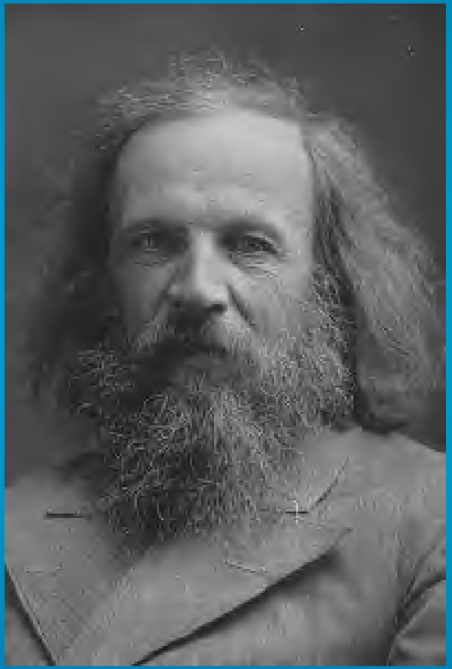
Periodic Table of Elements

1 IA	2 IIA	3	4	5	6	7	8	9	10	11	12	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.41	31 Ga 69.72	32 Ge 72.64	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (97.9)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La* 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac~ (227)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Ds (271)	111 Uuu (272)	112 Uub (277)	113 Uut	114 Uuq	115 Uup	116 Uuh		

*Lanthanides	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
~Actinides	90 Th 232.0	91 Pa (231)	92 U (238)	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

Mendeleev

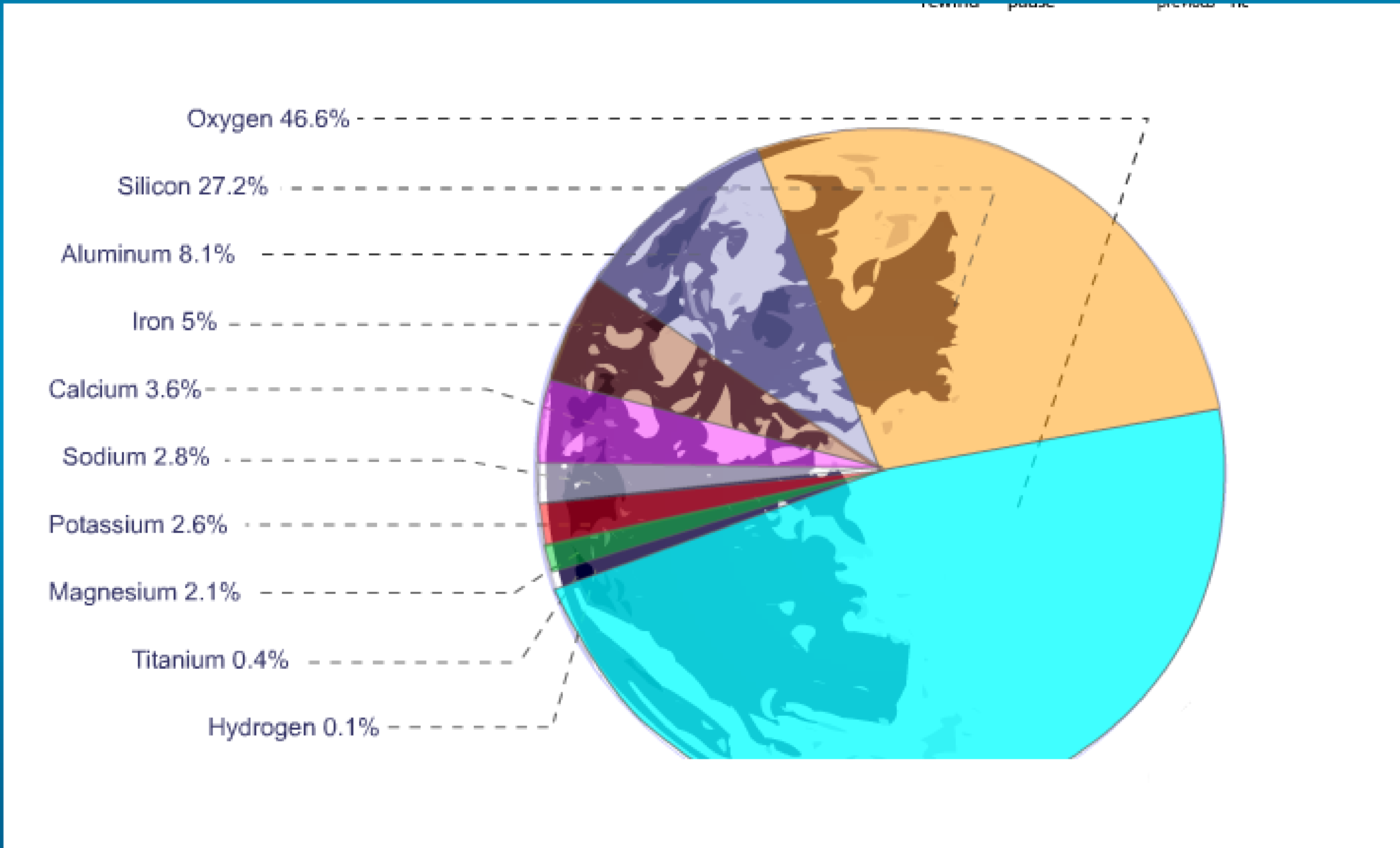
- In 1869, Dmitri Ivanovitch Mendeléev created the first accepted version of the periodic table.
- He grouped elements according to their atomic mass, and as he did, he found that the families had similar chemical properties.
- Blank spaces were left open to add the new elements he predicted would occur.



Elements

- Science has come along way since Aristotle's theory of Air, Water, Fire, and Earth.
- Scientists have identified 90 naturally occurring elements, and created about 28 others.

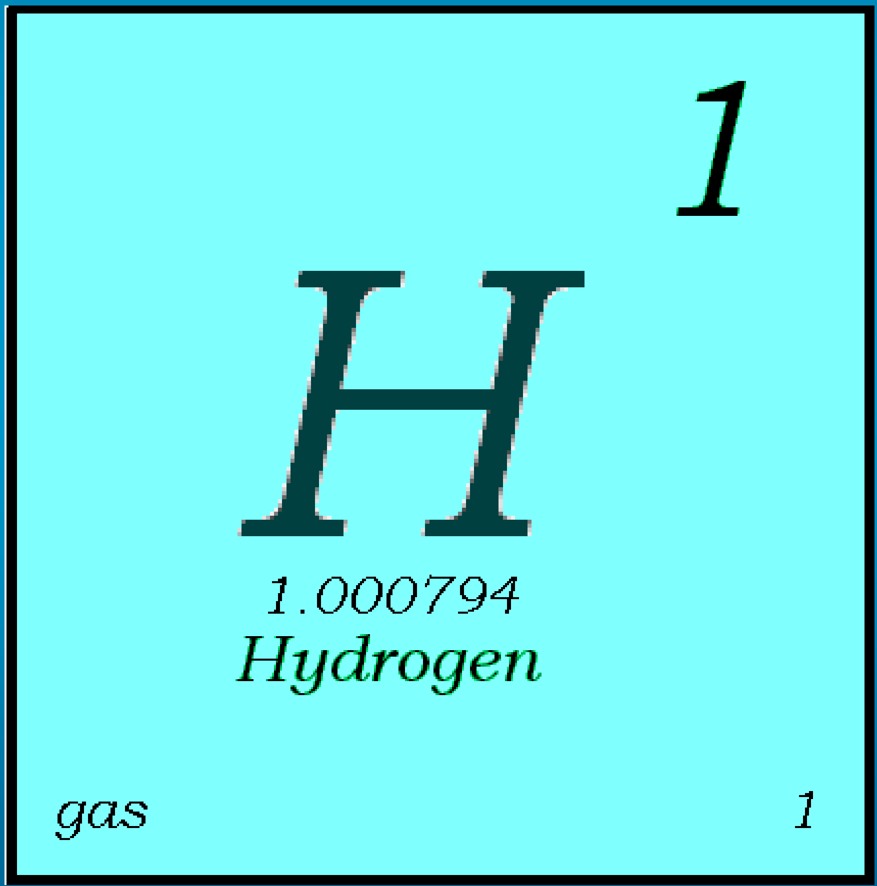
The most abundant element in the earth's crust is oxygen.



Periodic Table

- The periodic table organizes the elements in a particular way. A great deal of information about an element can be gathered from its position in the period table.
- For example, you can predict with reasonably good accuracy the physical and chemical properties of the element. You can also predict what other elements a particular element will react with chemically.
- Understanding the organization and plan of the periodic table will help you obtain basic information about each of the 118 known elements.

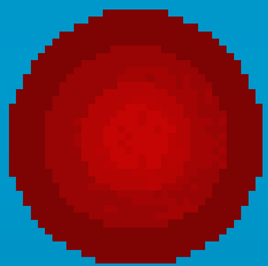
Key to the Periodic Table



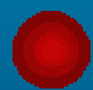
- Elements are organized on the table according to their atomic number, usually found near the top of the square.
  - The atomic number refers to how many protons an atom of that element has.
  - For instance, hydrogen has 1 proton, so it's atomic number is 1.
  - The atomic number is unique to that element. No two elements have the same atomic number.

Atomic Number

- This refers to how many protons an atom of that element has.
- No two elements, have the same number of protons.

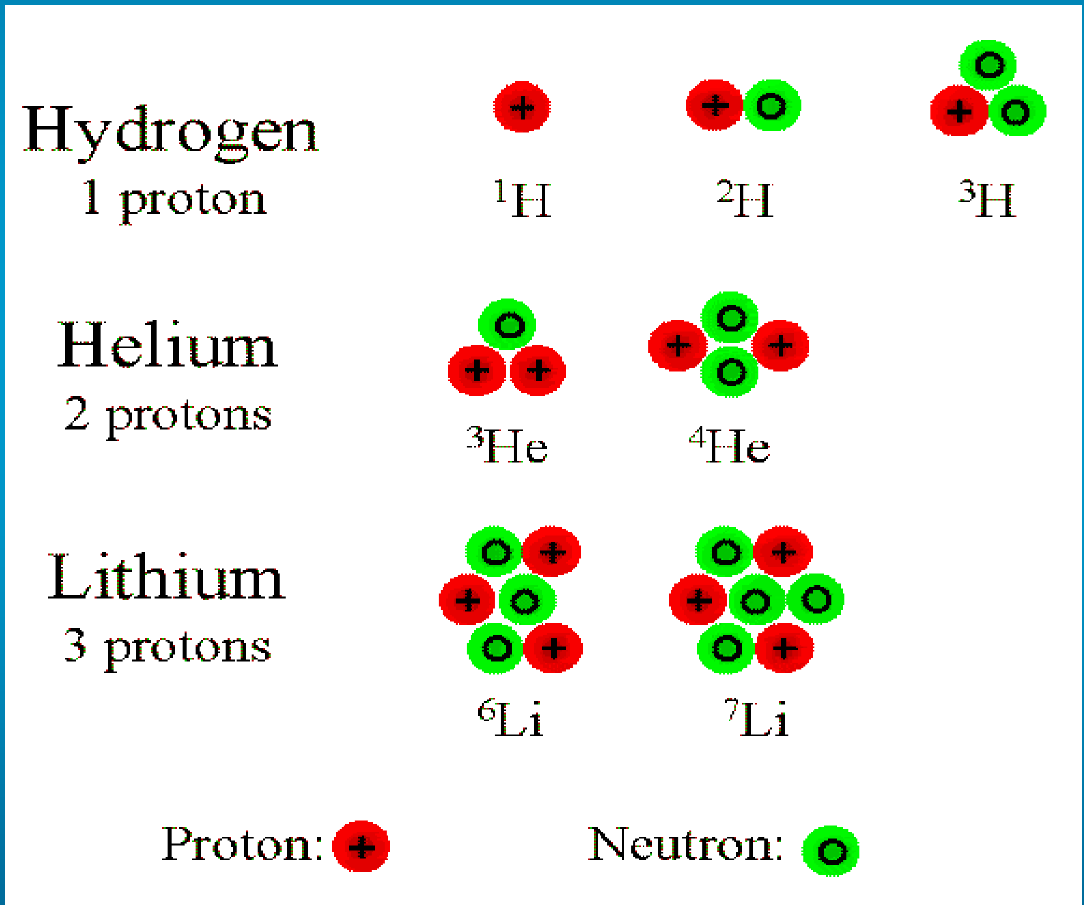


Bohr Model of Hydrogen Atom



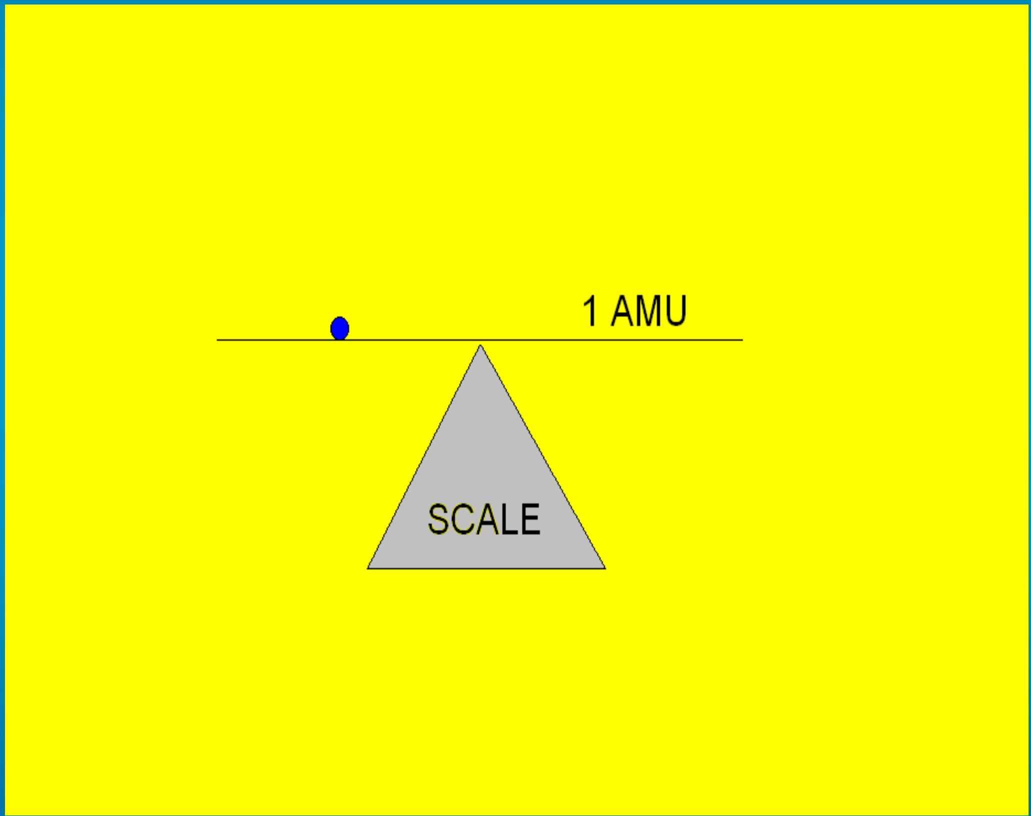
Wave Model

Atomic Mass and Isotopes



- While most atoms have the same number of protons and neutrons, some don't.
- Some atoms have more or less neutrons than protons. These are called isotopes.
- An atomic mass number with a decimal is the total of the number of protons plus the *average* number of neutrons.

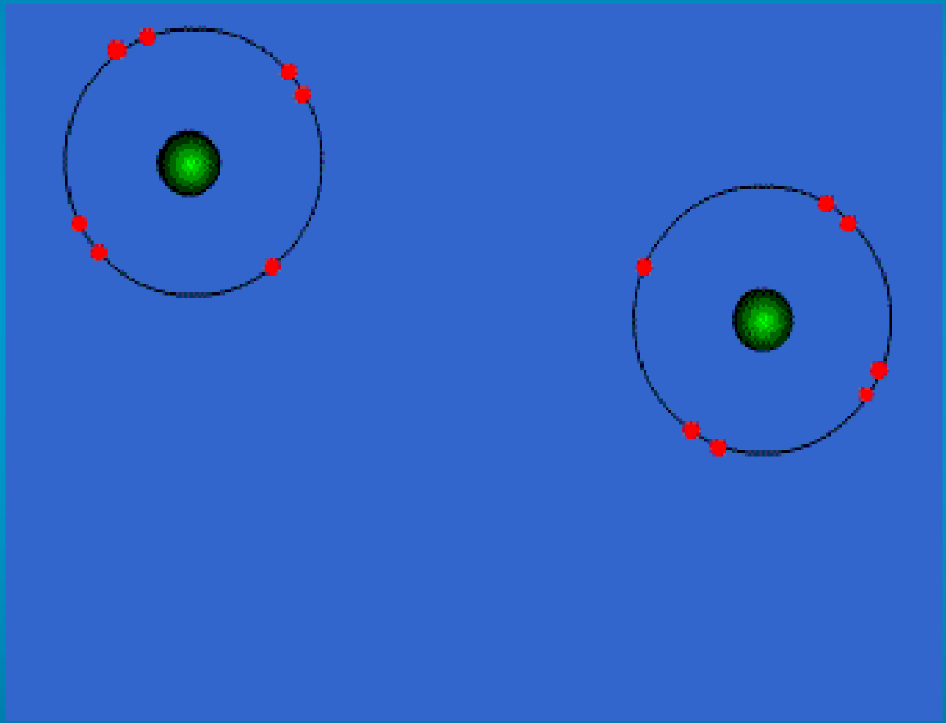
Atomic Mass Unit (AMU)



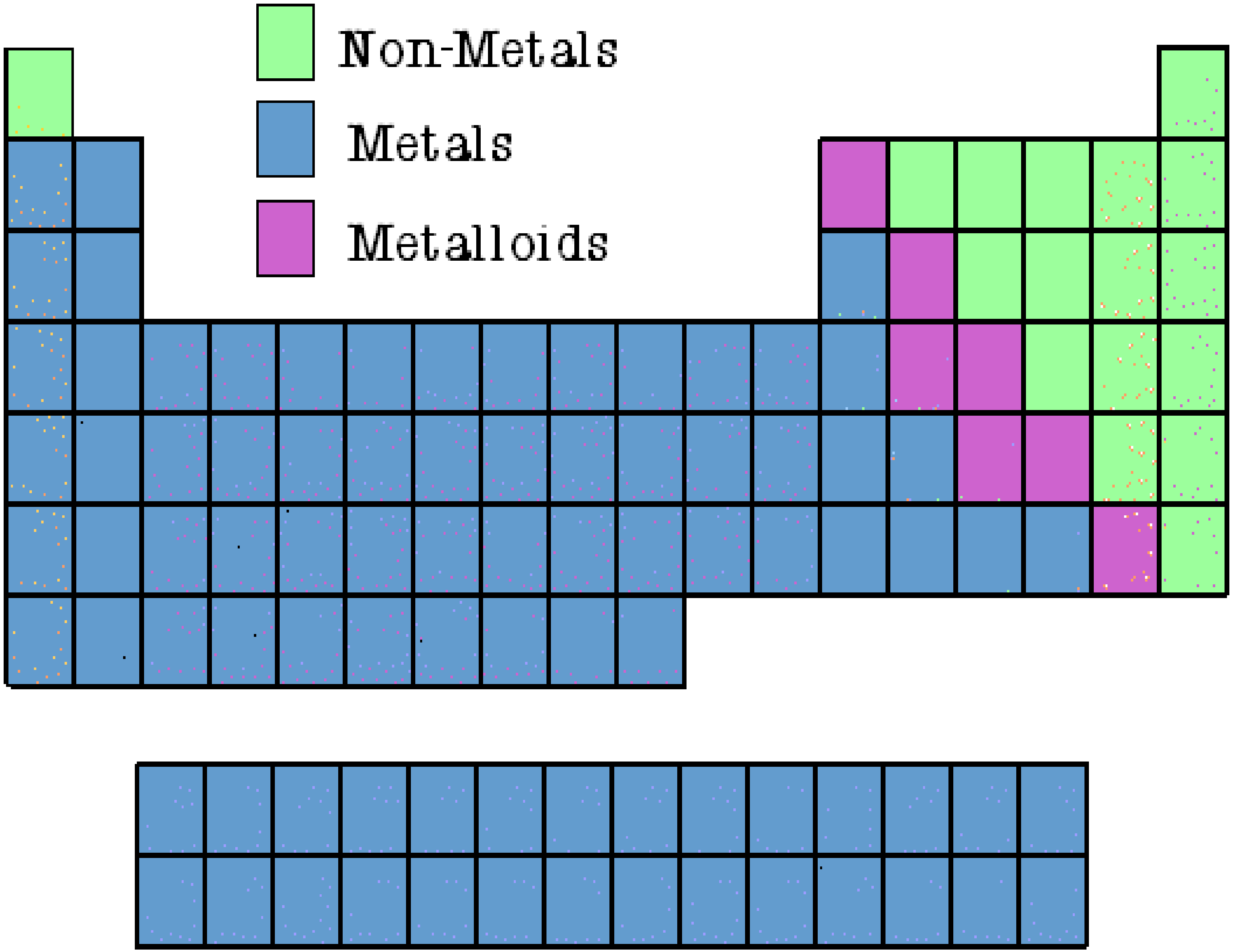
- The unit of measurement for an atom is an AMU. It stands for atomic mass unit.
- One AMU is equal to the mass of one proton.

Valence Electrons

- The number of valence electrons an atom has may also appear in a square.
- Valence electrons are the electrons in the outer energy level of an atom.
- These are the electrons that are transferred or shared when atoms bond together.



The elements of the periodic table can be divided into three main categories: Metals, Non-Metals, and Metalloids.



Properties of Metals

- Metals are good conductors of heat and electricity.
- Metals are shiny.
- Metals are ductile (can be stretched into thin wires).
- Metals are malleable (can be pounded into thin sheets).
- A chemical property of metal is its reaction with water which results in corrosion.

Properties of Non-Metals

Sulfur

- Non-metals are poor conductors of heat and electricity.
- Non-metals are not ductile or malleable.
- Solid non-metals are brittle and break easily.
- They are dull.
- Many non-metals are gases.

Properties of Metalloids

Silicon

- Metalloids (metal-like) have properties of both metals and non-metals.
- They are solids that can be shiny or dull.
- They conduct heat and electricity better than non-metals but not as well as metals.
- They are ductile and malleable.

Groups

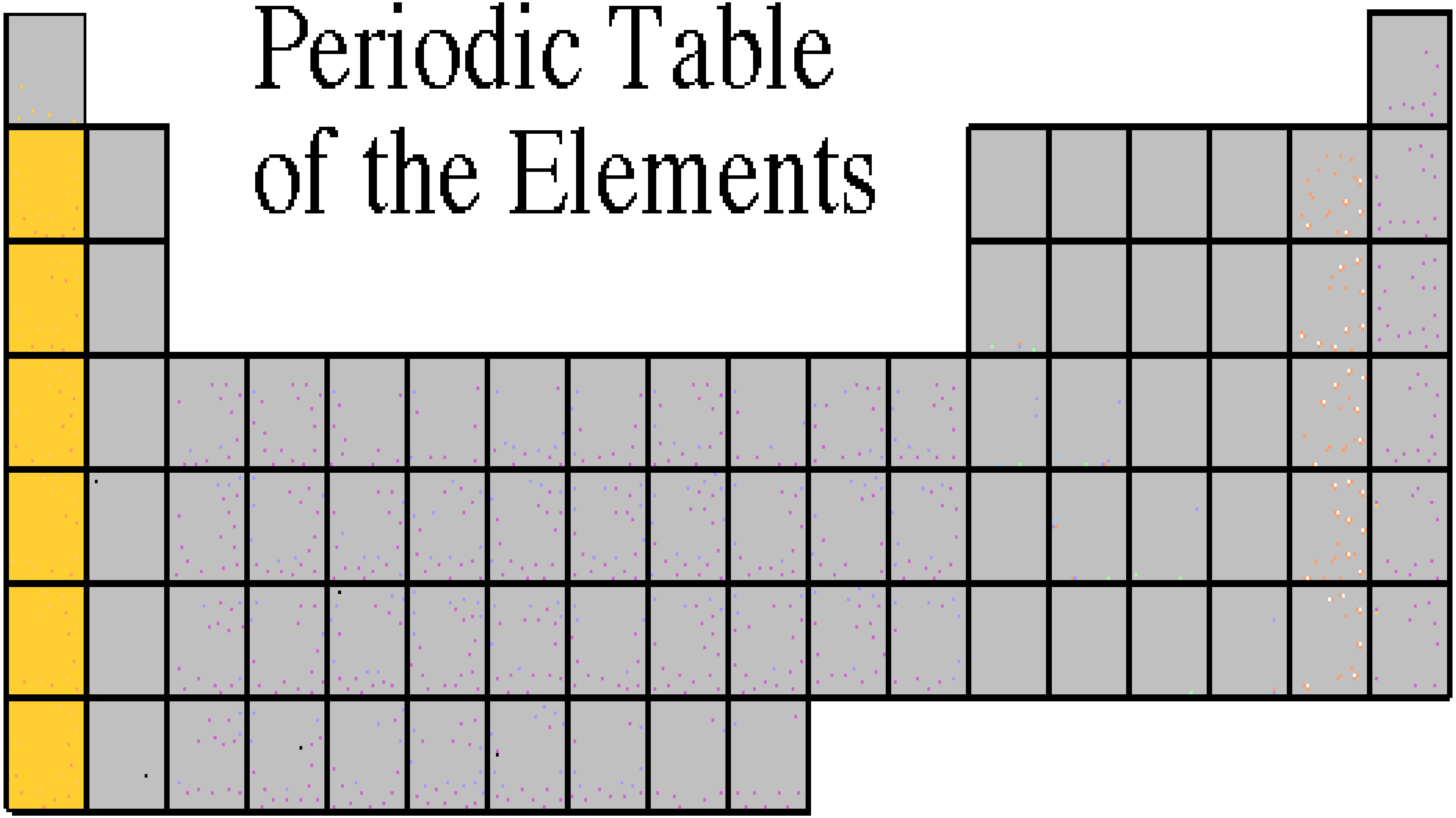
- Columns of elements are called groups or families.
- Elements in each family have similar but not identical properties.
- For example, lithium (Li), sodium (Na), potassium (K), and other members of family IA are all soft, white, shiny metals.
- All elements in a family have the same number of valence electrons.

Periods

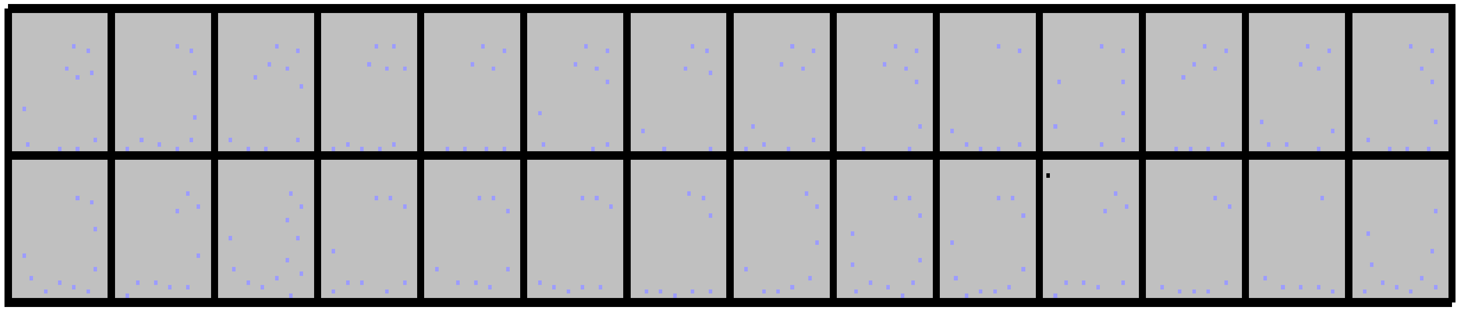
- Each horizontal row of elements is called a period.
- The elements in a period are not alike in properties.
- In fact, the properties change greatly across even given row.
- The first element in a period is always an extremely active solid. The last element in a period, is always an inactive gas.

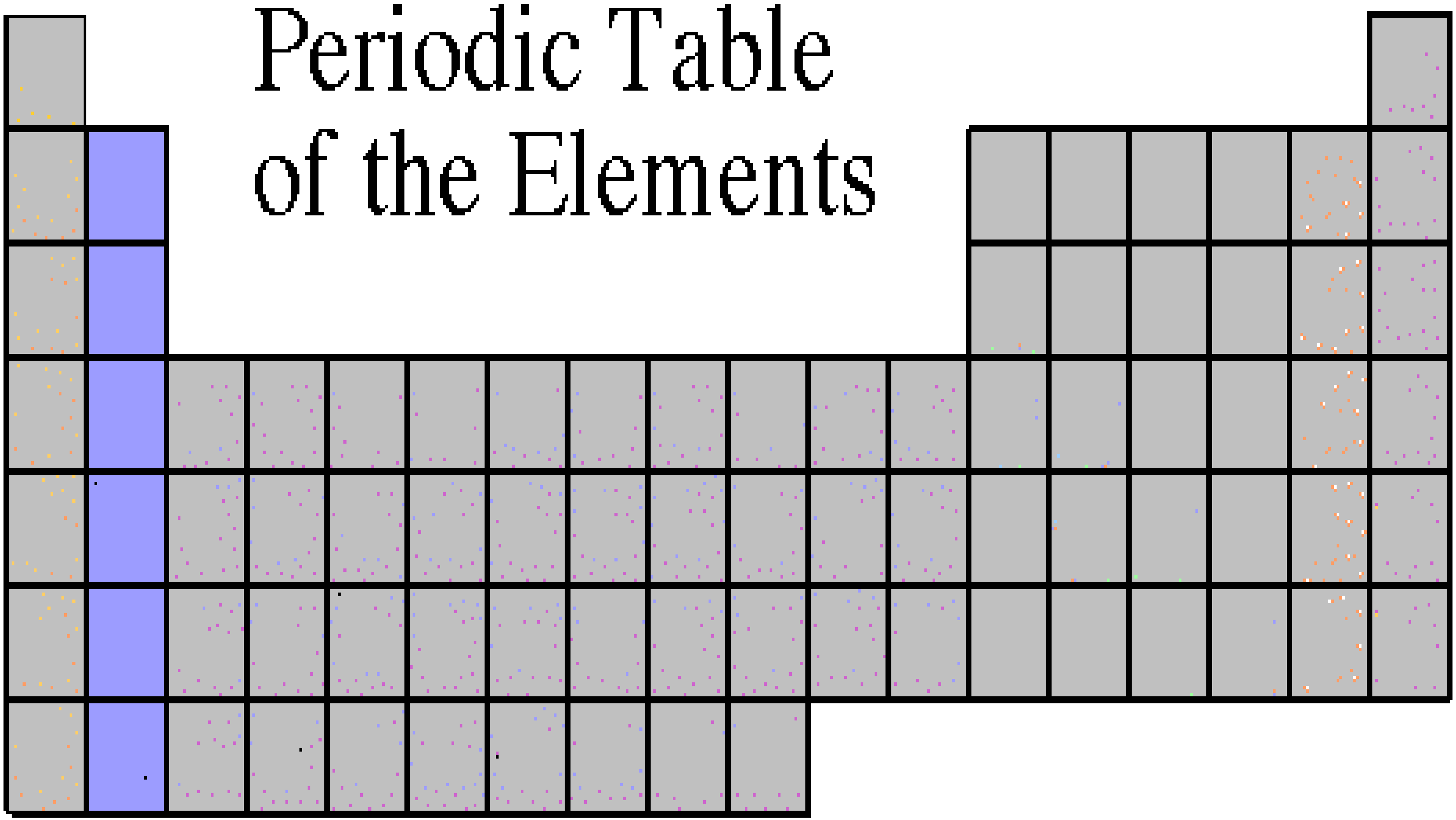
Group

Periodic Table of the Elements

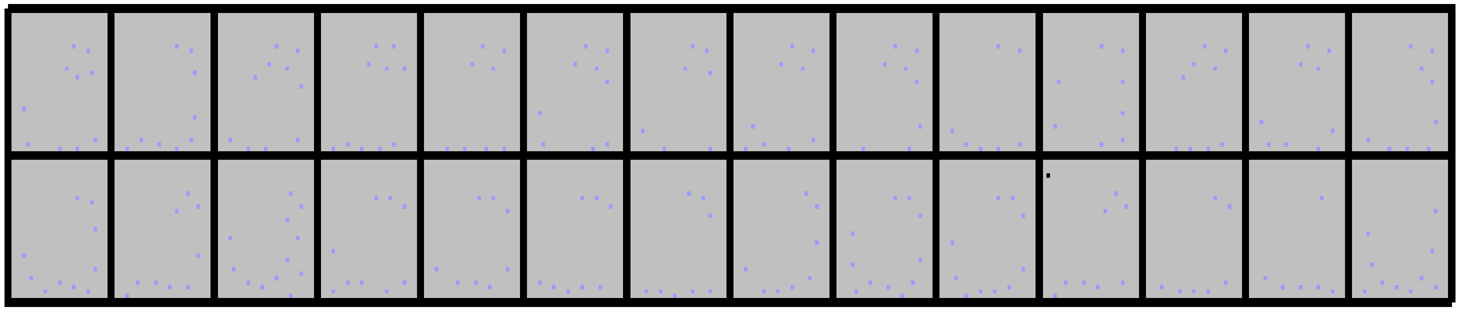


- S-block Elements, Alkali Metals

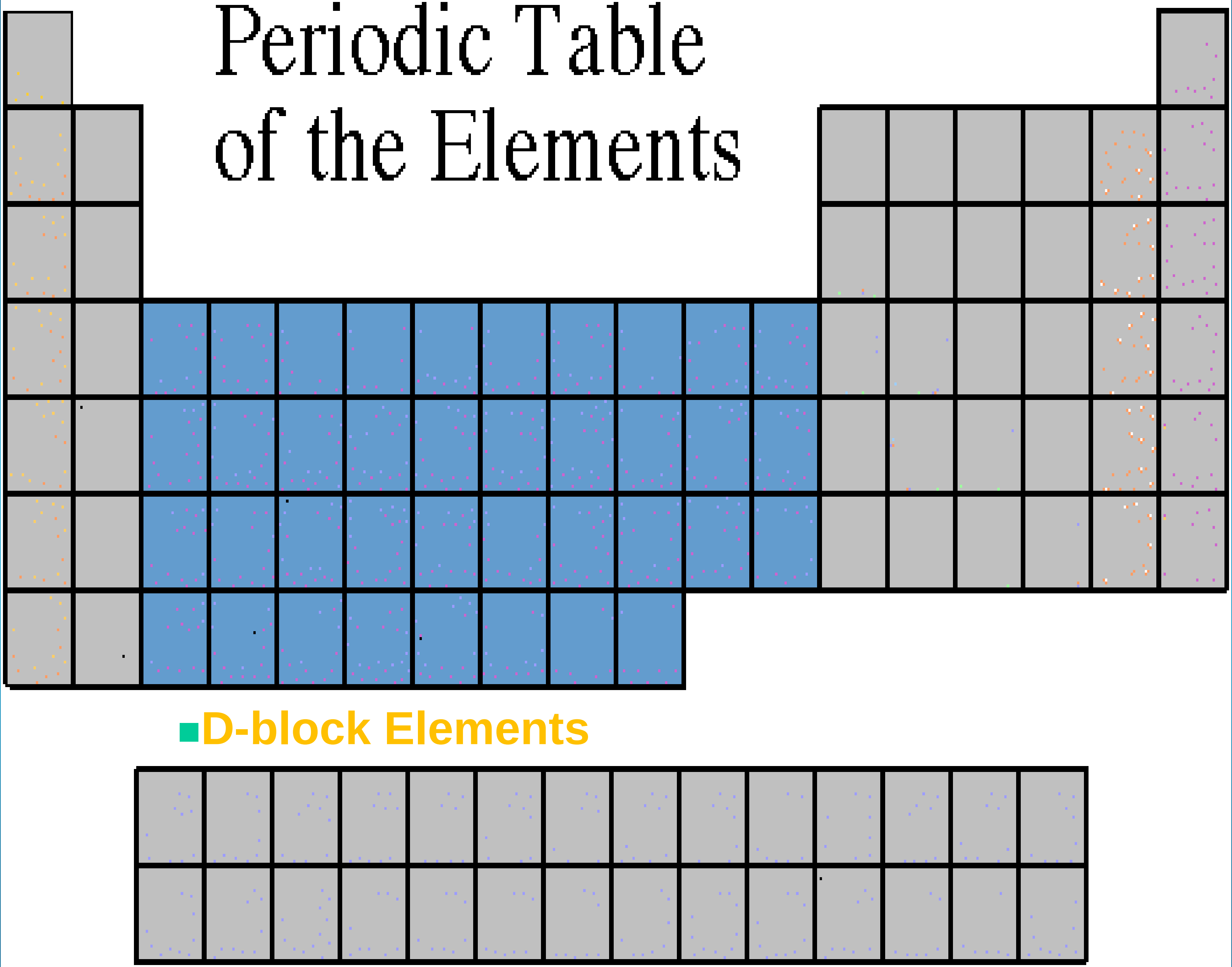




- S-block Elements, Alkaline Earth Metals

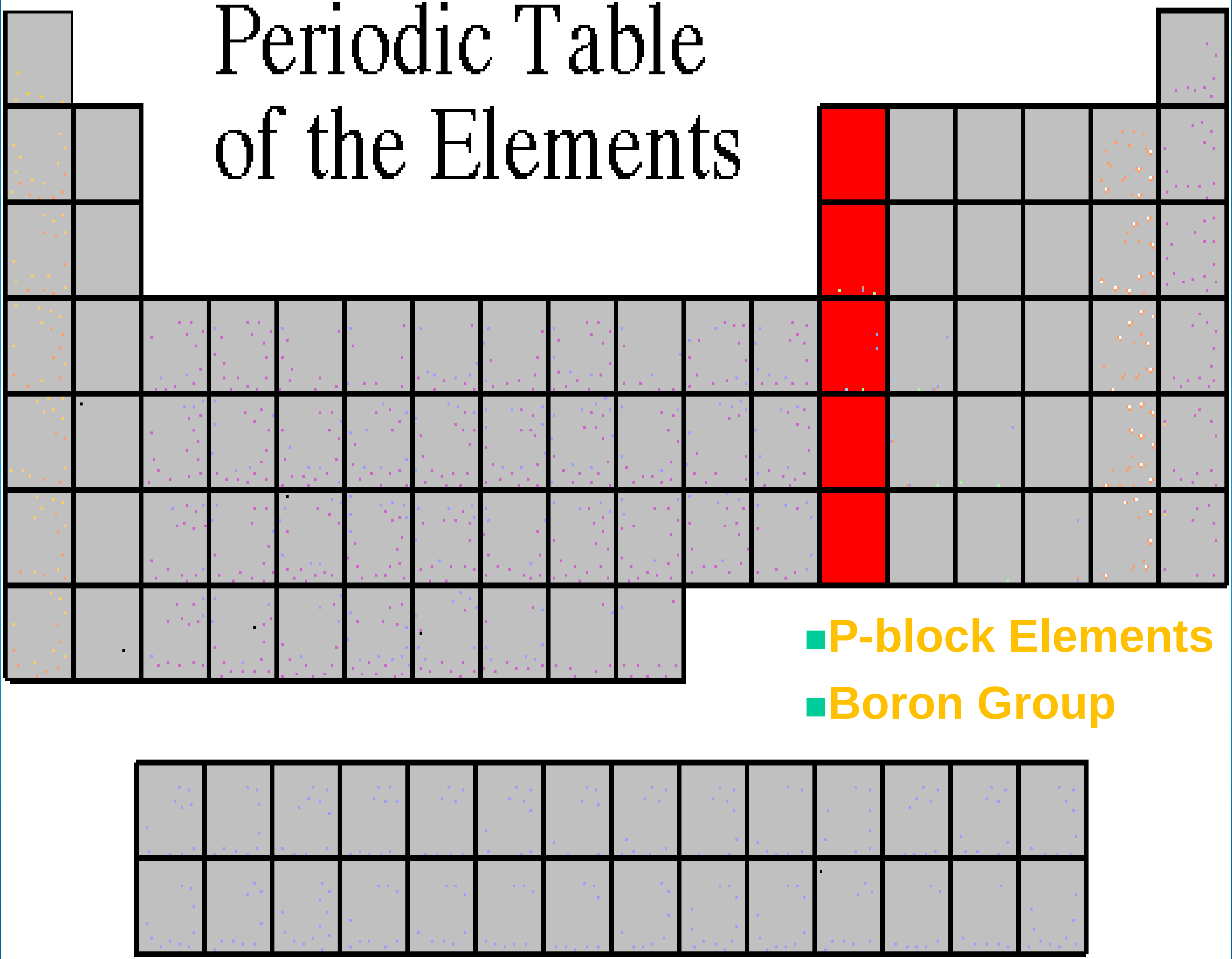


Periodic Table of the Elements



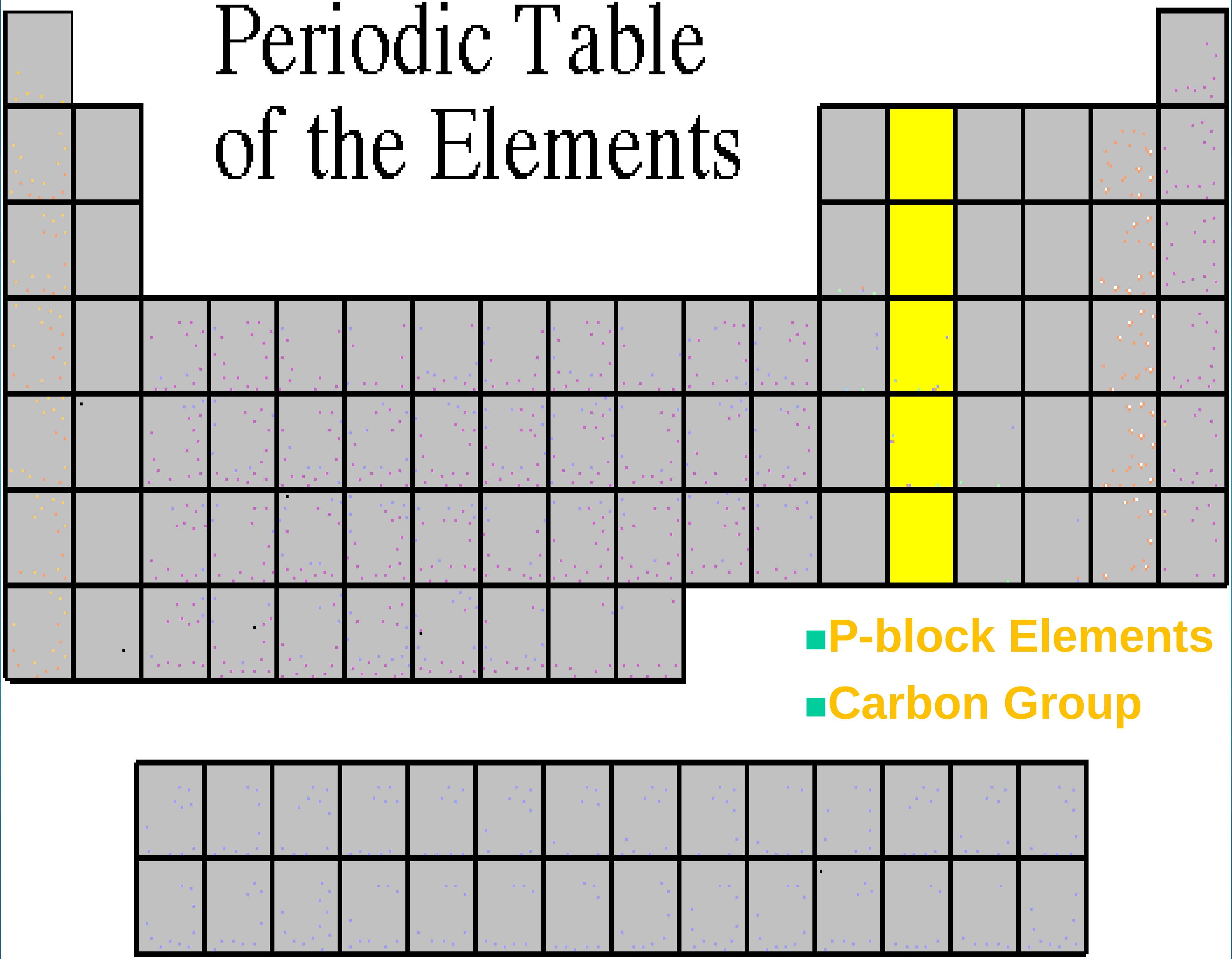
■ D-block Elements

Periodic Table of the Elements



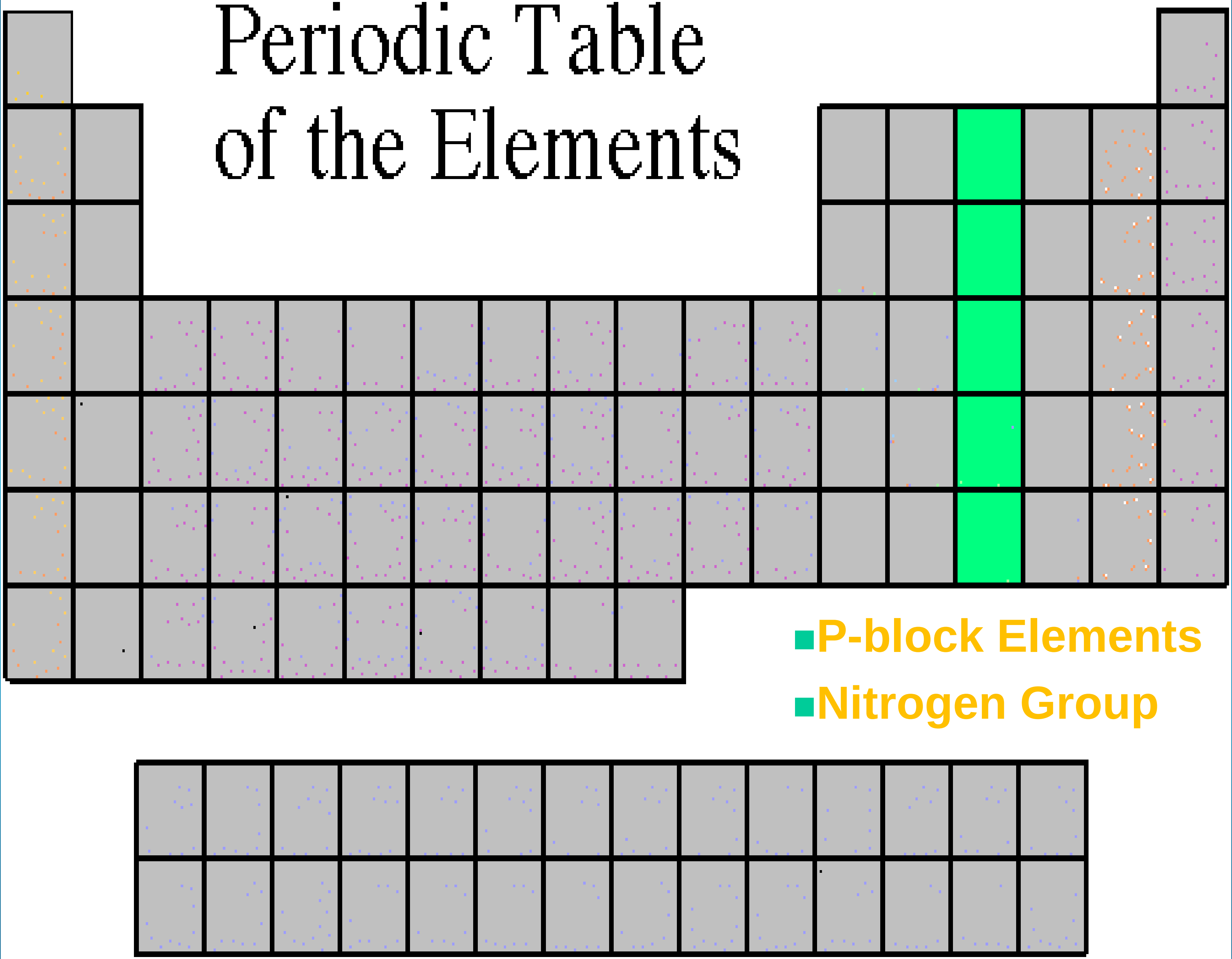
- P-block Elements
- Boron Group

Periodic Table of the Elements



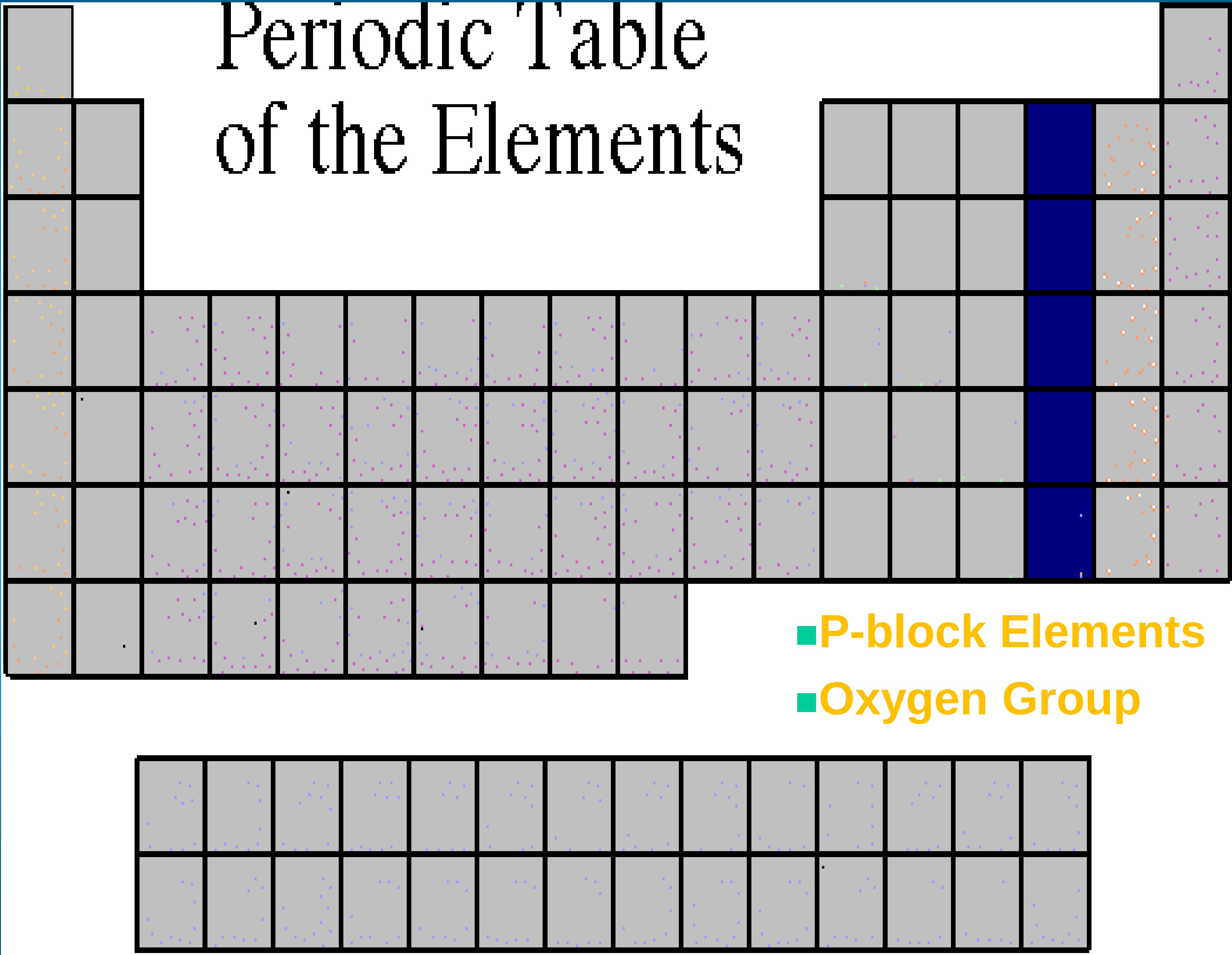
- P-block Elements
- Carbon Group

Periodic Table of the Elements



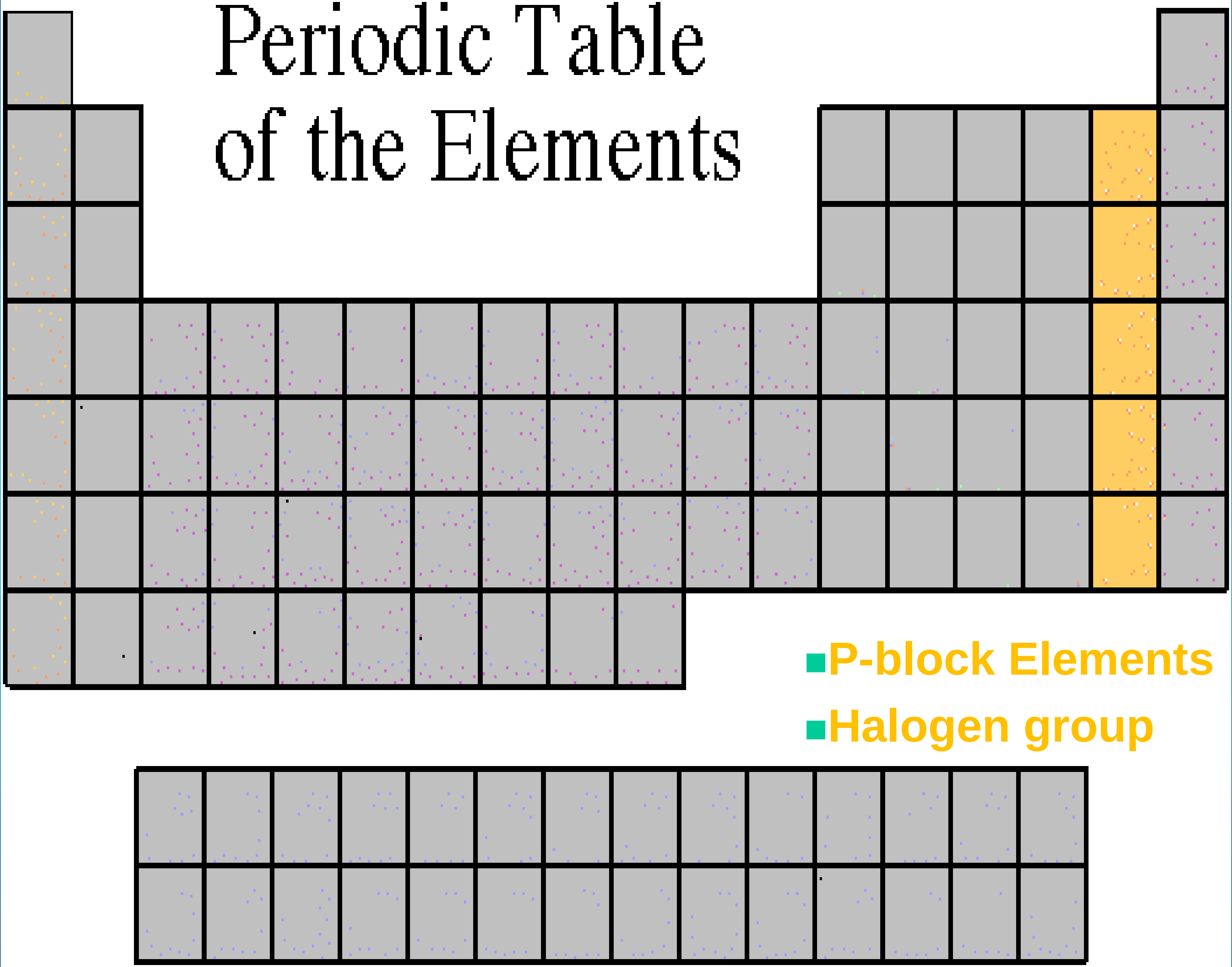
- P-block Elements
- Nitrogen Group

Periodic Table of the Elements



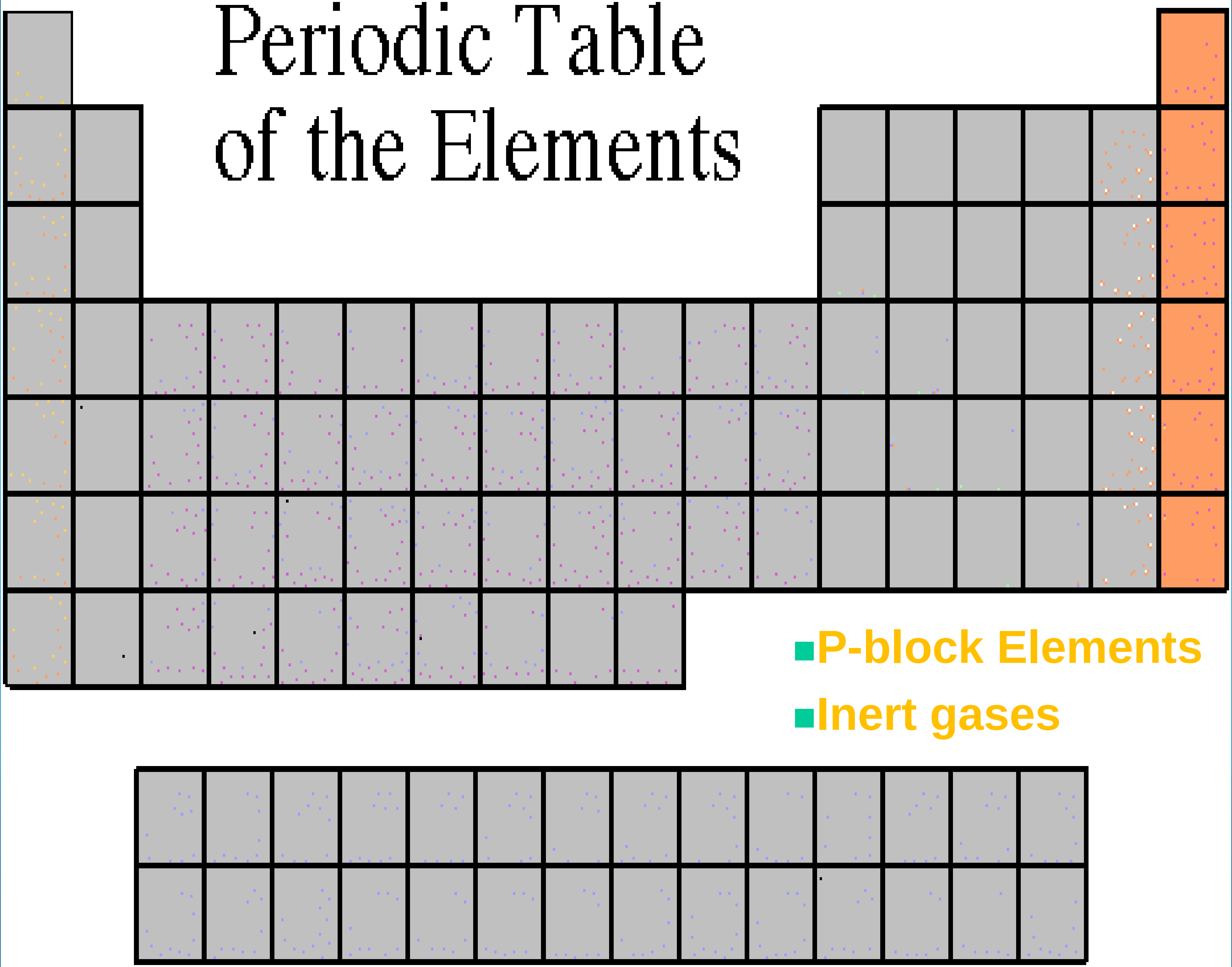
- P-block Elements
- Oxygen Group

Periodic Table of the Elements



- P-block Elements
- Halogen group

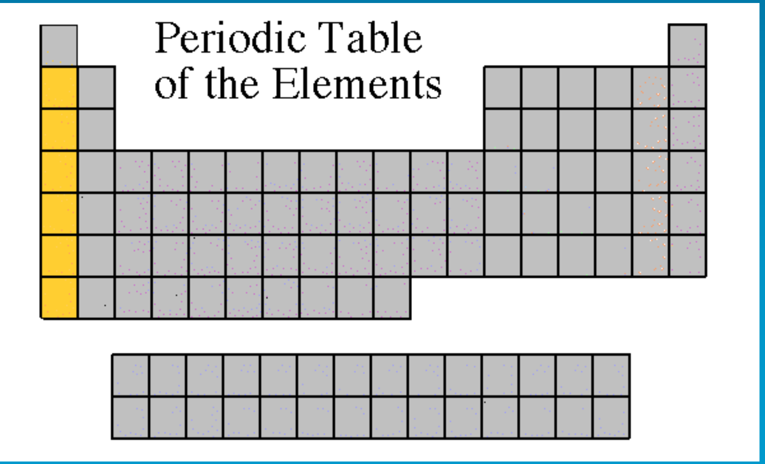
Periodic Table of the Elements

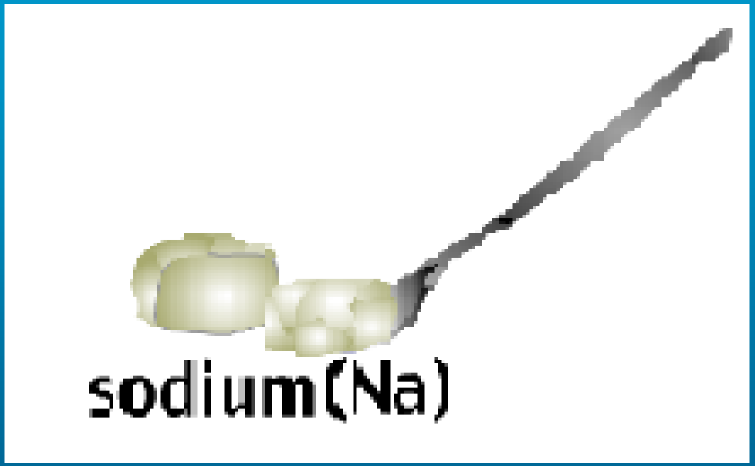


- P-block Elements
- Inert gases

Alkali Metals

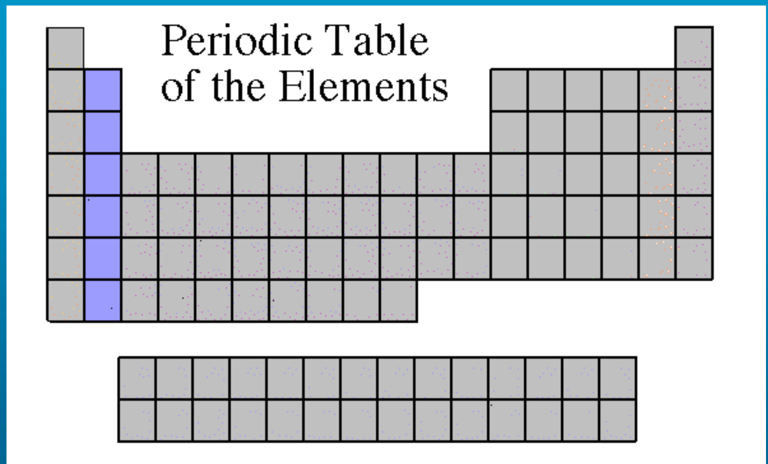
- The alkali family is found in the first column of the periodic table.
- Atoms of the alkali metals have a single electron in their outermost level, in other words, 1 valence electron.
- They are shiny, have the consistency of clay, and are easily cut with a knife.





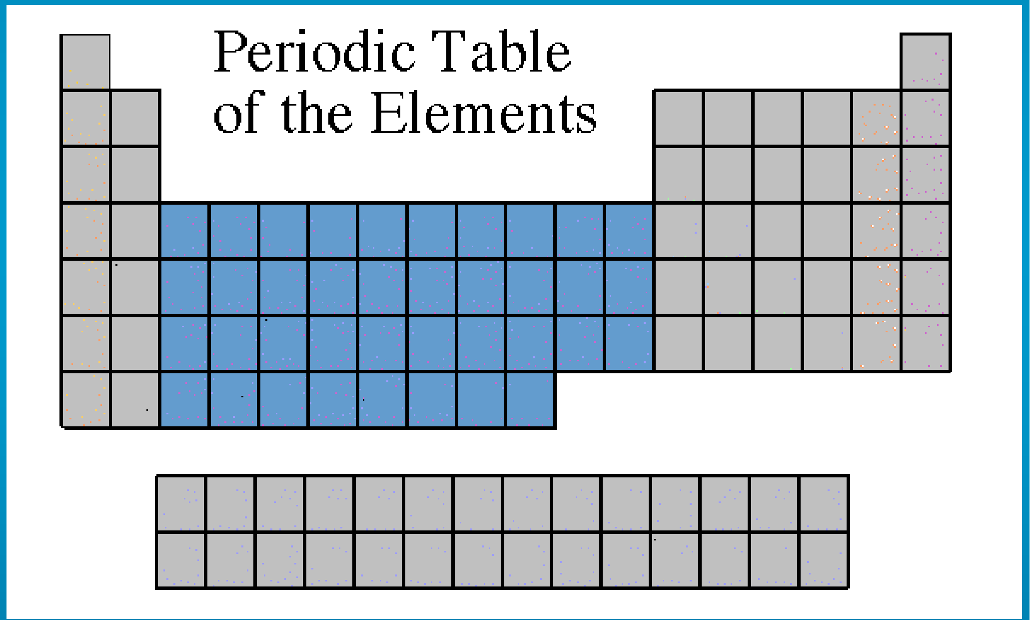
Alkaline Earth Metals

- They are never found uncombined in nature.
- They have two valence electrons.
- Alkaline earth metals include magnesium and calcium, among others.



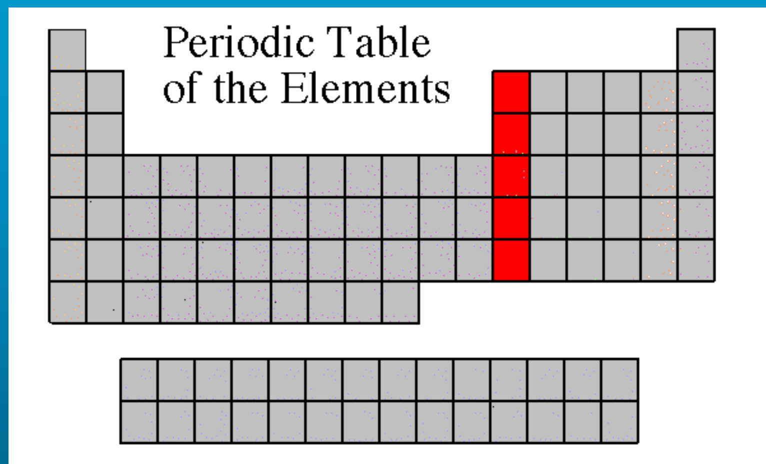
Transition Metals

- Transition Elements include those elements in the B families.
- These are the metals you are probably most familiar: copper, tin, zinc, iron, nickel, gold, and silver.
- They are good conductors of heat and electricity.



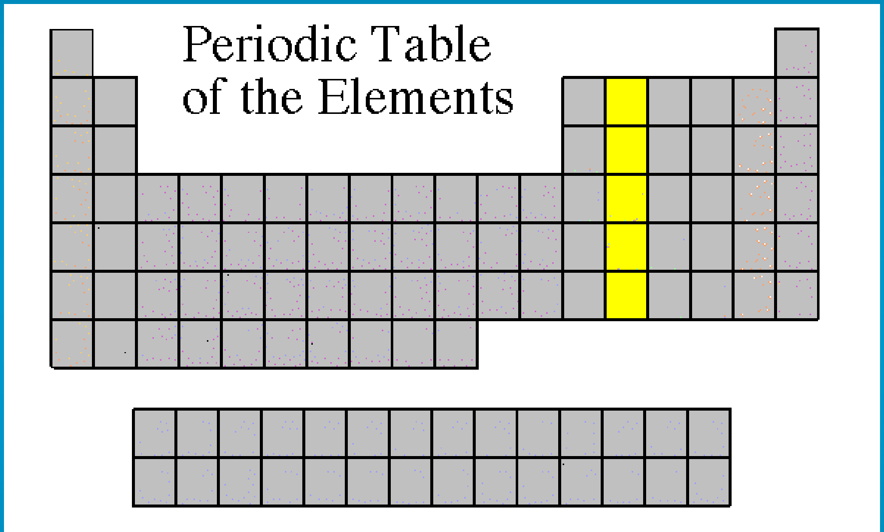
Boron Family

- The Boron Family is named after the first element in the family.
- Atoms in this family have 3 valence electrons.
- This family includes a metalloid (boron), and the rest are metals.
- This family includes the most abundant metal in the earth's crust (aluminum).



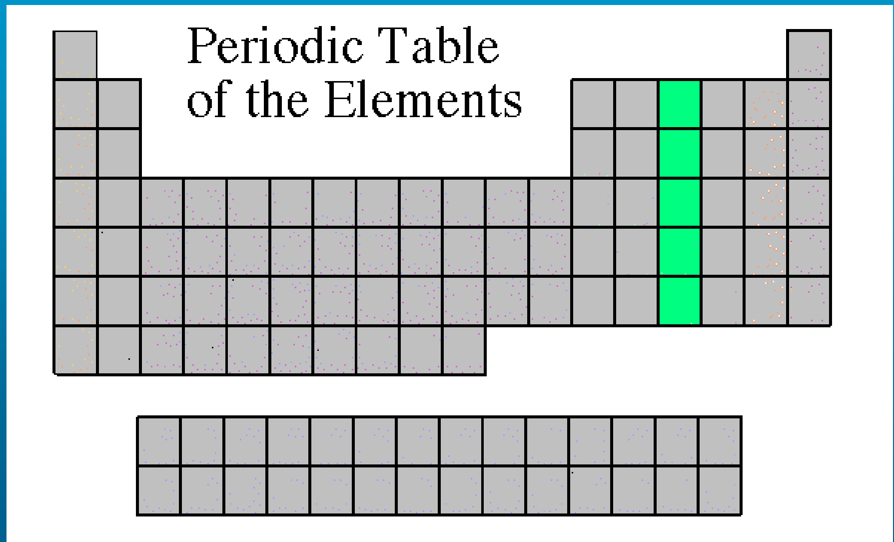
Carbon Family

- Atoms of this family have 4 valence electrons.
- This family includes a non-metal (carbon), metalloids, and metals.
- The element carbon is called the "basis of life." There is an entire branch of chemistry devoted to carbon compounds called organic chemistry.



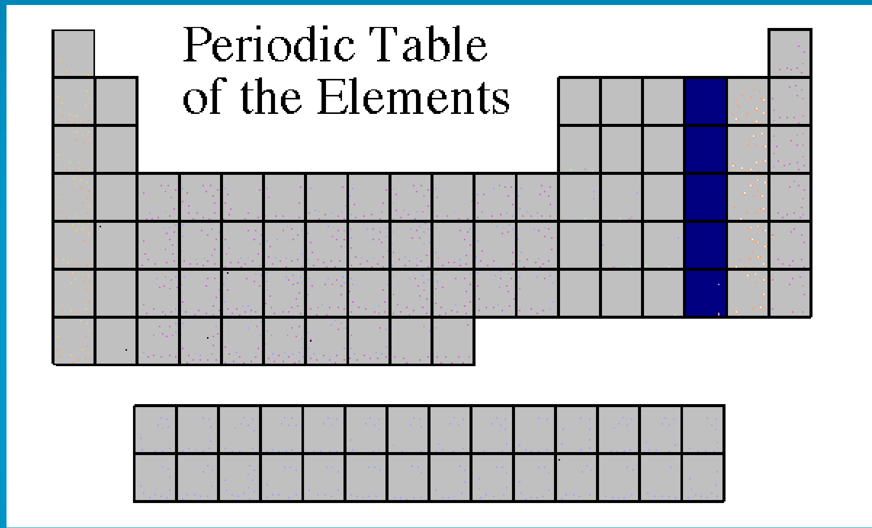
Nitrogen Family

- The nitrogen family is named after the element that makes up 78% of our atmosphere.
- This family includes non-metals, metalloids, and metals.
- Atoms in the nitrogen family have 5 valence electrons. They tend to share electrons when they bond.
- Other elements in this family are phosphorus, arsenic, antimony, and bismuth.



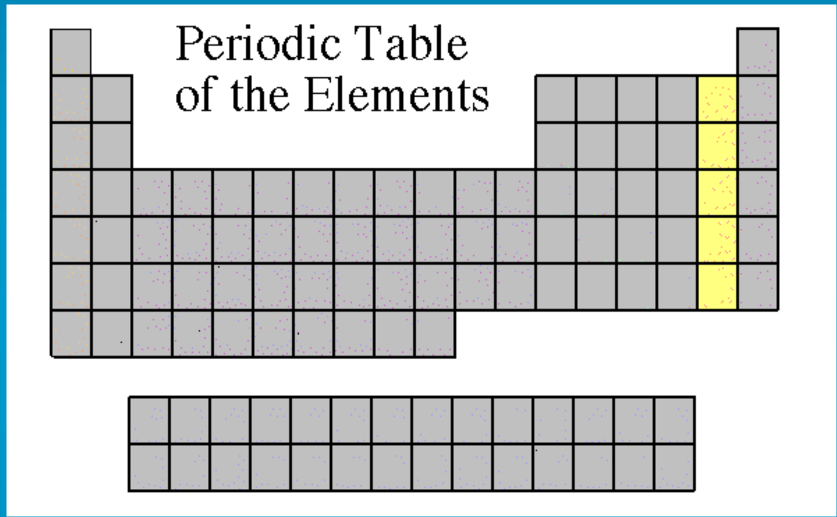
Oxygen Family

- Atoms of this family have 6 valence electrons.
- Most elements in this family share electrons when forming compounds.
- Oxygen is the most abundant element in the earth's crust. It is extremely active and combines with almost all elements.



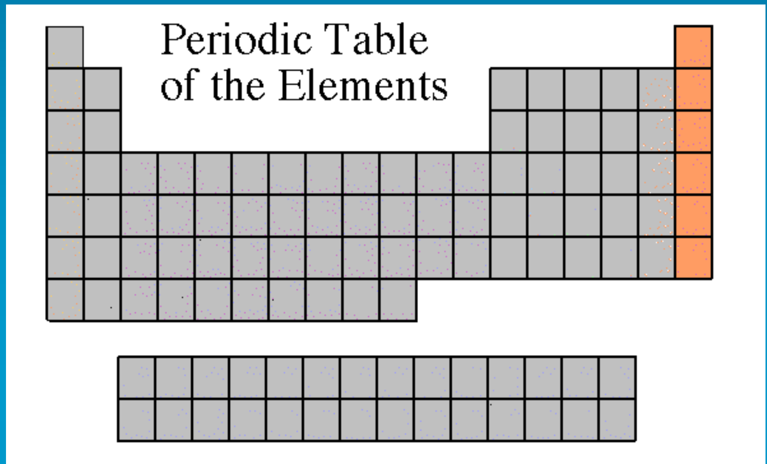
Halogen Family

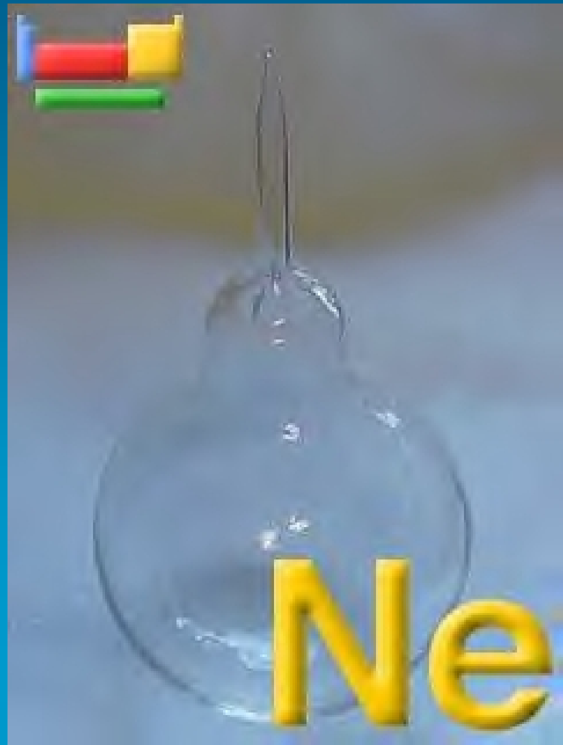
- The elements in this family are fluorine, chlorine, bromine, iodine, and astatine.
- Halogens have 7 valence electrons, which explains why they are the most active non-metals. They are never found free in nature.



- Halogen atoms only need to gain 1 electron to fill their outermost energy level.
- They react with alkali metals to form salts.

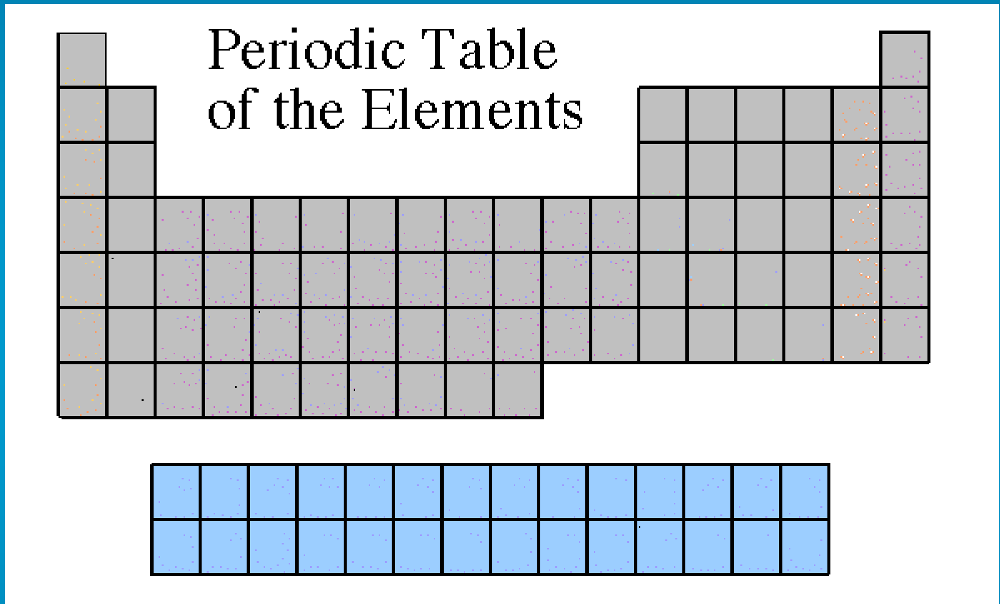
Noble Gases





- Noble Gases are colorless gases that are extremely un-reactive.
- One important property of the noble gases is their inactivity. They are inactive because their outermost energy level is full.
- Because they do not readily combine with other elements to form compounds, the noble gases are called inert.
- The family of noble gases includes helium, neon, argon, krypton, xenon, and radon.
- All the noble gases are found in small amounts in the earth's atmosphere.

Rare Earth Elements



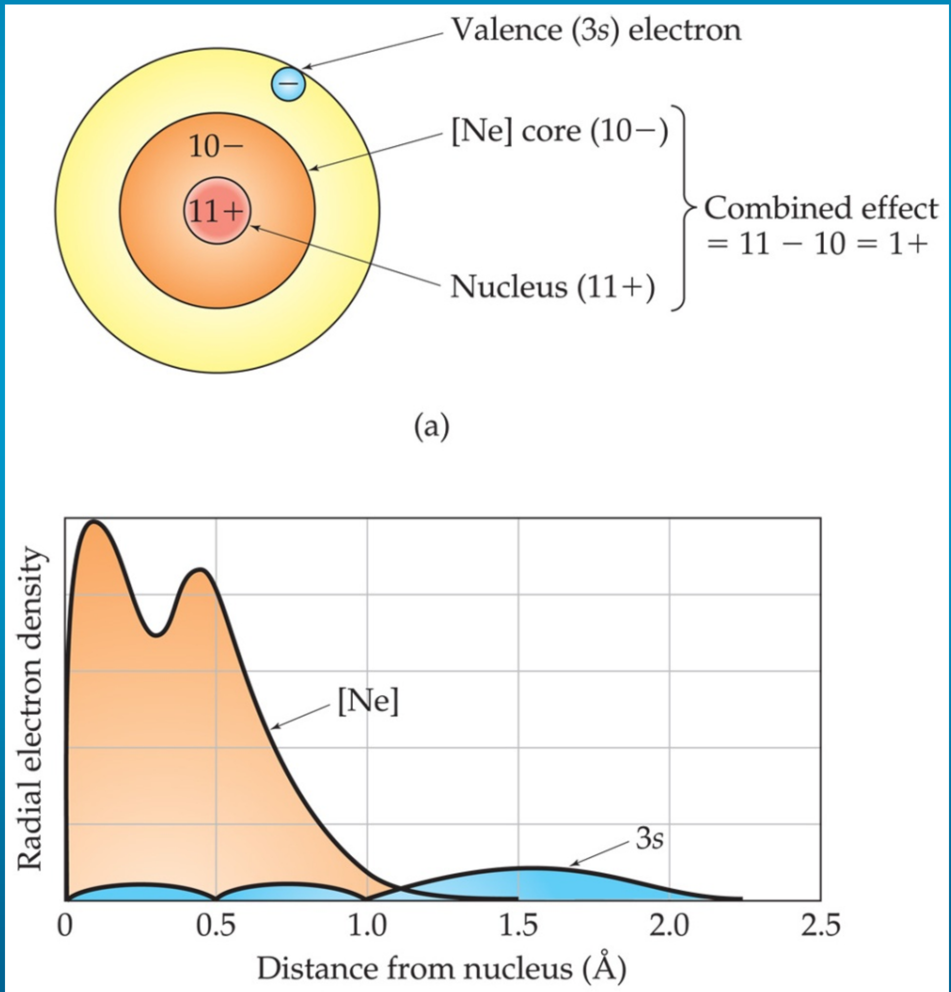
- The thirty rare earth elements are composed of the lanthanoid and actinoid series.
- One element of the lanthanoid series and most of the elements in the actinoid series are called trans-uranium, which means synthetic or man-made.

Periodic Trends

- In this chapter we'll explain why
- We'll then rationalize observed trends in
  - Sizes of atoms and ions.
  - Ionization energy.
  - Electron affinity.

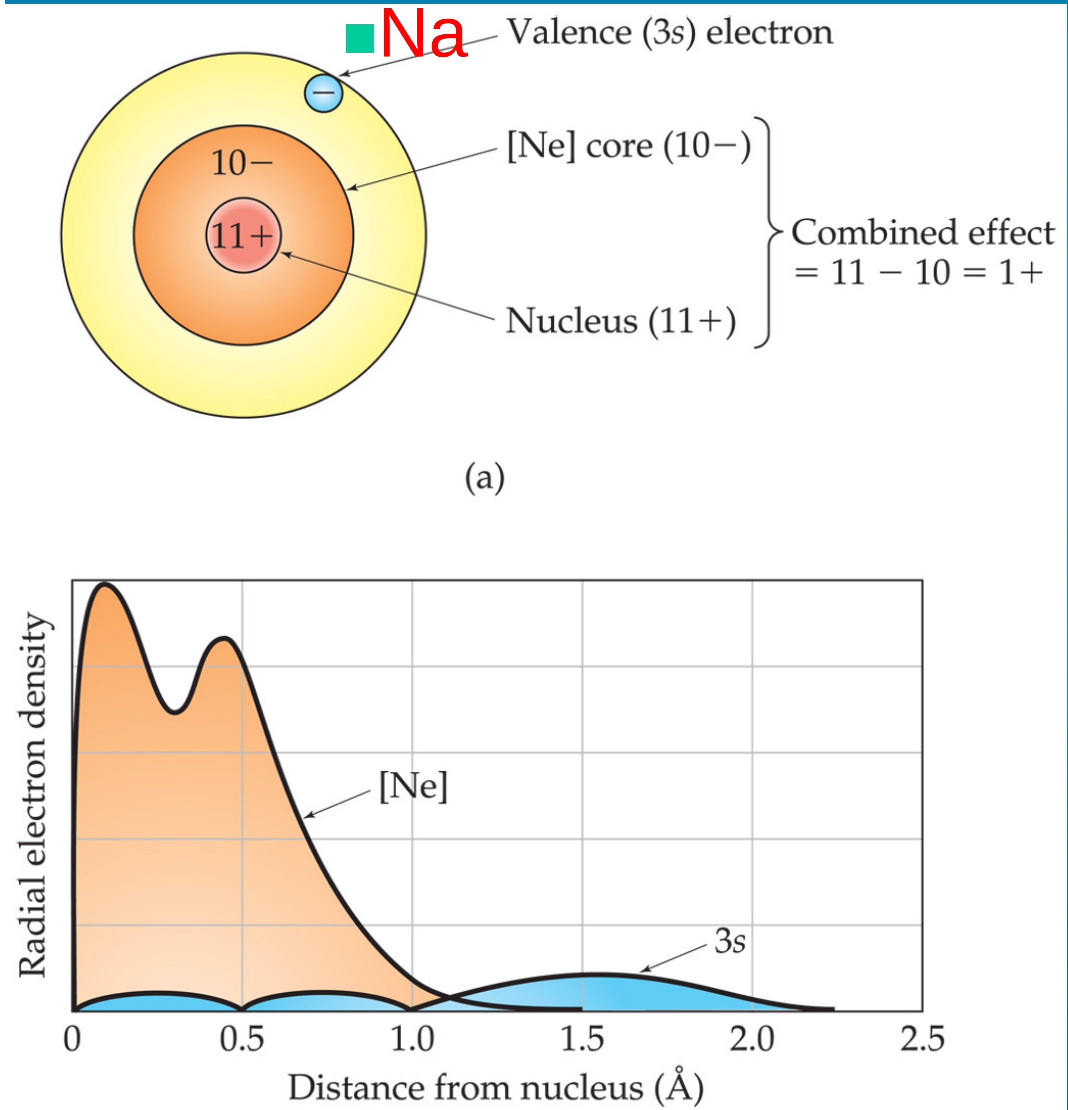
Effective Nuclear Charge

- Na atom looks like this:



- In a many-electron atom, electrons are both attracted to the nucleus and repelled by other electrons.
- The nuclear charge that an electron “feels” depends on both factors.
- It’s called Effective nuclear charge.
- electrons in lower energy levels “shield” outer electrons from positive charge of nucleus.

Effective Nuclear Charge



The effective nuclear charge, Z_{eff}, is:

$Z_{eff} = Z - S$

Where:

Z = atomic number

S = screening constant, usually close to the number of inner (n-1) electrons.

Effective Nuclear Charge

- Example: Which element's outer shell or "valence" electrons is predicted to have the largest Effective nuclear charge? Kr, Cl or O?

- Cl: $Z_{eff} \approx 17 - 10 = 7$
- O: $Z_{eff} \approx 8 - 2 = 6$
- N: $Z_{eff} \approx 7 - 2 = 5$
- Ca: $Z_{eff} \approx 20 - 18 = 2$

Valence electrons

Many chemical properties depend on the valence electrons.

Valence electrons: The outer electrons, that are involved in bonding and most other chemical changes of elements.

Rules for defining valence electrons.

1. In outer most energy level (or levels)
2. For main group (representative) elements (elements in s world or p world) electrons in filled d or f shells are not valence electrons
3. For transition metals, electrons in full f shells are not valence electrons.

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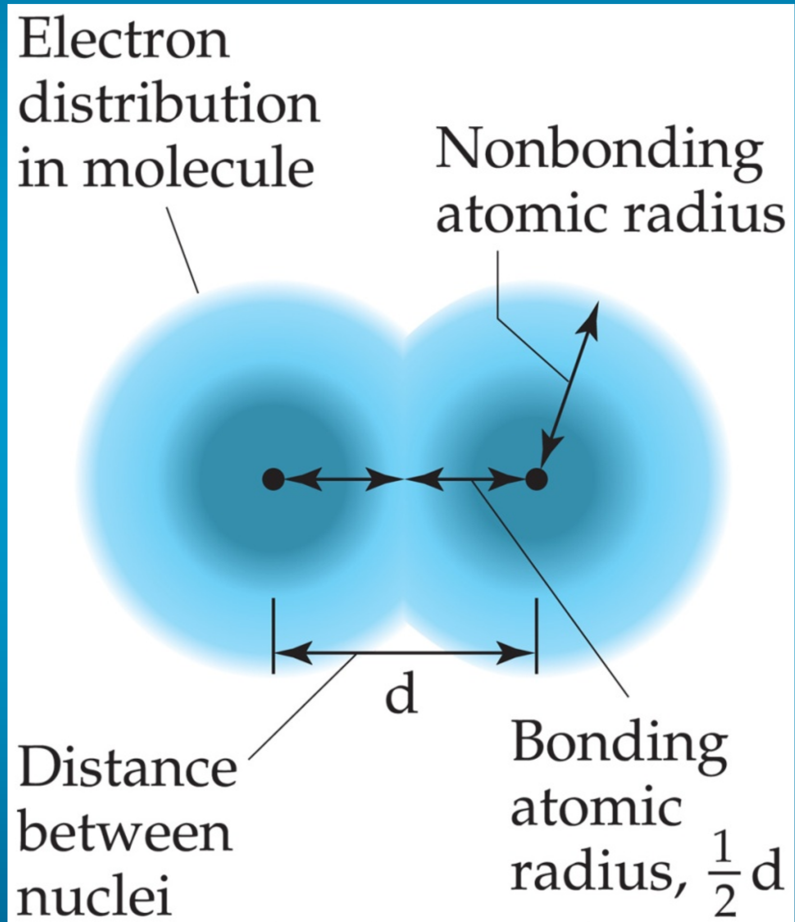
3. For transition metals, electrons in full f shells are not valence electrons.

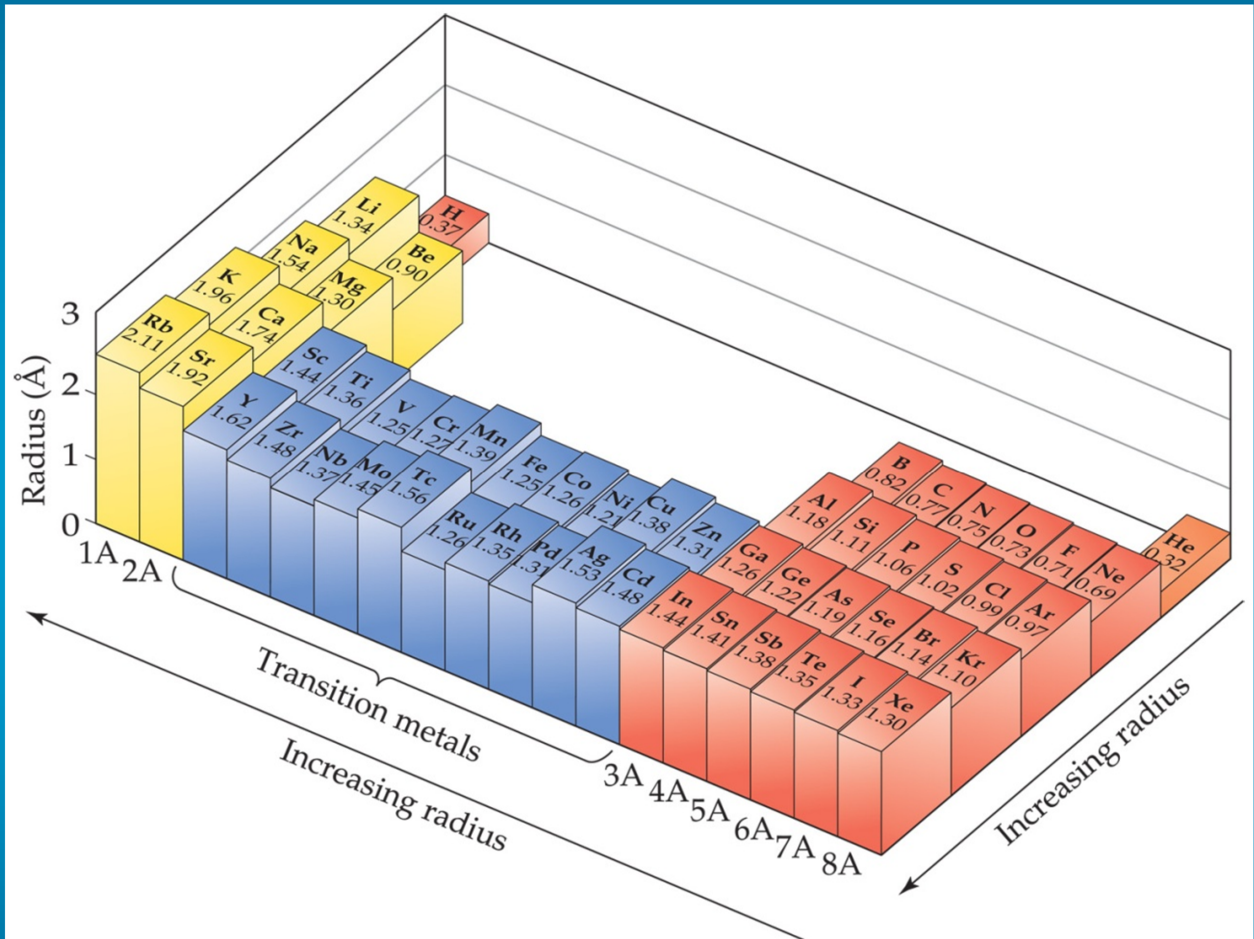
- Examples: (valence electrons in blue)
- P: [Ne]$3s^2 3p^3$
- As: [Ar] $4s^2 3d^{10} 4p3$
- I: [Kr]$5s^2 4d^{10} 5p^5$
- Ta: [Kr]$6s^2 4f^{14} 5d^3$
- Zn: [Ar]$4s^2 3d^{10}$

Sizes of Atoms

The bonding atomic radius is defined as one-half of the distance between covalently bonded nuclei.



Sizes of Atoms

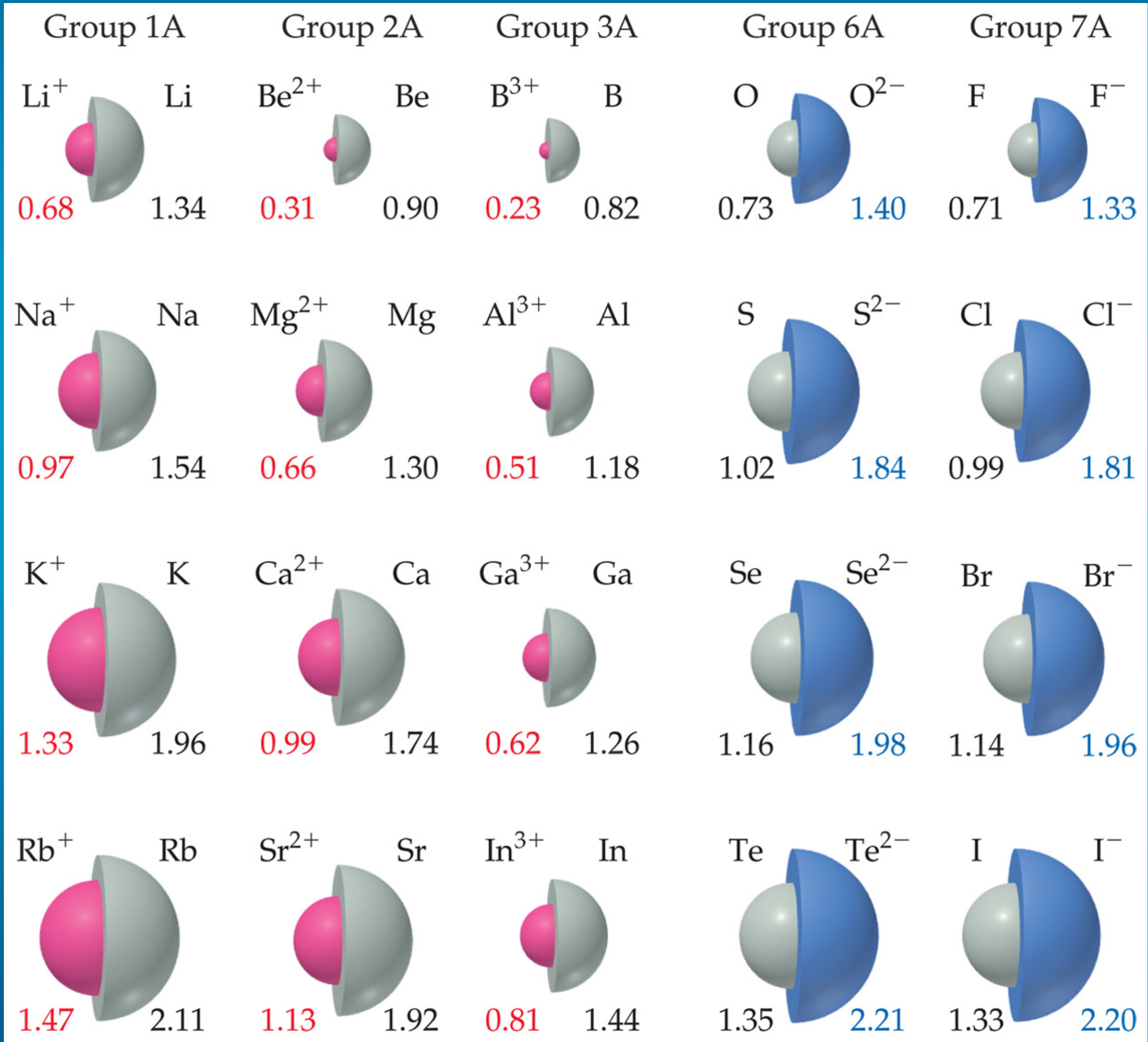


Bonding atomic radius tends to…

…decrease from left to right across a row due to increasing Z_{eff}.

…increase from top to bottom of a column due to increasing value of *n*

Sizes of Ions



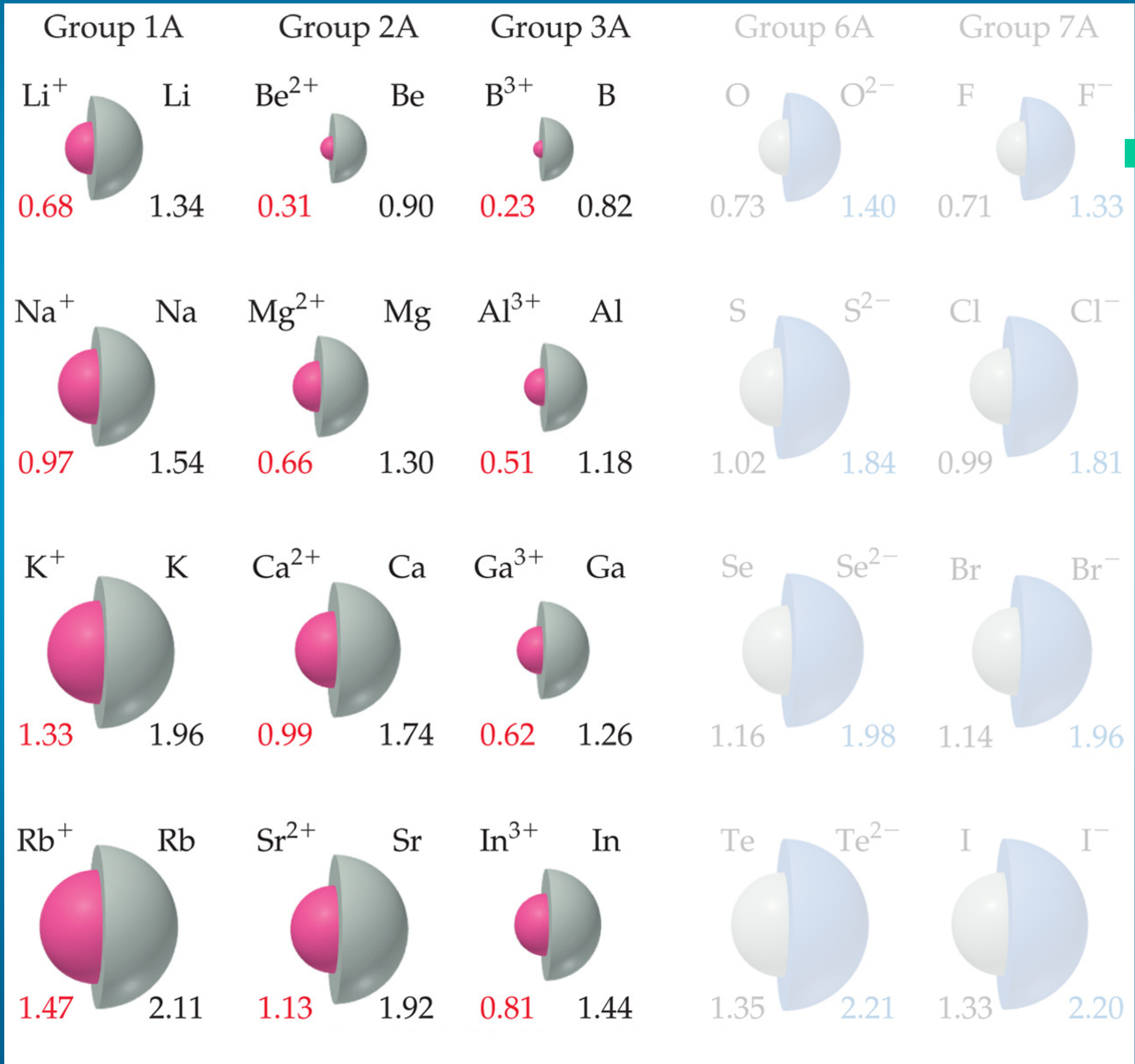
Ionic size depends upon:

Nuclear charge.

Number of electrons.

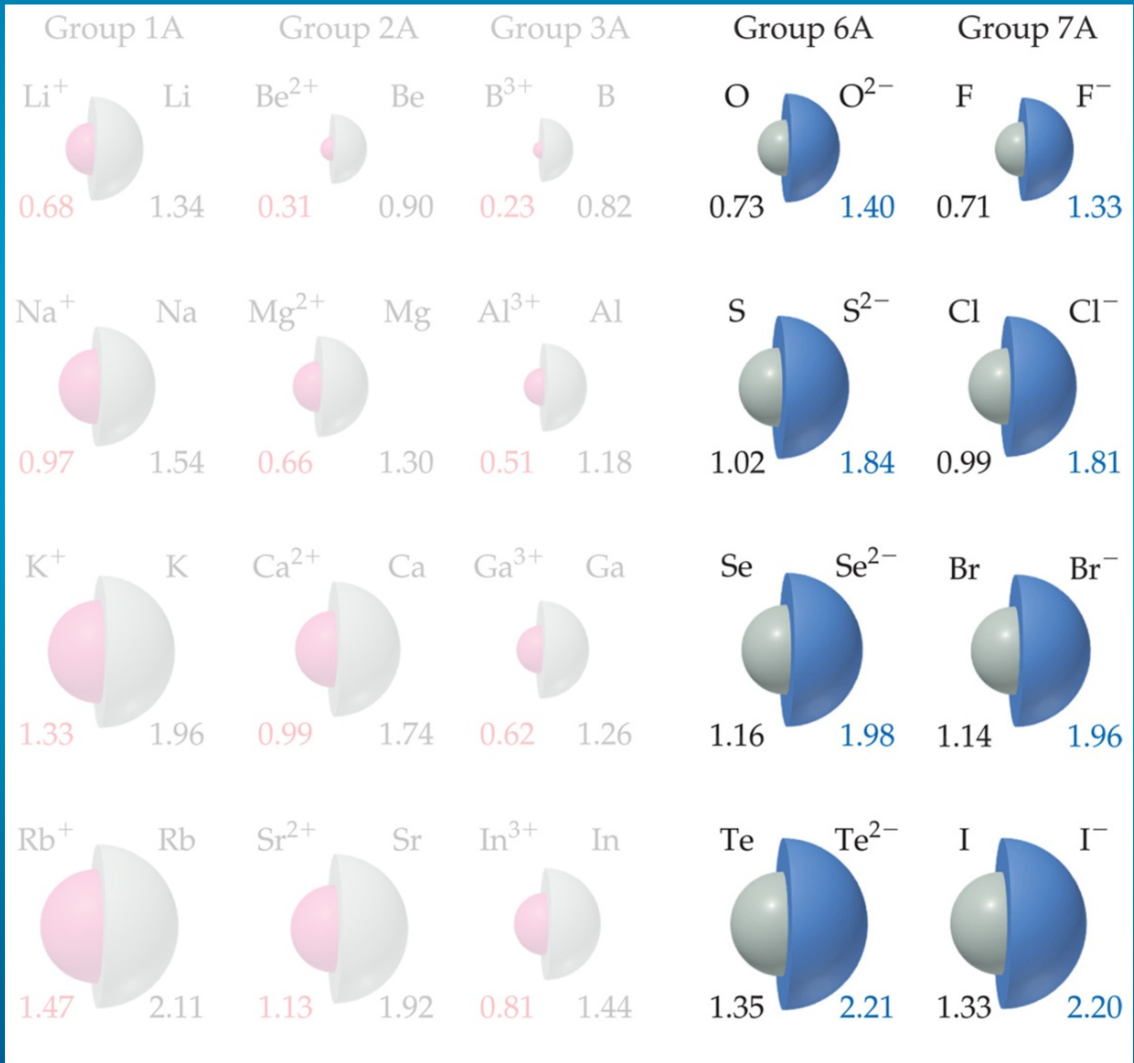
Orbitals in which electrons reside.

Sizes of Ions



- Cations are smaller than their parent atoms.
  - The outermost electron is removed and repulsions are reduced.

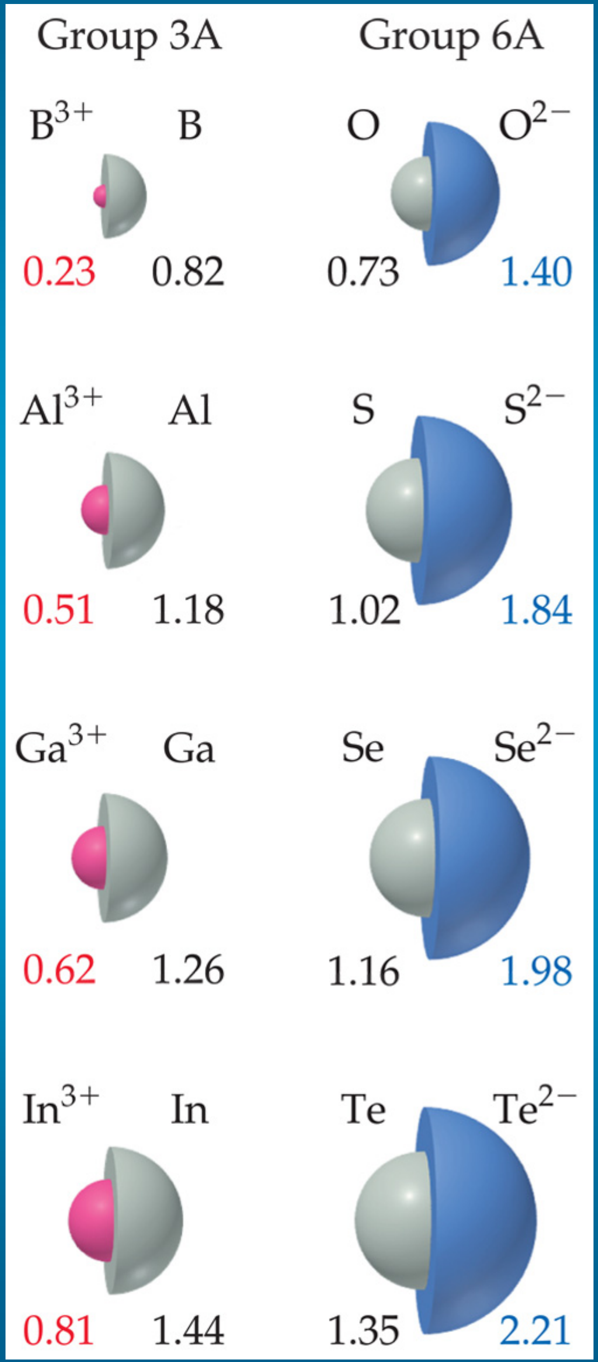
Sizes of Ions



- Anions are larger than their parent atoms.
  - Electrons are added and repulsions are increased.

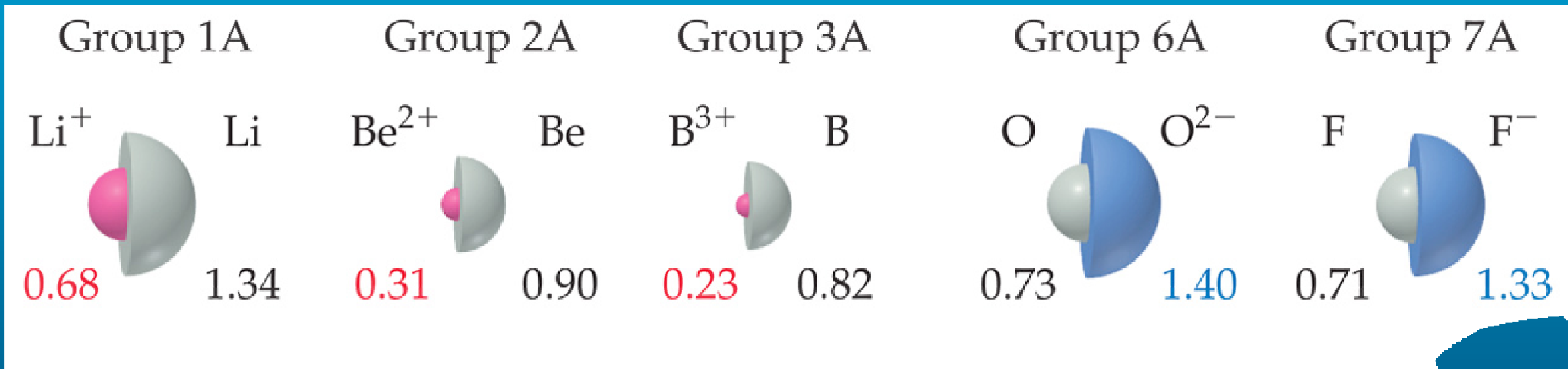
Sizes of Ions

- Ions increase in size as you go down a column.
    - Due to increasing value of *n*.



Sizes of Ions

- In an isoelectronic series, ions have the same number of electrons.
- Ionic size decreases with an increasing nuclear charge.



atom/ion size examples

- Put the following in order of size, smallest to largest:

- Na, Na^{+}, Mg, Mg^{2+}, Al, Al^{3+}, S, S^{2-}, Cl, Cl^{-}

Atom size examples

Al^{3+}, Mg^{2+}, Na^{+}, Cl, S, Al, Mg, Na, Cl^{-}, S^{2-}

Start with atoms with no n=3 electrons, order isoelectronic by nuclear charge.

Next, neutral atoms highest E_{ff} first

Last, anions, highest E_{ff} first

Ambiguity: anions versus neutrals (is Cl^{-} really larger than Na?)

Don’t worry about it.

Ionization Energy

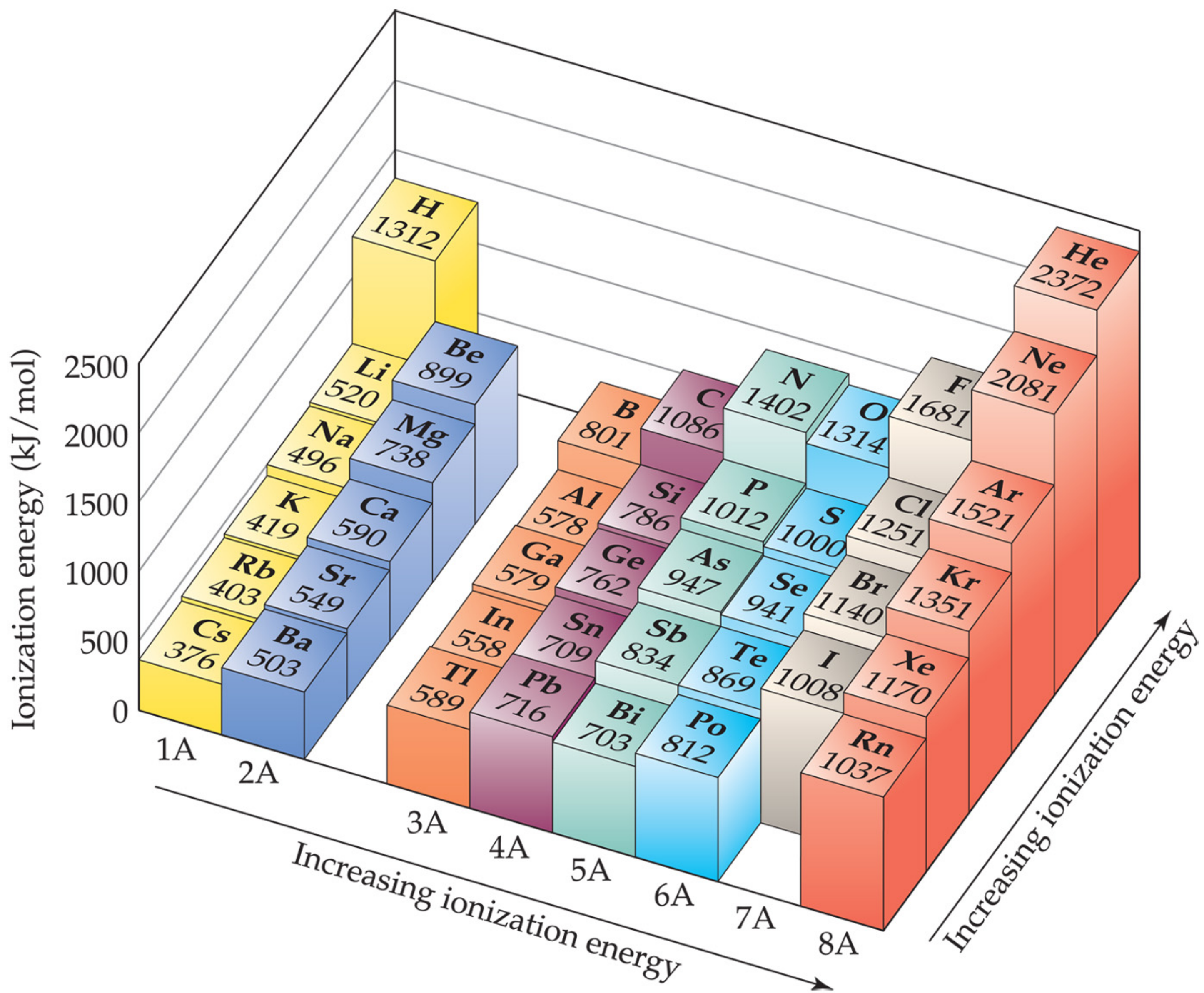
- Amount of energy required to remove an electron from the ground state of a gaseous atom or ion.
  - First ionization energy is that energy required to remove first electron.
  - Second ionization energy is that energy required to remove second electron, etc.
    - El -------> $El^+ + e^-$
    - Na -------> $Na^+ + e^-$

Ionization Energy

- It requires more energy to remove each successive electron.
- When all valence electrons have been removed, the ionization energy takes a

Element	I_1	I_2	I_3	I_4	I_5	I_6	I_7
Na	495	4562	(inner-shell electrons)				
Mg	738	1451	7733				
Al	578	1817	2745	11,577			
Si	786	1577	3232	4356	16,091		
P	1012	1907	2914	4964	6274	21,267	
S	1000	2252	3357	4556	7004	8496	27,107
Cl	1251	2298	3822	5159	6542	9362	11,018
Ar	1521	2666	3931	5771	7238	8781	11,995

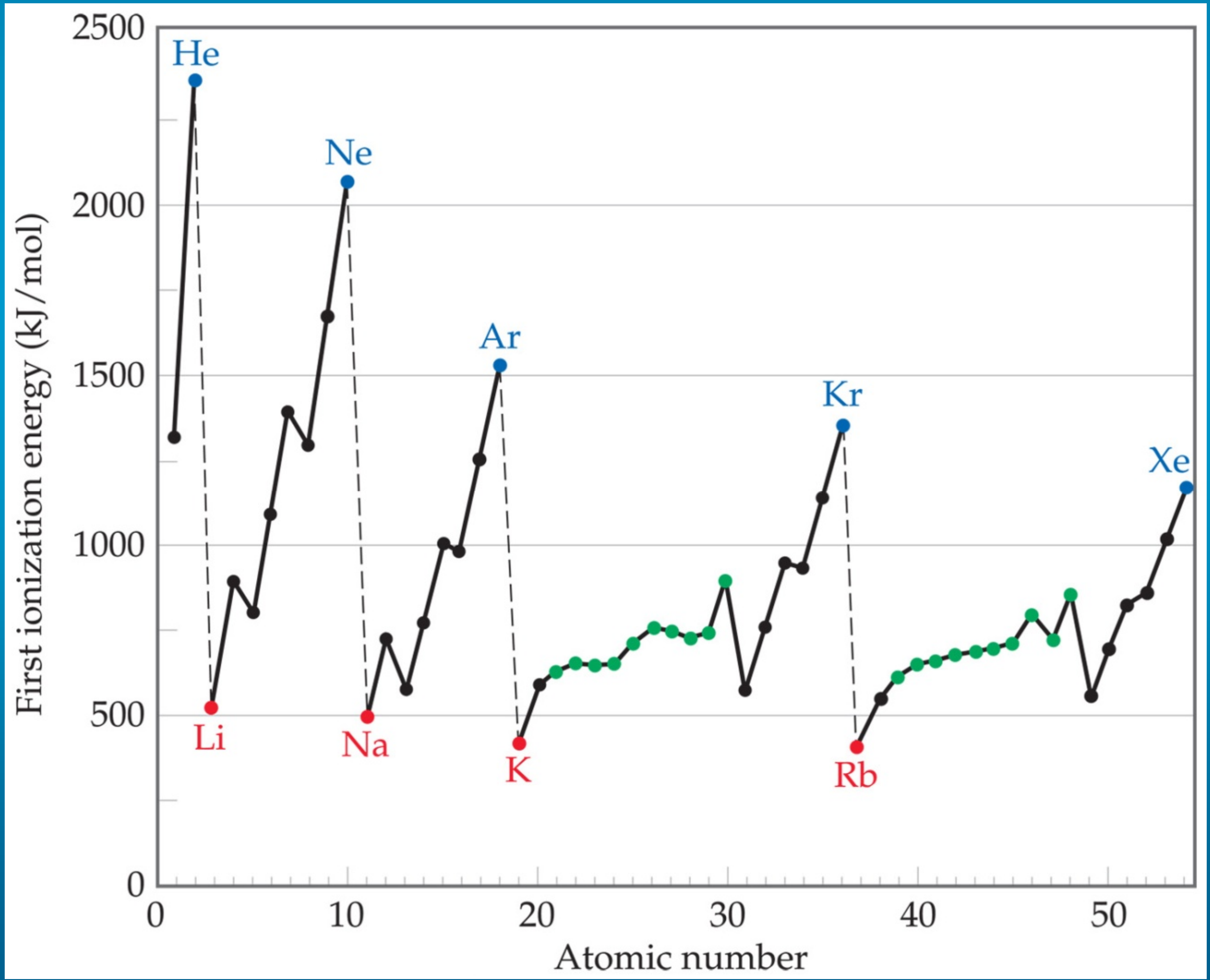
Trends in First Ionization Energies



- going down a column, less energy to remove the first electron.
  - For atoms in the same group, Z_{eff} is essentially the same, but the valence electrons are farther from the nucleus.

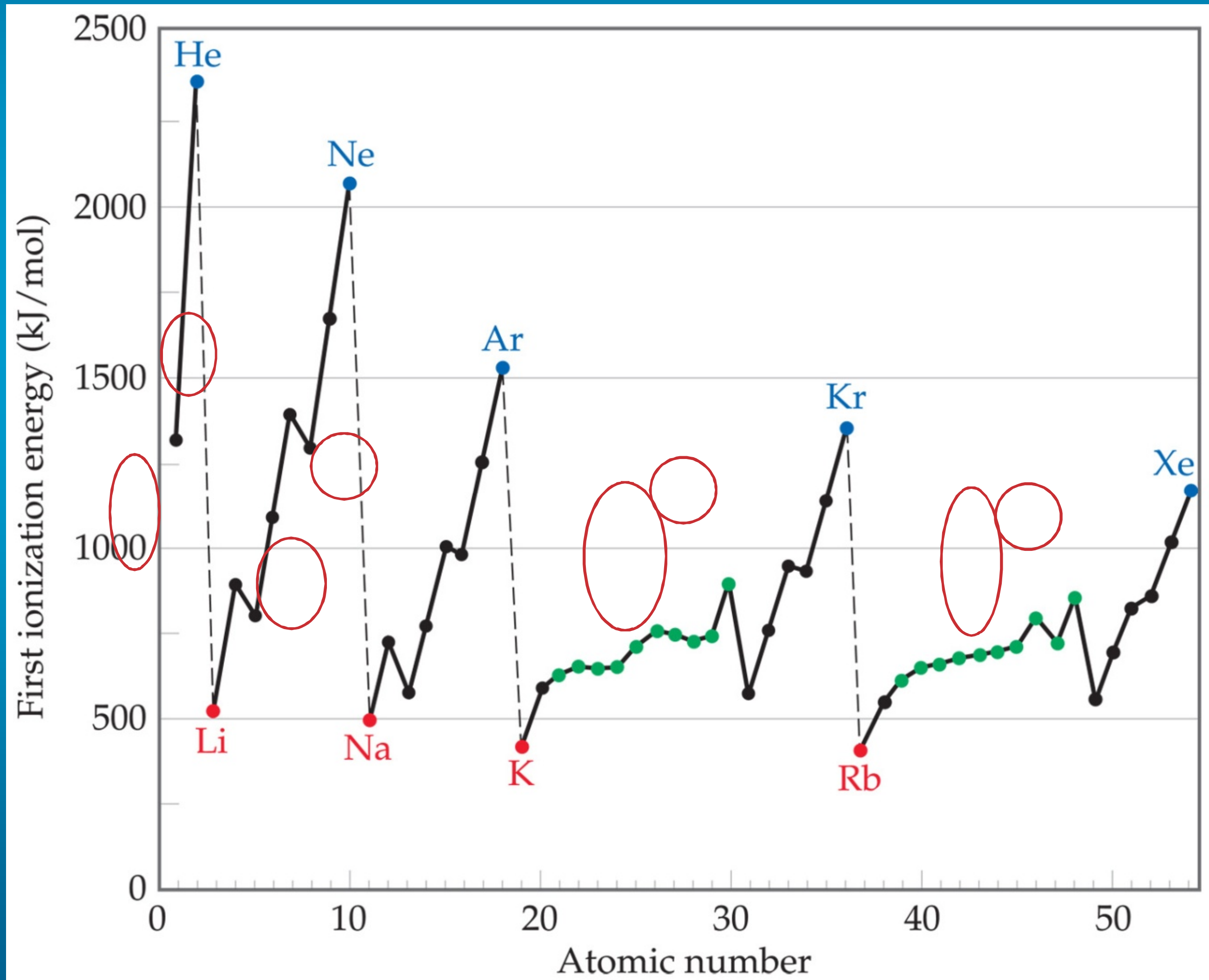
Trends in First Ionization Energies

- Generally, it gets harder to remove an electron going across.
  - As you go from left to to right, Z_{eff} increases.



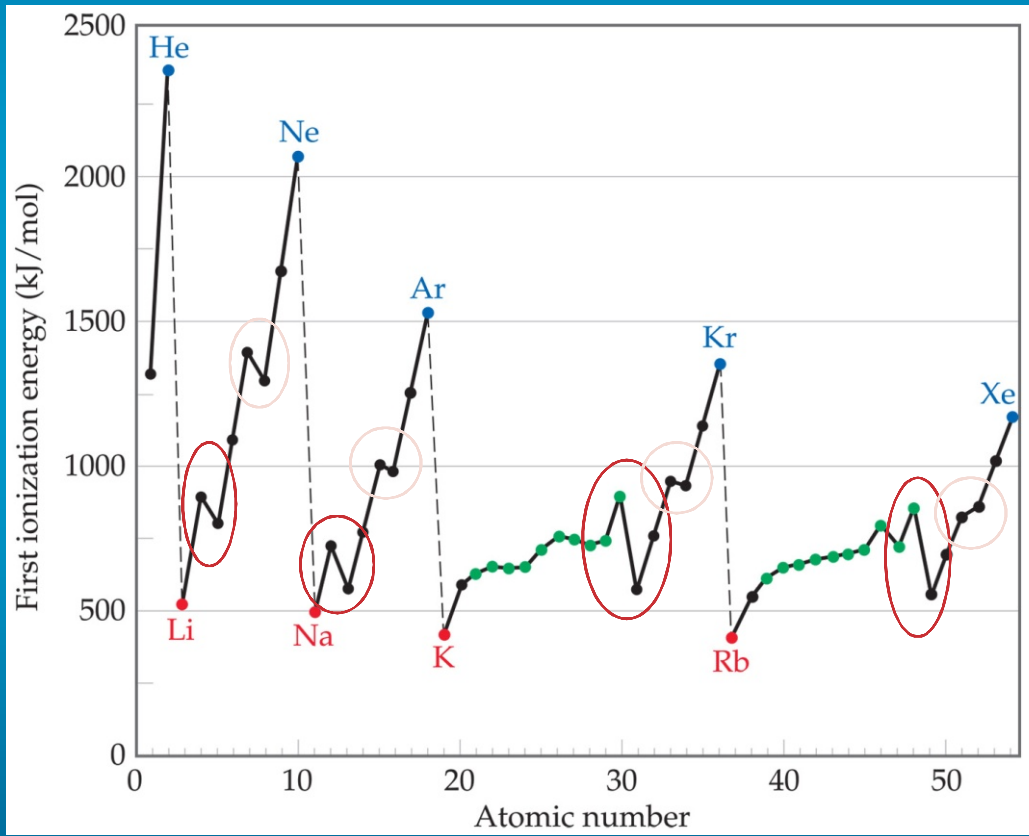
Trends in First Ionization Energies

On a smaller scale, there are two jags in each line. Why?



Trends in First Ionization Energies

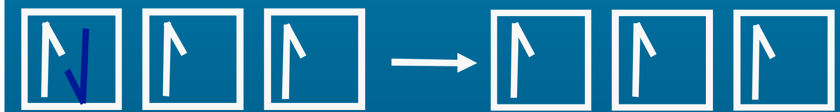
- The first occurs between Groups IIA and IIIA.
- Electron removed from *p*-orbital rather than *s*-orbital
  - Electron farther from nucleus
  - Small amount of repulsion by *s* electrons.

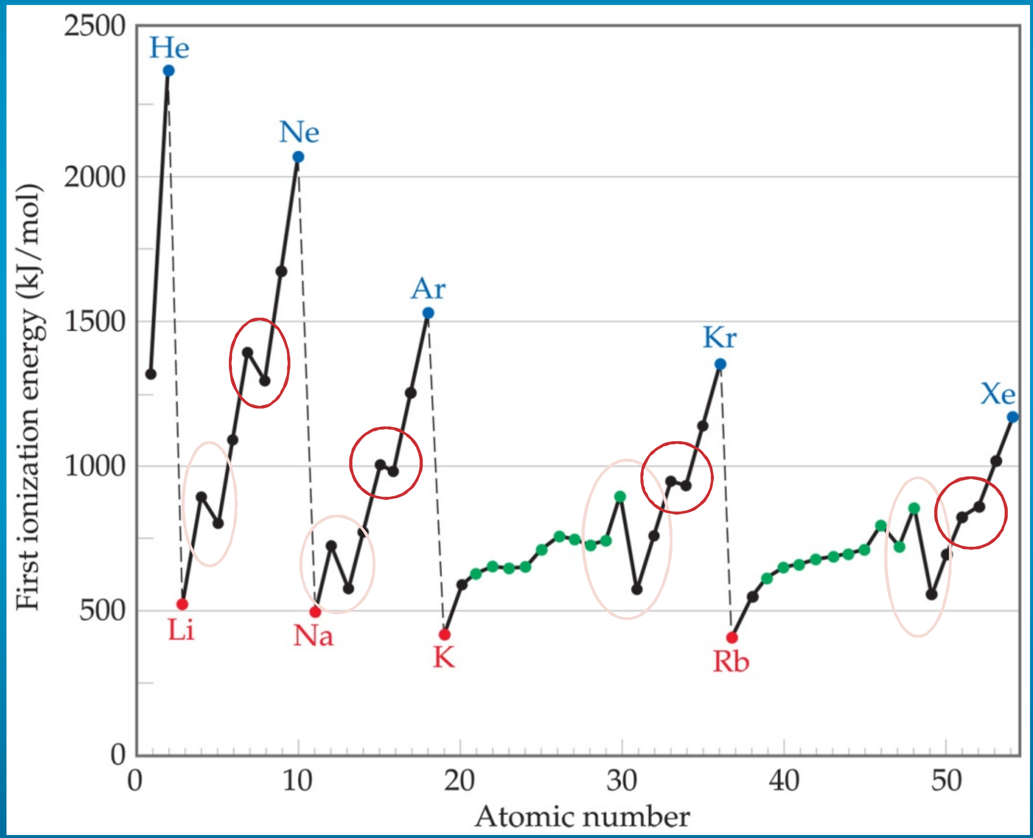


Trends in First Ionization Energies

- The second occurs between Groups VA and VIA.
  - Electron removed comes from doubly occupied orbital.
  - Repulsion from other electron in orbital helps in its removal.

- versus:





Electron Affinity

Energy change accompanying addition of electron to gaseous atom:

$$Cl + e^- \longrightarrow Cl^-$$

Trends in Electron Affinity

1A	2A	3A	4A	5A	6A	7A	8A
H −73							**He** > 0
Li −60	**Be** > 0	**B** −27	**C** −122	**N** > 0	**O** −141	**F** −328	**Ne** > 0
Na −53	**Mg** > 0	**Al** −43	**Si** −134	**P** −72	**S** −200	**Cl** −349	**Ar** > 0
K −48	**Ca** −2	**Ga** −30	**Ge** −119	**As** −78	**Se** −195	**Br** −325	**Kr** > 0
Rb −47	**Sr** −5	**In** −30	**Sn** −107	**Sb** −103	**Te** −190	**I** −295	**Xe** > 0

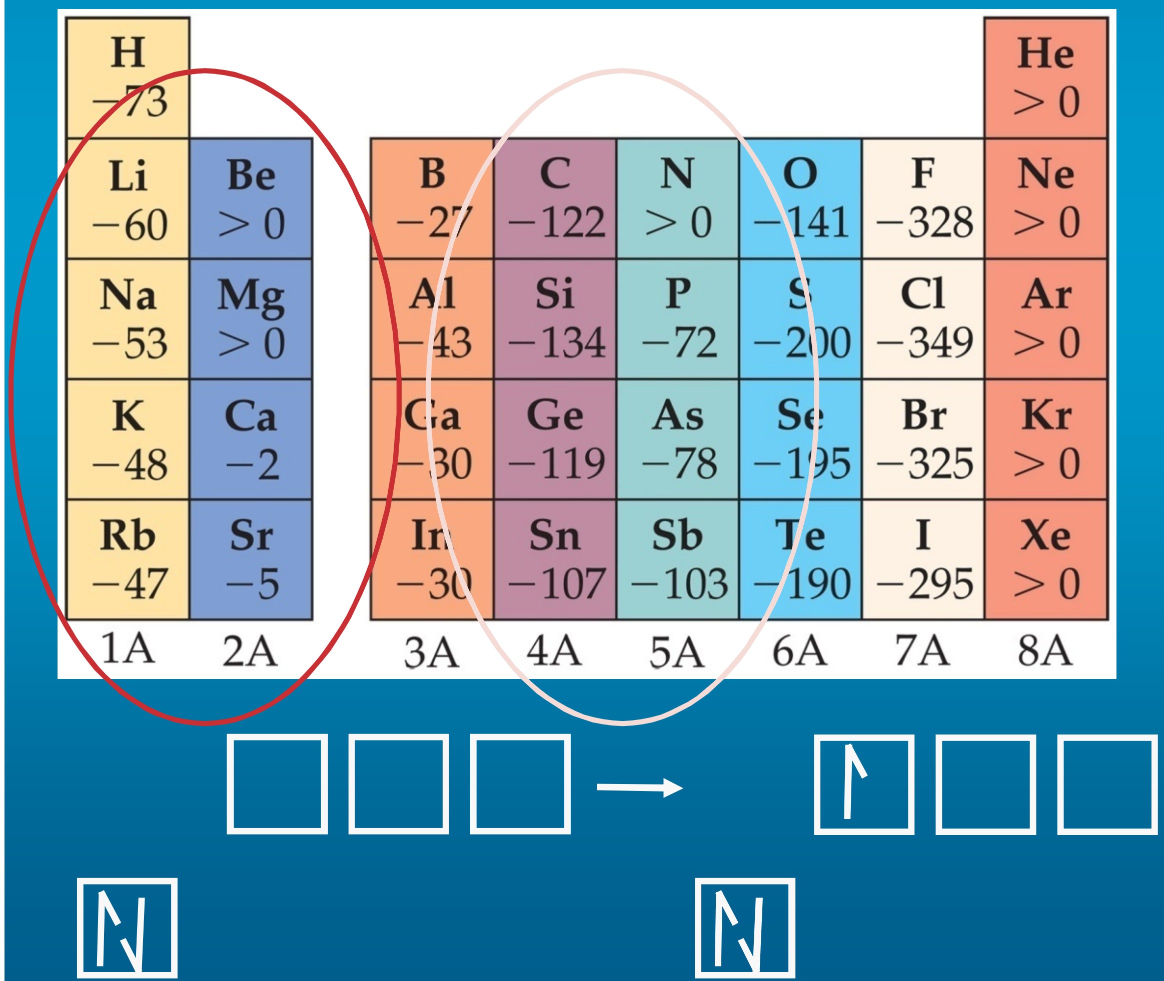
In general, electron affinity becomes more exothermic as you go from left to right across a row.

Trends in Electron Affinity

1A	2A	3A	4A	5A	6A	7A	8A
H −73							He > 0
Li −60	Be > 0	B −27	C −122	N > 0	O −141	F −328	Ne > 0
Na −53	Mg > 0	Al −43	Si −134	P −72	S −200	Cl −349	Ar > 0
K −48	Ca −2	Ga −30	Ge −119	As −78	Se −195	Br −325	Kr > 0
Rb −47	Sr −5	In −30	Sn −107	Sb −103	Te −190	I −295	Xe > 0

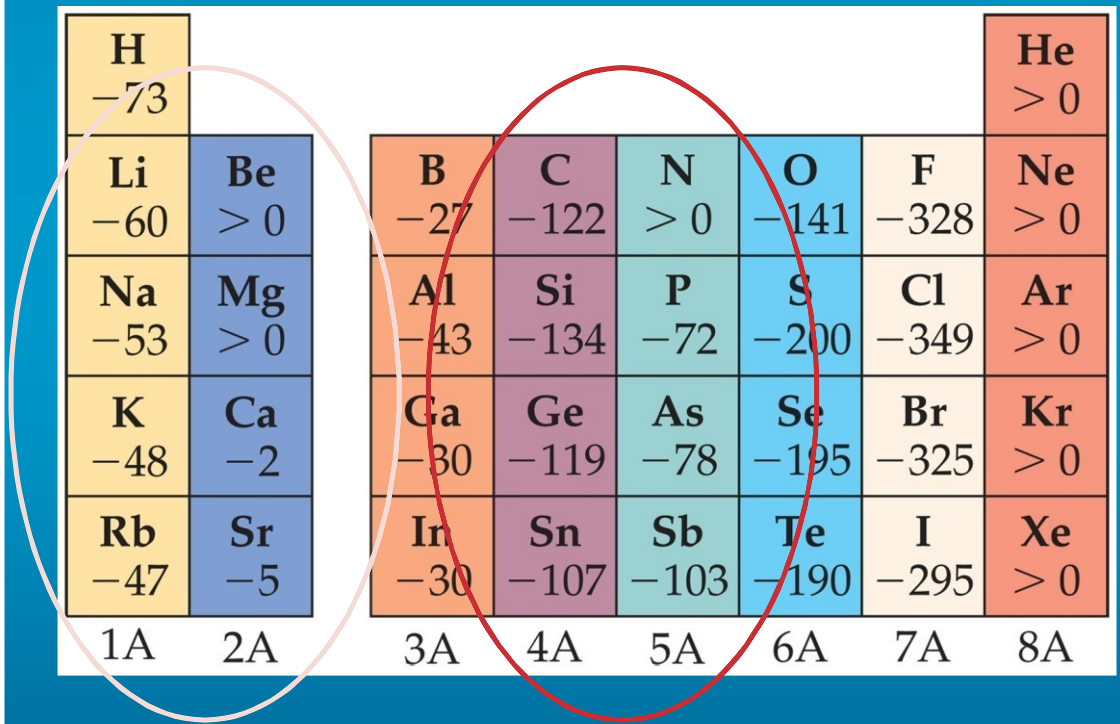
There are also two discontinuities in this trend.

Trends in Electron Affinity



- The first occurs between Groups IA and IIA.
  - Added electron must go in *p*-orbital, not *s*-orbital.
  - Electron is farther from nucleus and feels repulsion from *s*-electrons.

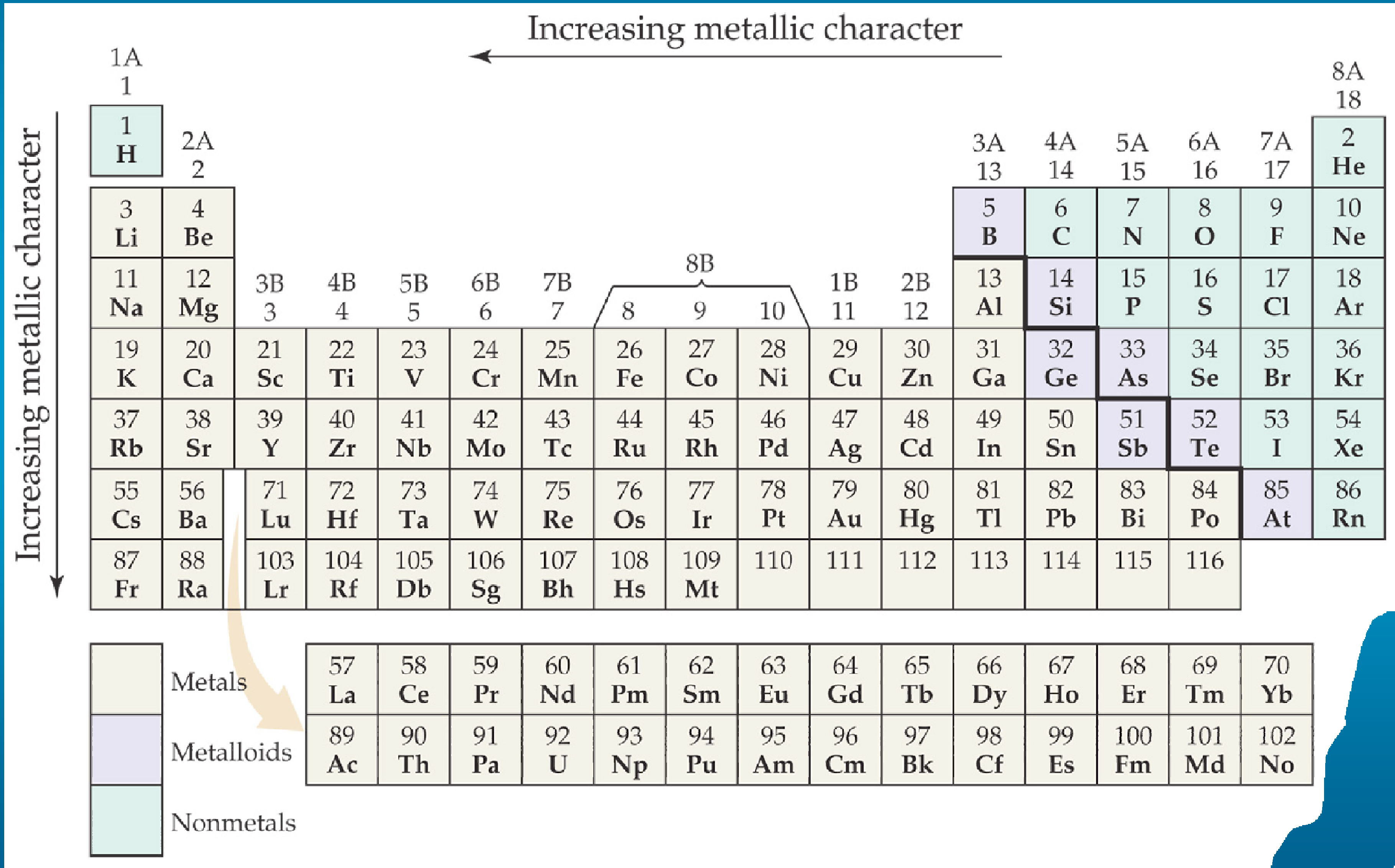
Trends in Electron Affinity



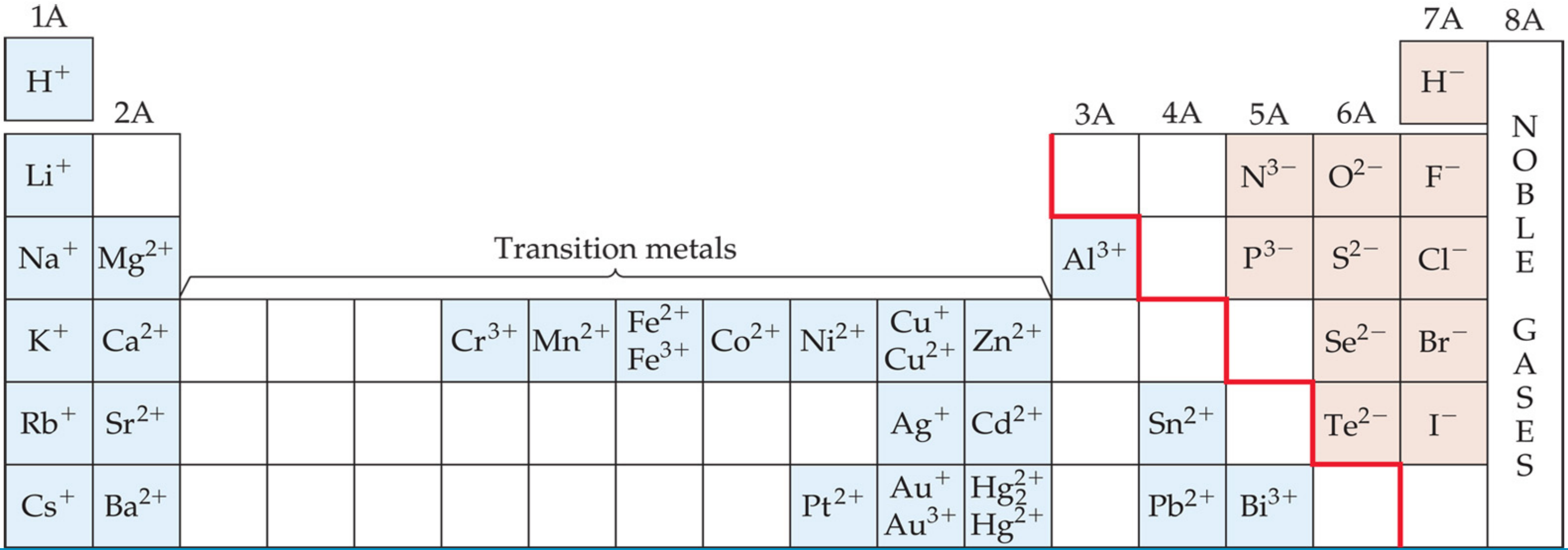
1A	2A	3A	4A	5A	6A	7A	8A
H −73							He > 0
Li −60	Be > 0	B −27	C −122	N > 0	O −141	F −328	Ne > 0
Na −53	Mg > 0	Al −43	Si −134	P −72	S −200	Cl −349	Ar > 0
K −48	Ca −2	Ga −30	Ge −119	As −78	Se −195	Br −325	Kr > 0
Rb −47	Sr −5	In −30	Sn −107	Sb −103	Te −190	I −295	Xe > 0

- The second occurs between Groups IVA and VA.
  - Group VA has no empty orbitals.
  - Extra electron must go into occupied orbital, creating repulsion.

Properties of Metals, Nonmetals, and Metalloids



Transition Metal ions



- Note: many have +2 charge.
- They actually lose all their ns electrons first!
- Mn --> Mn^{2+}: [Ar]$4s^2 3d^5$ --->   [Ar]$3d^5$
- Cu --> Cu^+ [Ar]$4s^2 3d^9$ --->   [Ar]$3d^{10}$