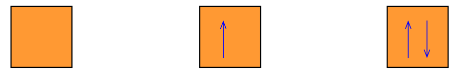


Filling an Orbital with Electrons

- each orbital may have a maximum of 2 electrons
  - ✓Pauli Exclusion Principle
- electrons spin on an axis
  - ✓generating their own magnetic field
- when two electrons are in the same orbital, they must have opposite spins
  - ✓so there magnetic fields will cancel

Orbital Diagrams

- we often represent an orbital as a square and the electrons in that orbital as arrows
  - ✓the direction of the arrow represents the spin of the electron

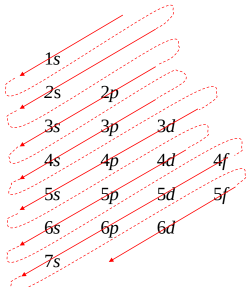


unoccupied orbital | orbital with 1 electron | orbital with 2 electrons

Order of Subshell Filling in Ground State Electron Configurations

start by drawing a diagram putting each energy shell on a row and listing the subshells, (*s*, *p*, *d*, *f*), for that shell in order of energy, (left-to-right)

next, draw arrows through the diagonals, looping back to the next diagonal each time



Filling the Orbitals in a Subshell with Electrons

- energy shells fill from lowest energy to high
- subshells fill from lowest energy to high
  - ✓ $s \rightarrow p \rightarrow d \rightarrow f$
- orbitals that are in the same subshell have the same energy
- when filling orbitals that have the same energy, place one electron in each before completing pairs
  - ✓Hund's Rule

Electron Configuration of Atoms in their Ground State

- the electron configuration is a listing of the subshells in order of filling with the number of electrons in that subshell written as a superscript

Kr = 36 electrons = $1s^22s^22p^63s^23p^64s^23d^{10}4p^6$

- a shorthand way of writing an electron configuration is to use the symbol of the previous noble gas in [] to represent all the inner electrons, then just write the last set

Rb = 37 electrons = $1s^22s^22p^63s^23p^64s^23d^{10}4p^65s^1$ = [Kr]$5s^1$

Example – Write the Ground State Orbital Diagram and Electron Configuration of Magnesium.

1. Determine the atomic number of the element from the Periodic Table
   - ✓ This gives the number of protons and electrons in the atom

   Mg Z = 12, so Mg has 12 protons and 12 electrons

Example – Write the Ground State Orbital Diagram and Electron Configuration of Magnesium.

2. Draw 9 boxes to represent the first 3 energy levels ***s*** and ***p*** orbitals

1s	2s	2p	3s	3p
[ ]	[ ]	[ ][ ][ ]	[ ]	[ ][ ][ ]

Example – Write the Ground State Orbital Diagram and Electron Configuration of Magnesium.

3. Add one electron to each box in a set, then pair the electrons before going to the next set until you use all the electrons
   - When pair, put in opposite arrows

1s	2s	2p	3s	3p
[↑↓]	[↑↓]	[↑↓][↑↓][↑↓]	[↑↓]	[ ][ ][ ]

Example – Write the Ground State Orbital Diagram and Electron Configuration of Magnesium.

4. Use the diagram to write the electron configuration
   - ✓ Write the number of electrons in each set as a superscript next to the name of the orbital set

$1s^2 2s^2 2p^6 3s^2$ = [Ne]$3s^2$

1s	2s	2p	3s	3p
[↑↓]	[↑↓]	[↑↓][↑↓][↑↓]	[↑↓]	[ ][ ][ ]

Valence Electrons

- the electrons in all the subshells with the highest principal energy shell are called the **valence electrons**
- electrons in lower energy shells are called **core electrons**
- chemists have observed that one of the most important factors in the way an atom behaves, both chemically and physically, is the number of valence electrons

Valence Electrons

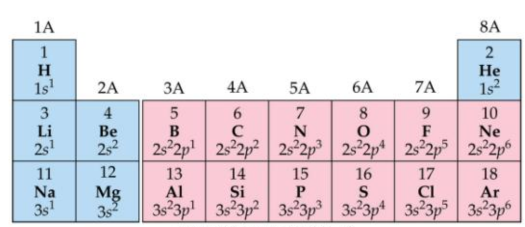
Rb = 37 electrons = $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^1$

- the highest principal energy shell of Rb that contains electrons is the 5th, therefore Rb has 1 valence electron and 36 core electrons

Kr = 36 electrons = $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6$

- the highest principal energy shell of Kr that contains electrons is the 4th, therefore Kr has 8 valence electrons and 28 core electrons

Electrons Configurations and the Periodic Table



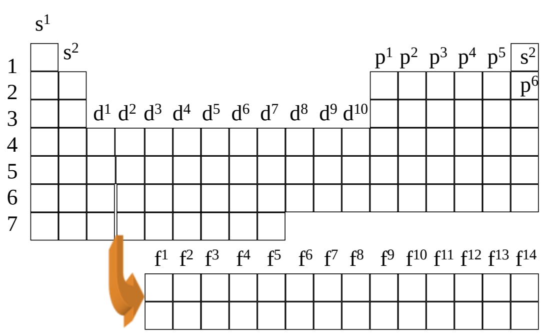
1A	2A	3A	4A	5A	6A	7A	8A
1 H $1s^1$							2 He $1s^2$
3 Li $2s^1$	4 Be $2s^2$	5 B $2s^2 2p^1$	6 C $2s^2 2p^2$	7 N $2s^2 2p^3$	8 O $2s^2 2p^4$	9 F $2s^2 2p^5$	10 Ne $2s^2 2p^6$
11 Na $3s^1$	12 Mg $3s^2$	13 Al $3s^2 3p^1$	14 Si $3s^2 3p^2$	15 P $3s^2 3p^3$	16 S $3s^2 3p^4$	17 Cl $3s^2 3p^5$	18 Ar $3s^2 3p^6$

Electron Configurations from the Periodic Table

- elements in the same period (row) have valence electrons in the same principal energy shell
- the number of valence electrons increases by one as you progress across the period
- elements in the same group (column) have the same number of valence electrons and they are in the same kind of subshell

Electron Configuration & the Periodic Table

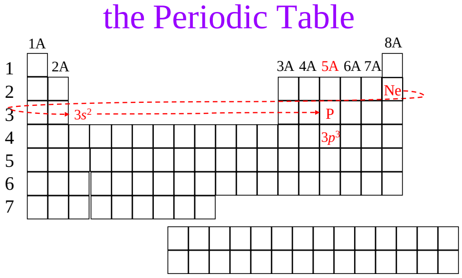
- elements in the same column have similar chemical and physical properties because their valence shell electron configuration is the same
- the number of valence electrons for the main group elements is the same as the group number



Electron Configuration from the Periodic Table

- the inner electron configuration is the same as the noble gas of the preceding period
- to get the outer electron configuration, from the preceding noble gas, loop through the next period, marking the subshells as you go, until you reach the element
  - ✓ the valence energy shell = the period number
  - ✓ the *d* block is always one energy shell below the period number and the *f* is two energy shells below

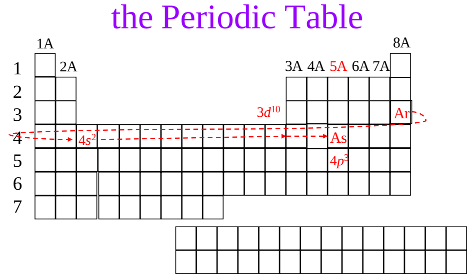
Electron Configuration from the Periodic Table



P = [Ne]$3s^2 3p^3$

P has 5 valence electrons

Electron Configuration from the Periodic Table



As = [Ar]$4s^2 3d^{10} 4p^3$

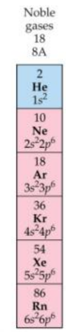
As has 5 valence electrons

The Explanatory Power of the Quantum-Mechanical Model

- the properties of the elements are largely determined by the number of valence electrons they contain
- since elements in the same column have the same number of valence electrons, they show similar properties

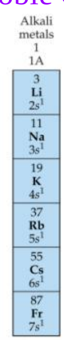
The Noble Gas Electron Configuration

- the noble gases have 8 valence electrons
  - ✓ except for He, which has only 2 electrons
- we know the noble gases are especially nonreactive
  - ✓ He and Ne are practically inert
- the reason the noble gases are so nonreactive is that the electron configuration of the noble gases is especially stable



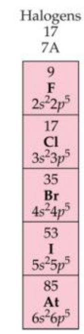
Everyone Wants to Be Like a Noble Gas! The Alkali Metals

- the alkali metals have one more electron than the previous noble gas
- in their reactions, the alkali metals tend to lose their extra electron, resulting in the same electron configuration as a noble gas
  - ✓ forming a cation with a 1+ charge



Everyone Wants to Be Like a Noble Gas! The Halogens

- the electron configurations of the halogens all have one fewer electron than the next noble gas
- in their reactions with metals, the halogens tend to gain an electron and attain the electron configuration of the next noble gas
  - ✓ forming an anion with charge 1-
- in their reactions with nonmetals they tend to share electrons with the other nonmetal so that each attains the electron configuration of a noble gas



Everyone Wants to Be Like a Noble Gas!

- as a group, the alkali metals are the most reactive metals
  - ✓ they react with many things and do so rapidly
- the halogens are the most reactive group of nonmetals
- one reason for their high reactivity is the fact that they are only one electron away from having a very stable electron configuration
  - ✓ the same as a noble gas

Stable Electron Configuration And Ion Charge

- Metals form cations by losing enough electrons to get the same electron configuration as the previous noble gas
- Nonmetals form anions by gaining enough electrons to get the same electron configuration as the next noble gas

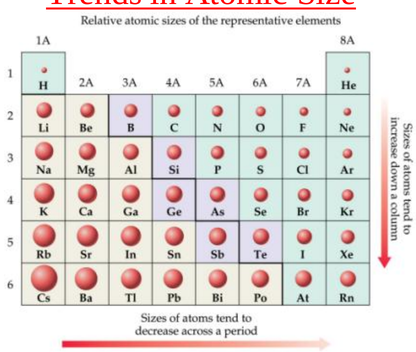
Atom	Atom's Electron Config	Ion	Ion's Electron Config
Na	$[Ne]3s^1$	Na^+	[Ne]
Mg	$[Ne]3s^2$	Mg^{2+}	[Ne]
Al	$[Ne]3s^23p^1$	Al^{3+}	[Ne]
O	$[He]2s2p^4$	O^{2-}	[Ne]
F	$[He]2s^22p^5$	F^-	[Ne]

Periodic Trends in the Properties of the Elements

Trends in Atomic Size

- either volume or radius
  - ✓treat atom as a hard marble
- Increases down a group
  - ✓valence shell farther from nucleus
  - ✓effective nuclear charge fairly close
- Decreases across a period (left to right)
  - ✓adding electrons to same valence shell
  - ✓effective nuclear charge increases
  - ✓valence shell held closer

Trends in Atomic Size

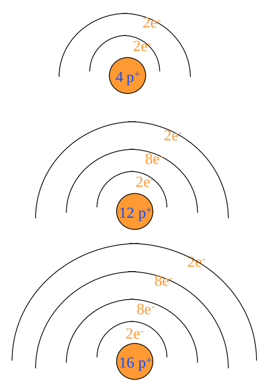


Group IIA

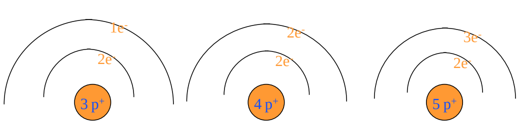
Be (4p$^+$ & 4e$^-$)

Mg (12p$^+$ & 12e$^-$)

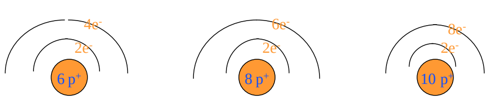
Ca (20p$^+$ & 20e$^-$)



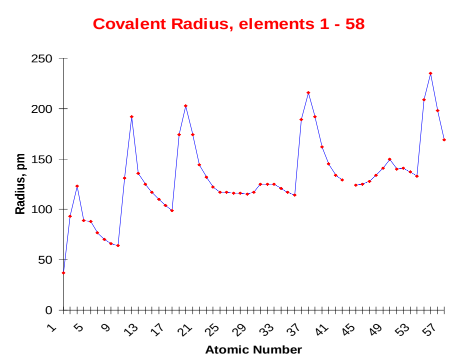
Period 2



Li (3p$^+$ & 3e$^-$) Be (4p$^+$ & 4e$^-$) B (5p$^+$ & 5e$^-$)

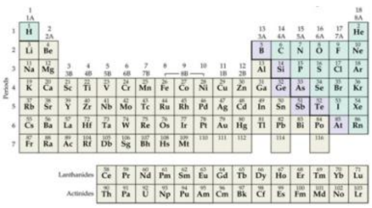


C (6p$^+$ & 6e$^-$) O (8p$^+$ & 8e$^-$) Ne (10p$^+$ & 10e$^-$)



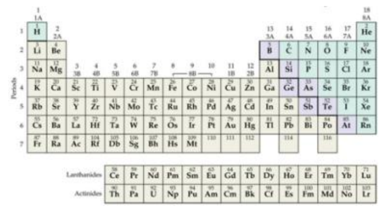
Example 9.6 – Choose the Larger Atom in Each Pair

- C or O
- Li or K
- C or Al
- Se or I



Example 9.6 – Choose the Larger Atom in Each Pair

- C or O
- Li or K
- C or Al
- Se or I?



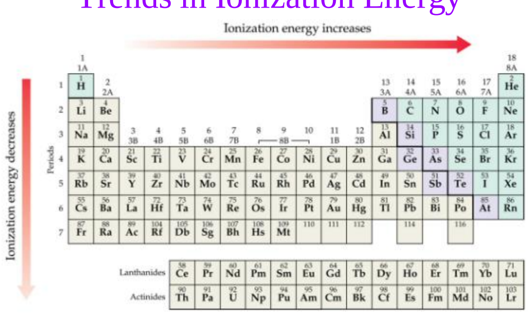
Ionization Energy

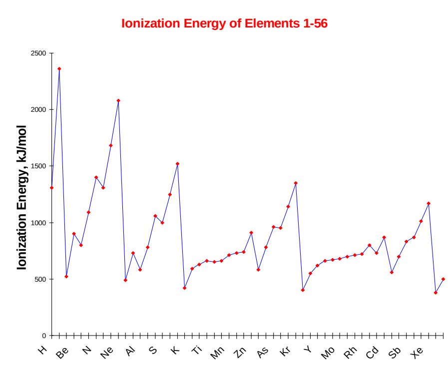
- minimum energy needed to remove an electron from an atom
  - ✓gas state
  - ✓endothermic process
  - ✓valence electron easiest to remove
  - ✓M(g) + 1st IE → M^{1+}(g) + 1 e^-
  - ✓M^{+1}(g) + 2nd IE → M^{2+}(g) + 1 e^-
    - ➢first ionization energy = energy to remove electron from neutral atom; 2nd IE = energy to remove from +1 ion; etc.

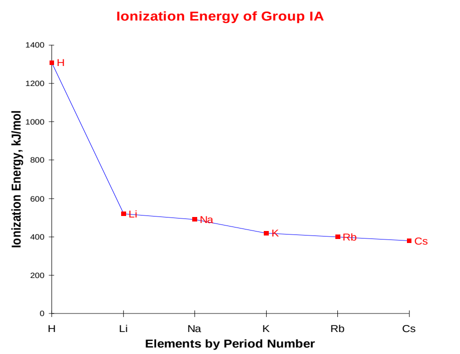
Trends in Ionization Energy

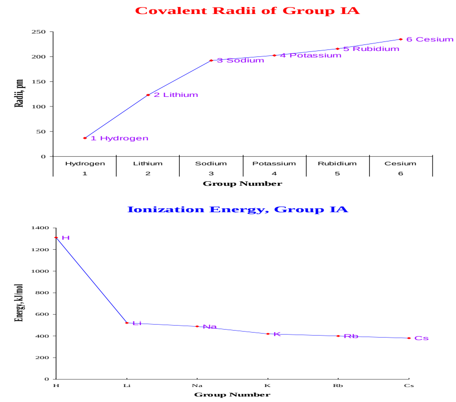
- as atomic radius increases, the IE generally decreases
  - ✓because the electron is closer to the nucleus
- 1st IE < 2nd IE < 3rd IE …
- 1st IE **decreases** down the group
  - ✓valence electron farther from nucleus
- 1st IE generally **increases** across the period
  - ✓effective nuclear charge increases

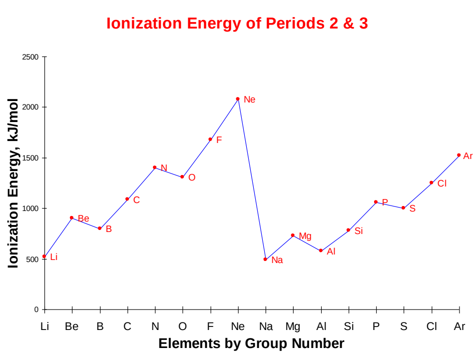
Trends in Ionization Energy





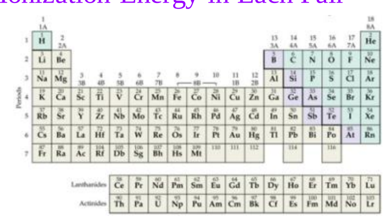






Example 9.7 – Choose the Atom with the Highest Ionization Energy in Each Pair

- Mg or P
- As or Sb
- N or Si
- O or Cl



Example 9.7 – Choose the Atom with the Highest Ionization Energy in Each Pair

- Mg or P
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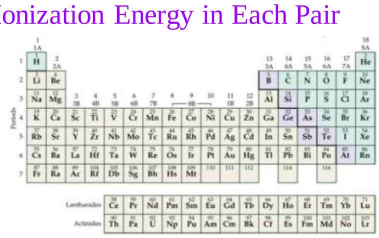
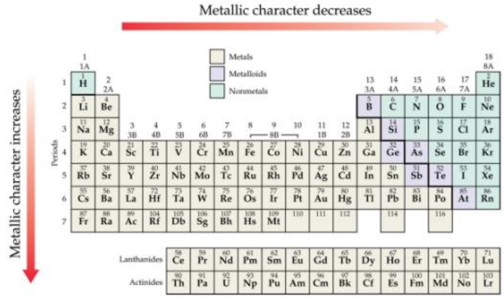
- N or Si
- O or Cl?



Metallic Character

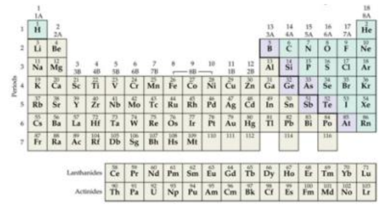
- how well an element's properties match the general properties of a metal
- Metals
  - ✓ malleable & ductile
  - ✓ shiny, lusterous, reflect light
  - ✓ conduct heat and electricity
  - ✓ most oxides basic and ionic
  - ✓ form cations in solution
  - ✓ lose electrons in reactions - **oxidized**
- Nonmetals
  - ✓ brittle in solid state
  - ✓ dull
  - ✓ electrical and thermal insulators
  - ✓ most oxides are acidic and molecular
  - ✓ form anions and polyatomic anions
  - ✓ gain electrons in reactions - **reduced**

Trends in Metallic Character



Example 9.8 – Choose the More Metallic Element in Each Pair

- Sn or Te
- Si or Sn
- Br or Te
- Se or I



Example 9.8 – Choose the More Metallic Element in Each Pair

- Sn or Te
- Si or Sn
- Br or Te
- Se or I?