TOPIC: 1.1 MOLES AND MOLAR MASS

LEARNING OBJECTIVE:

1.1.A	Calculate quantities of a substance or its relative number of particles using dimensional analysis and the mole concept.

ESSENTIAL KNOWLEDGE:

1.1.A.1	One cannot count particles directly while performing laboratory work. Thus, there must be a connection between the masses of substances reacting and the actual number of particles undergoing chemical changes.
1.1.A.2	Avogadro's number ($N_A = 6.022 \times 10^{23}$ particles/mole) provides the connection between the number of moles in a pure sample of a substance and the number of constituent particles (or formula units) of that substance.
1.1.A.3	Expressing the mass of an individual atom or molecule in atomic mass units (amu) is useful because the average mass in amu of one particle (atom or molecule) or formula unit of a substance will always be numerically equal to the molar mass of that substance in grams. Thus, there is a quantitative connection between the mass of a substance and the number of particles that the substance contains.

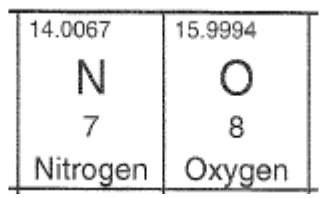
EQUATION(S):

$$n = \frac{m}{\boldsymbol{M}}$$

$$\text{moles} = \frac{\text{mass}}{\text{molar mass}}$$

NOTES:

It is impractical to count atoms as they are so small, so in chemistry we can "count" atoms by weighing them or measuring them in some other way. We need to convert the measurements that we make into numbers of atoms so that we can be sure to react the right amounts of materials. Atomic masses are measured in atomic mass units, amu, which is a relative unit, based on the carbon-12 isotope being assigned a mass of exactly 12 grams per mole. A mole is a term used to describe a group of atoms containing 6.022×10^{23} items. Chemists use moles to discuss amounts of atoms because using the actual amount of atoms is such a large number it is often impractical. You can calculate the mass for one mole of a substance by referring to the periodic table to find the average atomic mass of each atom then adding up the total mass for the formula.



Calculate the molar mass of dinitrogen tetroxide:

N_2O_4

N = 2 x 14.01 = 28.02

O = 4 x 16.00 = <u>64.00</u>

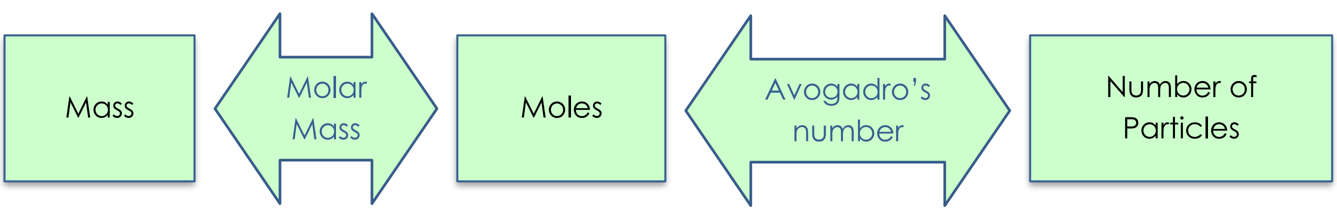
92.02g/mole

How to calculate <u>Molar Mass</u>:

1) List the atoms
2) Count the atoms
3) Find the mass of each atom from the periodic table
4) Multiply the number of atoms (#2) by the mass of each atom (#3)
5) Add together the values (#4)

Molar mass can be used as a conversion factor to convert between moles and grams. It is unique for each sample.

Avogadro's Number, 6.022×10^{23} particles/mole, is the conversion factor to convert between number of particles (molecules, atoms, formula units, ions) and moles.



I DO:

How many moles of Lead (II) iodide, PbI_2, are there in a 25.0 gram sample?

How many atoms of lead, Pb, are in the sample?

WE DO:

A 0.244 g sample of calcium carbonate, $CaCO_3$, was recovered from a sample of hard water. How many formula units of $CaCO_3$ were in the sample?

SCAN ME

YOU DO:

1) Methane, CH_4, is the gas commonly found in labs to fuel Bunsen burners.
   a) How many moles of methane are there in a 7.21 gram sample?
   b) How many particles of methane are there in the sample?
   c) How many atoms of hydrogen are found in the sample of methane?

2) Helium, He, is used in balloons, deep sea diving tanks, and in industry. Helium is the second most abundant element in the universe, however, there was a shortage of helium which caused the prices to rise in 2019. If 150. grams of helium are needed to cool a superconductor, how many atoms of helium are used?

3) If you know the mass and identity of a sample, what other information do you need in order to find the number of each atom in the sample?

4) Given 10.0 gram samples of LiCl, LiBr, LiF and LiI, place the samples in order of least to greatest number of atoms of Lithium, Li.

5) What is the mass of one atom of carbon-12?

6) What is the mass of 2.30×10^{24} particles of water, H_2O?

7) Which is a greater mass, 0.25 moles of carbon dioxide, CO_2, or 1.5×10^{23} particles of carbon monoxide, CO?

TOPIC: 1.2 MASS SPECTRA OF ELEMENTS

LEARNING OBJECTIVE:

1.2.A	Explain the quantitative relationship between the mass spectrum of an element and the masses of the element's isotopes.

ESSENTIAL KNOWLEDGE:

1.2.A.1	The mass spectrum of a sample containing a single element can be used to determine the identity of the isotopes of that element and the relative abundance of each isotope in nature.
1.2.A.2	The average atomic mass of an element can be estimated from the weighted average of the isotopic masses using the mass of each isotope and its relative abundance *Exclusion Statement: Interpreting mass spectra of samples containing multiple elements or peaks arising from species other than singly charged monatomic ions will not be assessed on the AP Exam.*

EQUATION(S):

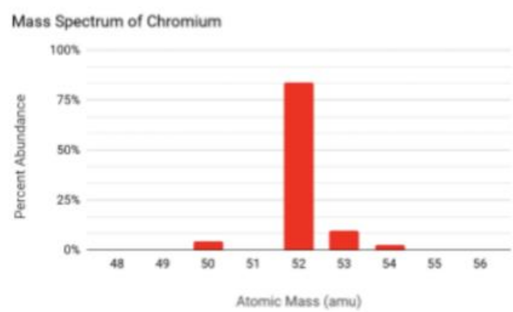
	N/A

NOTES:

A sample of a pure element contains a variety of *isotopes* (atoms with the same number of protons and electrons, but different numbers of neutrons and therefore different mass numbers). The percentage of each atom with a specific atomic mass in the sample is that isotope's *relative abundance.*

For example, chromium has four naturally occurring isotopes which are shown in the data table below.
We can see that most of the naturally occurring chromium is chromium-52, so we expect the *average atomic mass* (the weighted average of the masses of all of the naturally occurring isotopes of an element, the mass given on the periodic table) to be close to 52 amu. When we check the periodic table, we see that chromium's average atomic mass is in fact 52.00 amu.

Isotope	Protons	Neutrons	Mass (amu)	Abundance (%)
Chromium-50	24	26	49.95	4.35
Chromium-52	24	28	51.94	83.79
Chromium-53	24	29	52.94	9.50
Chromium-54	24	30	53.94	2.36



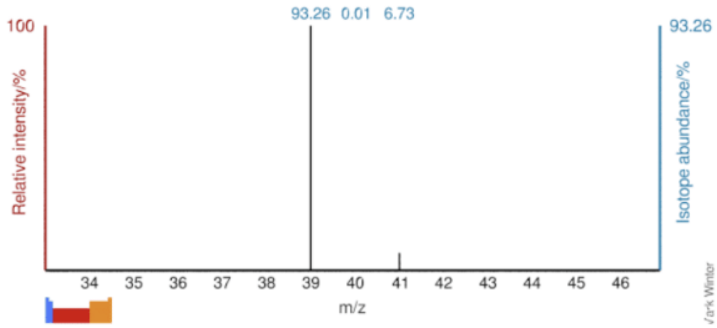
(Data from IUPAC Periodic Table of Isotopes: https://applets.kcvs.ca/IPTEI/IPTEI.html)

Mass Spectroscopy (Mass Spec) is an analytical chemistry lab technique that separates the components of a sample by their mass.
The mass spectrum of a sample containing a single pure element gives information about the naturally occurring isotopes of that element. By reading a mass spectrum, you can determine the isotopic masses (x-axis) as well as the relative abundances of those isotopes (y-axis).

The average atomic mass of an element can be calculated using the relative abundance and mass of each naturally occurring isotope of that element using the following equation.

$$Average\ Atomic\ Mass = \sum_{n} (relative\ abundance\ of\ isotope\ n) \times (mass\ of\ isotope\ n)$$

I DO:



(Mass Spectrum from www.webelements.com)

The mass spectrum of a sample of a pure element is shown above. Calculate the average atomic mass of the element.

What is the identity of the element?

WE DO:

Rhenium, Re, is one of the rarest elements on Earth. Alloys containing rhenium are used for oven filaments and x-ray machines.

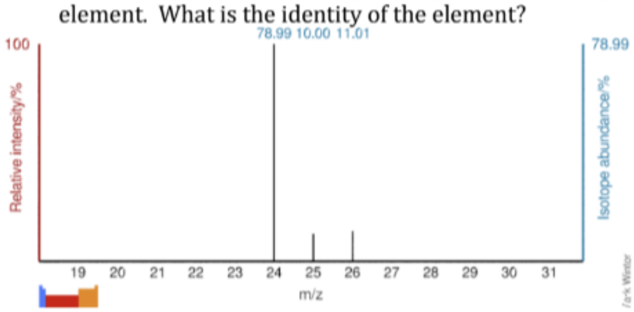
The average atomic mass of naturally occurring rhenium is 186.21 amu. There are two common isotopes of naturally occurring rhenium. Using the information given in the table below, calculate the percent abundance of naturally occurring rhenium.

Isotope	Mass (amu)
Re-185	184.95
Re-187	186.96

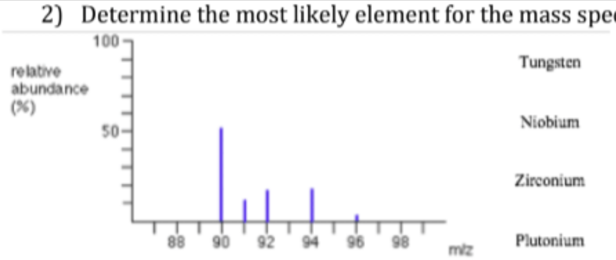
SCAN ME

YOU DO:

1) The mass spectrum of a sample of a pure element is given below. Calculate the average atomic mass of the element. What is the identity of the element?

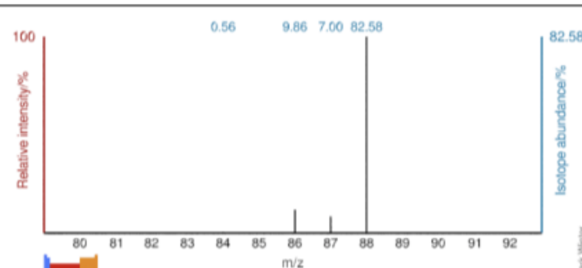


2) Determine the most likely element for the mass spectrum given below. Justify your choice.



3) In the chemical closet, you found an unlabeled vial with a solid piece of an unknown element inside (element Z). You decided to put it in the mass-spec to figure out its atomic mass. The results showed that it has two naturally occurring isotopes, Z-85, and Z-87. Z-85 has a natural abundance of 72.17% and a mass of 84.912 amu. Z-87 has a natural abundance of 27.83% and a mass of 86.909 amu. Calculate the average atomic mass and determine the identity of mystery element Z.

4) Use the mass spectrum below to fill out the information in the table about each isotope.



Isotope	Protons	Neutrons	Mass (amu)	Relative Abundance (%)

TOPIC: 1.3 ELEMENTAL COMPOSITION OF PURE SUBSTANCES

LEARNING OBJECTIVE:	
1.3.A	Explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance
ESSENTIAL KNOWLEDGE:	
1.3.A.1	Some pure substances are composed of individual molecules, while others consist of atoms or ions held together in fixed proportions as described by a formula unit.
1.3.A.2	According to the law of definite proportions, the ratio of the masses of the constituent elements in any pure sample of that compound is always the same.
1.3.A.3	The chemical formula that lists the lowest whole number ratio of atoms of the elements in a compound is the empirical formula.
EQUATION(S):	
	N/A

NOTES:

A pure substance is one with constant composition; a pure substance can either be an element or a compound.

Substance	Made from:	Described as:	Example:
One atom	Any	Atom	Mg, Zn, Ne
More than one element (ionic)	Metal + nonmetal(s)	Formula unit	NaCl, $Fe(NO_3)_2$
More than one element (molecular)	Nonmetal + nonmetal(s)	Molecule	H_2O, $C_6H_{12}O_6$, O_2
Atom or group of atoms with a charge	Any	Ion	Pb^{2+}, SO_4^{2-}

When dealing with compounds you can assume they follow the law of definite proportion, which states that compounds with the same elements in the same proportion are the SAME compound.

Following the law of definite proportion, you can find the percent composition which is the percent by mass of each element that makes up a compound.
To calculate the percent composition, you divide the mass of each element in a compound by the total molar mass of the substance.

In compounds, the **empirical formula** represents the simplest ratio of one element to another in a compound. The **molecular formula** represents the actual formula for the substance.

An example is glucose which has the molecular formula $C_6H_{12}O_6$ but the empirical formula is CH_2O.

To determine the empirical and molecular formula.

1. Determine the *empirical formula* for the compound when given percent of each element
   a. Assume you are given a 100g sample so you can change percent to grams
   b. For each element take grams / molar mass to get moles of each element
   c. Divide each mole value by the lowest of the values
   d. If you are within 0.1 of a whole number round to the whole number. If you are not, you must multiply by a factor that gives you whole numbers for all.
   e. The values you found are the subscripts for each element

2. Determine *molecular formula* (can only determine if given molar mass of substance)
   a. Find mass of empirical formula
   b. Molar mass/ empirical formula mass to find factor
   c. Multiply all subscripts in the empirical formula by the value

I DO:

A certain sugar used in treating patients with low blood sugar has the following chemical composition: 40.0 % carbon, 6.70 % hydrogen, and 53.3 percent oxygen. What is the empirical formula?

The molar mass of the compound is 180 grams/mole. What is the molecular formula of this compound?

WE DO:

a. A compound is found to contain 56.5% carbon, 7.11% hydrogen, and 36.4% phosphorus. Find the empirical formula.

b. If the compound has a molar mass of 170.14 g/mol, what is its molecular formula?

SCAN ME

YOU DO:

1. The most abundant molecule found in the human body is 88.810% oxygen and 11.190% hydrogen. Calculate the empirical formula for this substance.

2. Arginine is one of the amino acids; it is used in the biosynthesis of proteins. Analysis revealed that a sample of arginine was 41.368 % carbon, 8.101% hydrogen, 32.162 % nitrogen and 18.369% oxygen.
   a. What is the empirical formula of arginine?

   b. The molecular weight of arginine is 174.204 grams/mole. What is the molecular formula?

3. The empirical and molecular formulas of urea are the same. 90 % of the world's urea is used for fertilizer. If the percentage composition of the elements in urea are 19.999% carbon, 6.713% hydrogen, 46.646% nitrogen and 26.641% oxygen. Calculate the empirical/molecular formula.

4. A compound containing phosphorus and oxygen is a powerful desiccant. The compound is 43.642% phosphorus and 56.358% oxygen.
    a. Calculate the empirical formula for this compound.

    b. The molar mass of this compound is 283.889044 g/mol, determine the molecular formula.

5. Emeralds are composed of 4 different elements in a fixed proportion. They are composed of 5.030 % beryllium, 10.040 % Aluminum, 31.351% Silicon and 53.579% oxygen. The empirical and molecular formula are the same.
    a. Calculate the empirical formula.

    b. Calculate the molar mass.

6. Iron can form three different oxides, FeO, Fe_2O_3 and Fe_3O_4. A sample of iron oxide was analyzed and was found to contain 69.943% iron with the rest of the mass from oxygen. Determine the empirical formula to determine the identity of the iron oxide.

7. Serotonin is a chemical that nerve cells produce from an essential amino acid called tryptophan. Tryptophan must enter our body through a balanced diet, and is commonly found in nuts, cheese and red meat. Serotonin is considered to be a natural mood stabilizer as it helps with sleeping, eating and digestion. A sample of serotonin was found to be 6.864% hydrogen, 68.159% carbon, 15.897% nitrogen and 9.079% oxygen. Calculate the empirical formula for serotonin.

TOPIC: 1.4 COMPOSITION OF MIXTURES

LEARNING OBJECTIVE:

1.4.A	Explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture.

ESSENTIAL KNOWLEDGE:

1.4.A.1	While pure substances contain molecules or formula units of a single type, mixtures contain molecules or formula units of two or more types, whose relative proportions can vary.
1.4.A.2	Elemental analysis can be used to determine the relative numbers of atoms in a substance and to determine its purity.

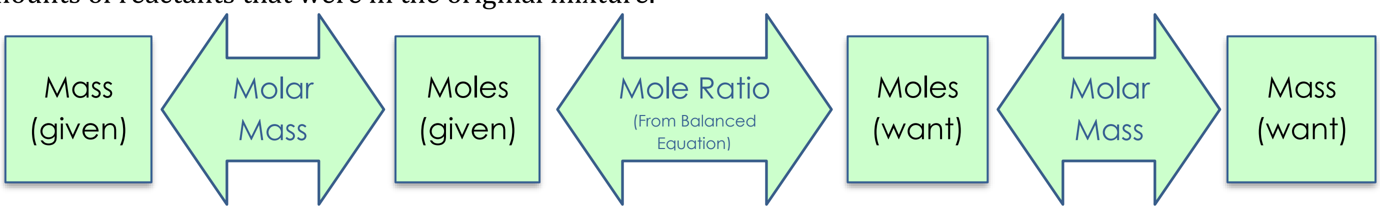
EQUATION(S):

	N/A

NOTES:

When two or more pure substances (elements and compounds) are combined they form a mixture. In mixtures the composition can vary. The mixture can be analyzed to determine the mass composition of each substance in that mixture.

You can use stoichiometry (mole ratios) to convert the masses of the products from the analysis to find the amounts of reactants that were in the original mixture.



The mass percentage of a substance in the mixture can be calculated:

$$\frac{\text{Mass of Substance}}{\text{Total Mass of Mixture}} \times 100 = \text{Mass Percentage}$$

Elemental Analysis to determine the composition of a mixture can be qualitative (identify the different elements present) or quantitative (identify the amounts of elements present.) Elemental analysis is a part of analytical chemistry.

Some examples of elemental analysis include:

- CHNX - Used by organic chemists to identify the mass fractions of carbon, hydrogen, nitrogen and other atoms such as halogens or sulfur. One form of this is combustion analysis. All the carbon in a sample is converted into carbon dioxide, all the hydrogen is converted into water, nitrogen is converted into nitrogen monoxide or nitrogen dioxide and sulfur (for example) is converted into sulfur dioxide.
- Spectroscopy
  - Optical – light is passed through a colored solution and the amount of light absorbed or transmitted is measured to determine the concentration of the solution (3.13 Beer-Lambert Law)
  - Mass – The charge to mass ratio is measured by atomizing then ionizing a sample, then accelerating the sample between charged plates and measuring the deflection of the sample. Greater deflection is found in smaller masses or larger charges. (1.2 Mass Spectroscopy)
  - Photoelectron – The energy to remove electrons from atoms is measured and can be translated into the electron configuration (arrangement) for an element. (1.7 Photoelectron Spectroscopy)

I DO:

Aluminum metal reacts with the air and forms a thin, corrosion resistant coating of aluminum oxide, Al_2O_3, according to the following unbalanced equation.

$$Al_{(s)} + O_{2\,(g)} \rightarrow Al_2O_{3\,(s)}$$

A sample of a mixture of aluminum and aluminum oxide weighing 120.91 grams were analyzed and the total mass of aluminum in the sample was found to be 120.32 grams of aluminum.

a) Balance the equation provided.

b) What mass of oxygen was in the sample?

c) What mass of aluminum oxide was in the mixture?

d) What is the mass percent of aluminum oxide in the aluminum and aluminum oxide mixture?

WE DO:

The main component of egg shells is the compound calcium carbonate, $CaCO_3$. If you react egg shells with acetic acid, HCH_3COO, from vinegar the following reaction will take place.

$$CaCO_{3\,(s)} + 2\ HCH_3COO_{(aq)} \rightarrow H_2O_{(l)} + CO_{2\,(g)} + Ca(CH_3COO)_{2\,(aq)}$$

If 4.421 grams of carbon dioxide, CO_2, was produced from 10.57 grams of egg shells, what percentage of the mass of the egg shells was calcium carbonate?

SCAN ME

YOU DO:

1) A 15.0 gram sample of sodium hydrogen carbonate, $NaHCO_3$, was contaminated with an impurity. In order to determine the purity of the sample, it was heated to decompose the material according to the following reaction:

   $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$

   If 6.35 grams of sodium carbonate, Na_2CO_3, were recovered, what percentage (by mass) of the sample was sodium hydrogen carbonate, $NaHCO_3$?

2) Devise a method to separate a mixture of sand, salt and iron filings.

3) A sample of brass weighing 1.203 grams was analyzed. Brass is an alloy composed of copper, Cu, and zinc, Zn. The zinc in the alloy was reacted with 35.123 grams of hydrochloric acid, HCl, in excess, according to the following balanced equation:

$$Zn_{(s)} + 2\ HCl_{(aq)} \rightarrow H_{2\,(g)} + ZnCl_{2\,(aq)}$$

After all of the zinc reacted the mass of the remaining solution weighed 36.309 grams.

a) What mass of hydrogen gas was produced?
b) What mass of zinc reacted?
c) What was the percentage of zinc (by mass) in the alloy?

4) A sample of sodium bromide, NaBr, has a mass percentage of sodium of 22.34%.

a) If the sample of sodium bromide were contaminated with sodium chloride, NaCl, would the mass percentage of Na in the sample be higher or lower than the pure sample? Justify your claim.
b) If the sample of sodium bromide were contaminated with sodium iodide, NaI, would the mass percentage of Na in the sample be higher or lower than the pure sample? Justify your claim.

5) A mixture consisting only of lithium chloride, LiCl, lithium carbonate, Li_2CO_3, and lithium nitrate, $LiNO_3$, was analyzed. The elemental analysis of the mixture revealed the following:

Element	% composition
Li	14.19 %
Cl	10.56 %
C	6.198 %
O	59.06%
N	10.01 %

Calculate the mass percentage of each compound in the mixture.

6) A sample of a mixture containing an unknown hydrocarbon and some nitrogen dioxide, NO_2, had a total mass of 31.25 grams. The mixture was analyzed using combustion analysis, producing 78.44 g of carbon dioxide, CO_2, and 32.12 g of water, H_2O.

a) Calculate the empirical formula of the hydrocarbon.

b) The molar mass of the compound was found to be 252.48 g/mol. What is the molecular formula of the hydrocarbon?

c) What percentage (by mass) of the original sample was the hydrocarbon?

TOPIC: 1.5 ATOMIC STRUCTURE AND ELECTRON CONFIGURATION

LEARNING OBJECTIVE:	
1.5.A	Represent the electron configuration of an element or ions of an element using the Aufbau principle.

ESSENTIAL KNOWLEDGE:	
1.5.A.1	The atom is composed of negatively charged electrons and a positively charged nucleus that is made of protons and neutrons.
1.5.A.2	Coulomb's law is used to calculate the force between two charged particles.
1.5.A.3	In atoms and ions, the electron can be thought of as being in "shells (energy levels)" and "subshells (sublevels)," as described by the electron configuration. Inner electrons are called core electrons, and outer electrons are called valence electrons. The electron configuration is explained by quantum mechanics, as delineated in the Aufbau principle and exemplified in the periodic table of the elements. *Exclusion Statement: The assignment of quantum numbers to electrons in subshells of an atom will not be assessed on the AP Exam*
1.5.A.4	The relative energy required to remove an electron from different subshells of an atom or ion or from the same subshell in different atoms or ions (ionization energy) can be estimated through a qualitative application of Coulomb's law. This energy is related to the distance from the nucleus and the effective (shield) charge of the nucleus.

EQUATION(S):	
Force due to Coulomb's law	$F_{coulombic} \propto \frac{q_1 q_2}{r^2}$

NOTES:

Atoms are made up from protons (positive), neutrons (neutral) and electrons (negative). The nucleus contains the protons and neutrons, while the electrons move around the nucleus. Most of the mass of the atom comes from the protons and neutrons, while most of the volume of an atom comes from the electrons.

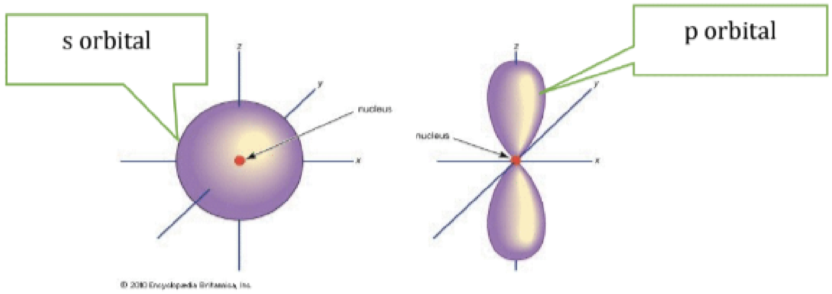
Electron Configurations are a way of describing the arrangement of electrons within an atom and are predicted by the Quantum Mechanical Model of the atom. By solving the **Schrödinger equation,** we obtain 4 quantum numbers that (n, l, m_l, m_s) which describe probable location of the electrons around the nucleus of an atom. The inner electrons are called core electrons. The outer electrons are called valence electrons.

	Name	Simple Description	Values	Notes
n	Principle quantum #	Distance from nucleus	1, 2, … n	Corresponds to the row on the periodic table for s and p. (n-1 for d, n-2 for f etc.)
l	Angular quantum #	Shape of orbital, the most likely place to find the electrons.	0, 1, 2… n-1	0 = s = o shape 1 = p = 8 shape 2 = d 3 = f
m_l	Magnetic quantum #	Orientation of orbital	-l…-1, 0, +1… l	s = 1 orientation p = 3 orientations (x, y, z) d = 5 orientations (1,2,3,4,5) f = 7 orientations (1,2,3,4,5,6,7)
m_s	Spin quantum #	Spin of electron (wave)	+1/2 , -1/2	Only two electrons fit into each orbital, often describe as "up" and "down"

THE ASSIGNMENT OF QUANTUM NUMBERS TO ELECTRONS IN SUBSHELLS OF AN ATOM WILL NOT BE ASSESSED ON THE AP EXAM.

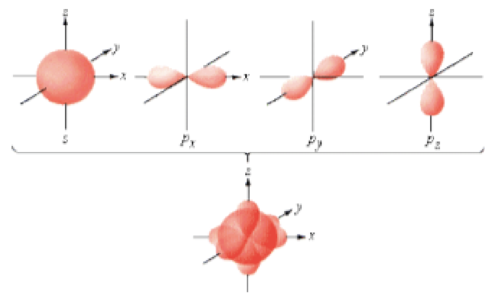
ORBITALS

There are four different cloud-shapes that describe the space that the electrons are most likely to occupy, called orbitals. They are described using 4 letters, *s, p, d* and *f*. The *s* shaped cloud is a sphere around the nucleus. The *p* shaped cloud looks like two balloons tied together.



https://socratic.org/chemistry/the-electron-configuration-of-atoms/arrangement-of-electrons-in-orbitals-spd-and-f

The p orbital can be arranged in three orientations around the nucleus. This picture shows the *s* orbital and the three different *p* orbitals apart and together. Since the orbitals are electron clouds, they can overlap.

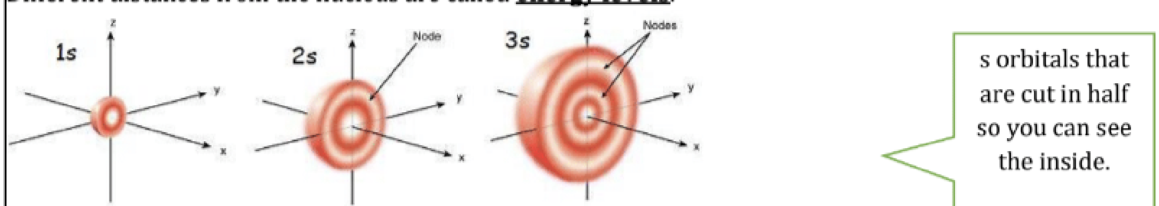


Each orbital can fit 2 electrons, each with a different spin, so the picture shows the potential location for 8 total electrons.

https://archives.library.illinois.edu/erec/University%20Archives/1505050/Rogers/Text5/Tx53/tx53.html

Energy Levels

Different distances from the nucleus are called **energy levels**.

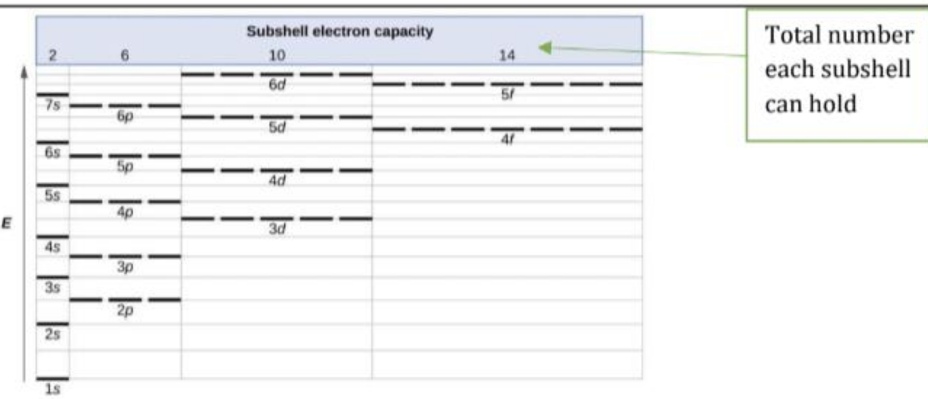


https://socratic.org/chemistry/the-electron-configuration-of-atoms/arrangement-of-electrons-in-orbitals-spd-and-f

Each energy level has different shapes possible.

Energy Level (Principle quantum number)	Possible Shapes (orbitals)	Number of electrons
1	s (2 electrons)	2
2	s (2 electrons) p (6 electrons)	8
3	s (2 electrons) p (6 electrons) d (10 electrons)	18
4	s (2 electrons) p (6 electrons) d (10 electrons) f (14 electrons)	32

Electron configurations describe the model of the atom by showing shells (energy levels) and orbitals.



https://courses.lumenlearning.com/chemistryformajors/chapter/electronic-structure-of-atoms-electron-configurations/

Each dark line shows an orbital that can hold up to 2 electrons. Electrons occupy the subshells starting with the lowest energy levels first. The "lowest" energy orbitals are the closest to the nucleus. They would require the greatest energy to remove them. Remember atoms have negatively charged electrons and a positively charged nucleus.

COULOMB'S LAW:

This tells us that the force between charged particles is proportional to the product of the two charges and the force is inversely proportional to the squared radius between them. The force will decrease the further away the particles are. Higher charges and smaller distances between the charges result in a greater force of attraction. This explains why it takes more energy to remove electrons that are closest to the nucleus.

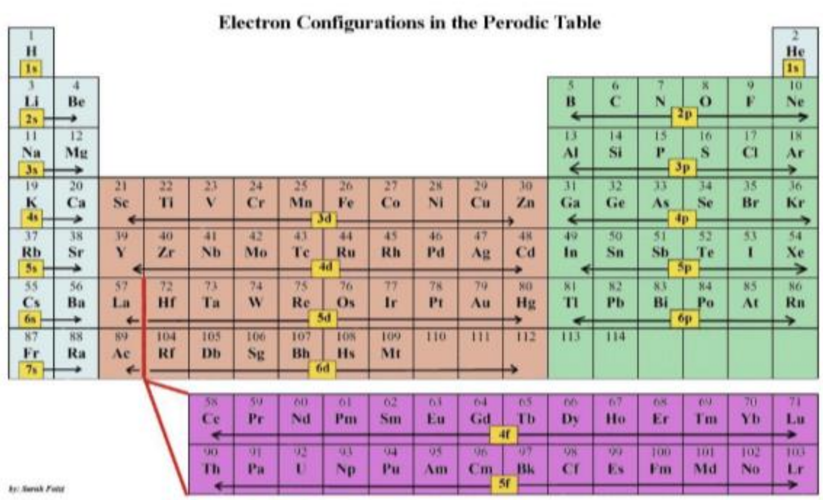
$$F \propto \frac{q1\,q2}{r^2}$$

In addition to the distance, the electrons that are on the valence shell, the outermost electrons, experience less of the nuclear pull because the electrons that are in the core of the atom block, or **shield**, the attraction of the nucleus from the valence electrons.

RULES FOR ELECTRON CONFIGURATIONS:

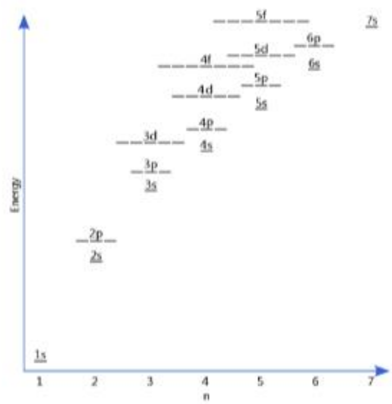
1. Aufbau principle which means "to build up," in other words electrons are added to the lowest subshells first and build up.
2. Hund's Rule: each subshell should have one electron before any are doubled up.
3. Pauli Exclusion Principle: no two electrons can have the same set of 4 quantum numbers.

You can use the periodic table to help you with the electron configuration.

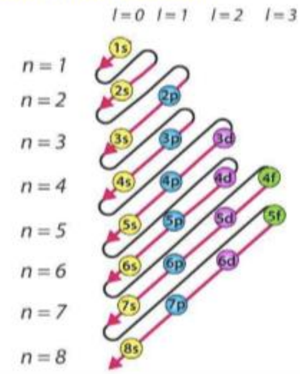


https://dashboard.dublinschools.net/lessons/?id=aaa4c826cb729596b7ca88766a73f063&v=1

THE AUFBAU DIAGRAM – TWO WAYS



https://www.chemicool.com/definition/aufbau-principle.html
https://byjus.com/chemistry/aufbau-principle/



HOW TO WRITE THE ELECTRON CONFIGURATION

Key Idea: Electrons occupy the lowest energy orbitals (closest to the nucleus) first.

Number of electrons in subshell

$$1s^2 2s^1$$

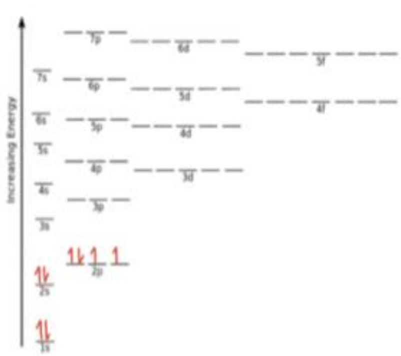
Subshells

The electron configuration for nitrogen would be as follows:

$$1s^2\ 2s^2\ 2p^3$$

- The numbers in front (1 or 2) means the energy level or the row.
- The letters (*s* or *p)* is talking about the shape of the orbitals. (This is the shape of the electron cloud- either a sphere for *s* or the 8-shape for *p*)
- The smaller numbers at the top (the superscripts $^{2\,2\,3}$) tell you about the number of electrons in that type of orbital.

Example: Oxygen = 8e⁻



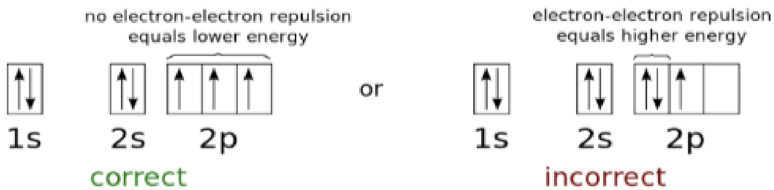
HOW TO COMPLETE AN ORBITAL DIAGRAM

Orbital diagrams are very similar to electron configurations. However, they show the electrons as arrows and provide additional insight into the interactions between the electrons in shared orbitals.

We will start by filling in a vertical orbital diagram, but they are often simply horizontal.

1) Electrons are shown as arrows. (↑↓)
2) Always start with an UP (↑) arrow.
3) Always start by filling the lowest energy level lines first. (Pay close attention to this!)
4) Only put one or two arrows in each box, never more.
5) If you have to put two arrows in a box they have to face opposite directions, this shows they have different spins. (This is the Pauli Exclusion Principle)
6) When you have three (or more) lines in the same subshell, you put one arrow in each box before you make them share a line. (This is Hund's Rule)

You can see the linear form of an orbital diagram below. There are two ways to arrange the electrons for nitrogen, but only one follows Hund's Rule and minimizes the electron-electron repulsions.

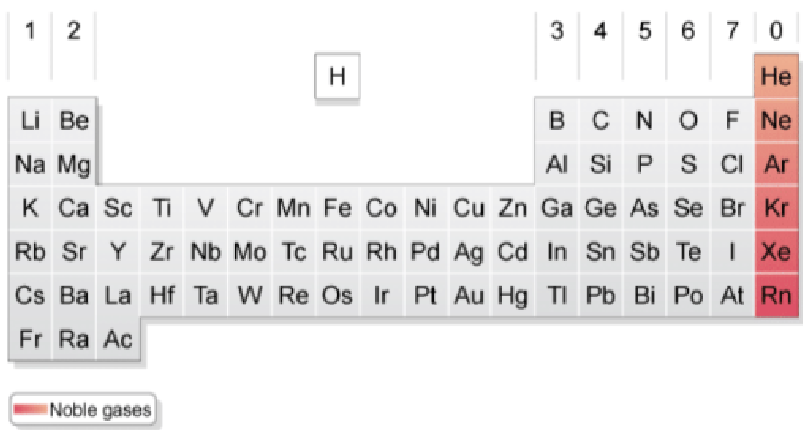


https://en.m.wikibooks.org/wiki/File:Orbital_diagram_nitrogen_-_Hund%27s_Rule.svg

NOBLE GAS/SHORT-CUT ELECTRON CONFIGURATIONS

As you can imagine, electron configurations can become very long and tedious to write. There is a shorter way to show an electron configuration. However, you must be able to write both electron configurations the long way and the short-cut way.

To write an electron configuration using the short-cut method, start by locating the noble gas preceding your element. The noble gases are the elements in group 8A on the periodic table. They are known for being unreactive. They are unreactive because they have filled valence shells. The fact that the noble gases are unreactive is why they are chosen for the noble gas short-hand electron configurations.



https://www.onlinemathlearning.com/noble-gases.html

The noble gas shorthand takes the noble gas before the element and then continues on from there.

The complete electron configuration for Calcium is: $1s^22s^22p^63s^23p^64s^2$.

The short-hand noble gas configuration for Calcium would be: $[Ar]^{18}\ 4s^2$

Writing $[Ar]^{18}$ is the same as writing $1s^22s^22p^63s^23p^6$.

I DO: Write the Ground State electron configuration for Arsenic

<u>WE DO:</u>

Write the electron configuration for Calcium ion, Ca^{2+}.

<u>YOU DO:</u>

1. Write the complete ground state electron configuration for chlorine, Cl.

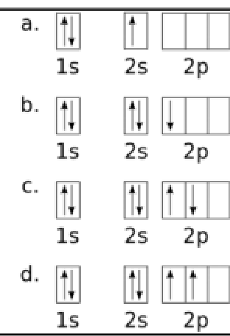
2. Write the complete electron configuration of fluoride ion, F^{-}.

3. Write the complete electron configuration for aluminum ion, Al^{3+}.

4. The valence electron configuration for an unknown element is $xs^2\ xp^4$, where x is an integer. Based on your knowledge of ion formation, predict the charge for the ion that would form when this element loses or gains electrons.

5. Write the noble gas electron configuration for scandium, Sc.

6. In the diagram on the right, three of the orbital diagrams are correct and one is incorrect. Identify the elements shown for each and correct the one that is wrong.



https://commons.wikimedia.org/w/index.php?curid=16713146

7. When an electron in an atom gains sufficient energy, it can move to a higher energy level (further away from the nucleus). This is called an excited state. Write an electron configuration for an excited state of sodium in which one of the 2p electrons jumps up to the 3p orbital.

P

TOPIC: 1.6 PHOTOELECTRON SPECTROSCOPY

LEARNING OBJECTIVE:

SAP-1.B	Explain the relationship between the photoelectron spectrum of an atom or ion and: a. The ground-state electron configuration of the species b. The interactions between the electrons and the nucleus.

ESSENTIAL KNOWLEDGE:

SAP-1.B.1	The energies of the electrons in a given shell can be measured experimentally with photoelectron spectroscopy (PES). The position of each peak in the PES spectrum is related to the energy required to remove an electron from the corresponding subshell, and the height of each peak is (ideally) proportional to the number of electrons in that subshell.

EQUATION(S):

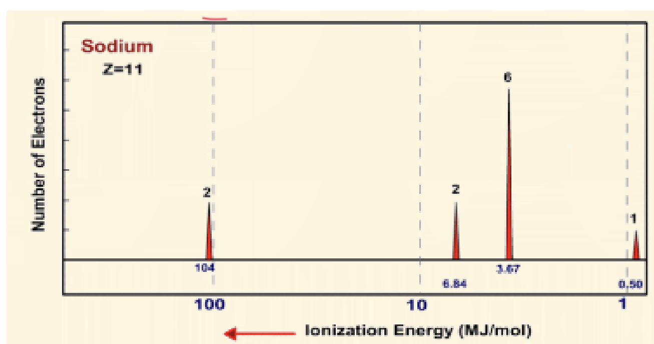
	N/A

NOTES:

Photoelectron spectroscopy (PES) is an experimental technique that measures the relative energies of electrons in atoms or molecules. It works by ejecting electrons from the materials using high energy electromagnetic radiation (like UV or x-rays) and then measuring the kinetic energy of those electrons. This process can be described as photoionization.

PES graphs show the relative number of electrons and their corresponding binding energy. The binding energy can be described as the amount of energy needed to remove an electron from an atom. The electrons with the highest binding energy are the ones that have the greatest coulombic attraction to the nucleus because they are the closest to the nucleus.

The PES graphs directly correspond to the electron configuration.
The PES for sodium is shown. The graphs are often set up so that the x axis gives the largest values first. The graphs are scaled so that they can show many orders of magnitude. ALWAYS read the axis! The highest value for the ionization energy (binding energy) will be the innermost electrons. On this graph they are the peak on the left. We know that there are 2 electrons in the 1s orbital so we can use the height of that peak to estimate the others. Often the graph is not labeled with the number of electrons in each peak.
The electron configuration for sodium is $1s^2\ 2s^2\ 2p^6\ 3s^1$; notice that this corresponds to the peaks given. This provides additional evidence for the quantum mechanical model of the atom as the $2s^2$ $2p^6$ peaks have different energy values.

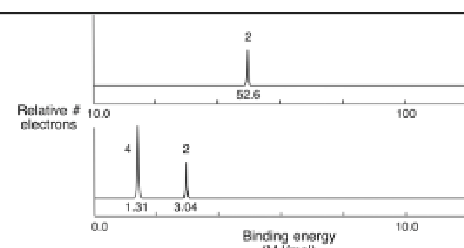


https://chemicalthinking.xyz/pem/pem.html

I DO:

Which element is represented by the PES absorption spectra shown?

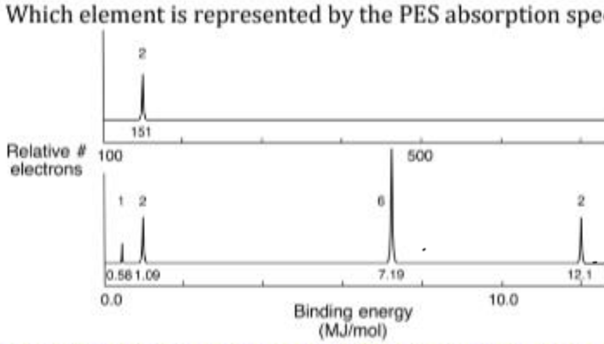
[redacted]



https://khanacademy.org/science/chemistry/electronic-structure-of-atoms/electron-configurations-jay-sal/a/photoelectron-spectroscopy

WE DO:

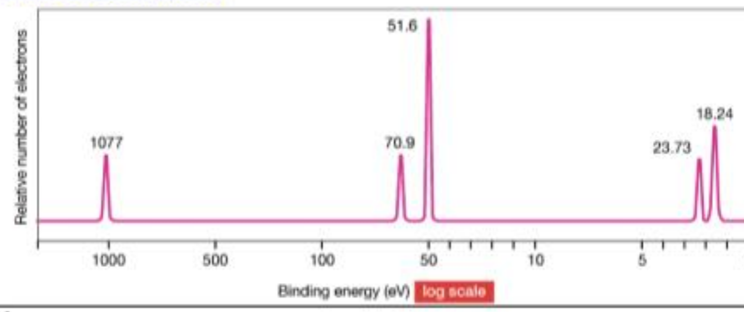
Which element is represented by the PES absorption spectra shown?



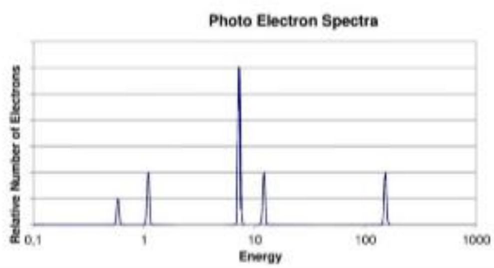
https://khanacademy.org/science/chemistry/electronic-structure-of-atoms/electron-configurations-jay-sal/a/photoelectron-spectroscopy

YOU DO:

1) Which element is represented by the PES absorption spectra shown?
   https://xaktly.com/PhotoelectronSpectroscopy.html

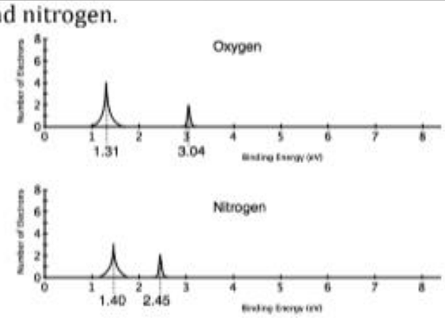


2) Inspect the PES spectra provided.
   https://slideplayer.com/slide/15177715/
   a) Identify the element shown
   b) Write the electron configuration
   c) Predict the charge this element will form as an ion



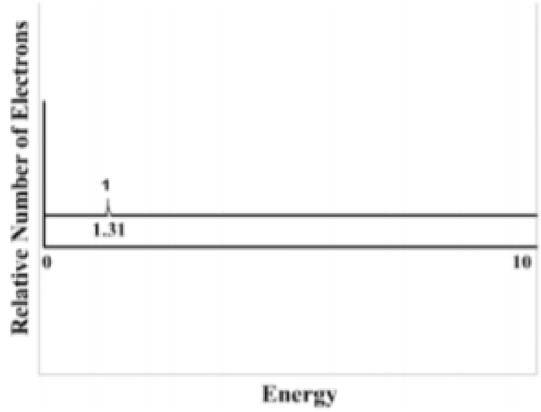
3) Below are the PES spectra for the **valence** electrons for oxygen and nitrogen.
   http://www.learnapchemistry.com/potd/problem.php?pc=5881a1ba31d56308ba187d6c6496a8af

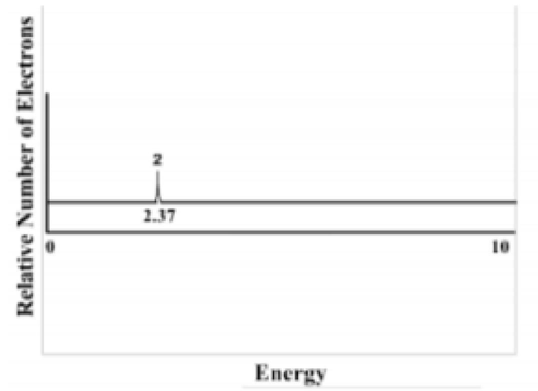
   a) Write a complete electron configuration for both elements.
   b) Identify and label the 2s peaks on each spectrum.
   c) Explain the difference in energy for the 2s peaks.
   d) Write/Draw a valence electron orbital diagram for each element.
   e) Based on the orbital diagram, propose an explanation for the difference in energy for the 2p peaks.



4) The PES spectra for hydrogen and helium are provided.

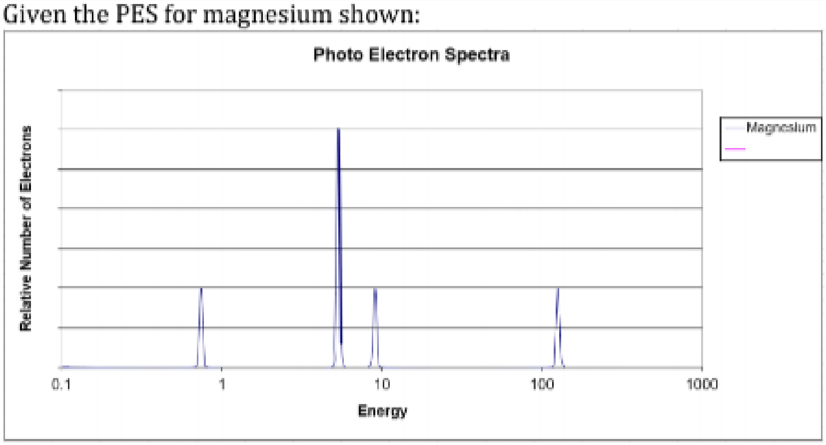
http://www.chem.arizona.edu/chemt/Flash/photoelectron.html





a) Label each graph as Hydrogen or Helium
b) Explain the difference in the intensity (height) of the peaks.
c) Explain the difference in the energy of the peaks.

5) Given the PES for magnesium shown:



https://mrbrewerblog.wordpress.com/2013/05/24/photoelectron-spectroscopy-graph-generator/

a) Identify the peak that corresponds with the electrons that are lost when this substance forms an ion.

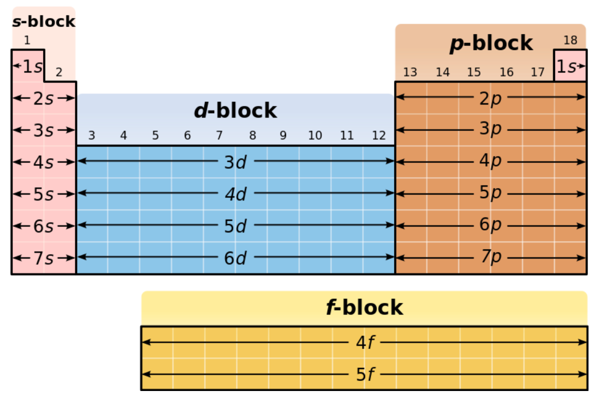
b) Explain why those electrons are first to be lost.

TOPIC: 1.7 PERIODIC TRENDS

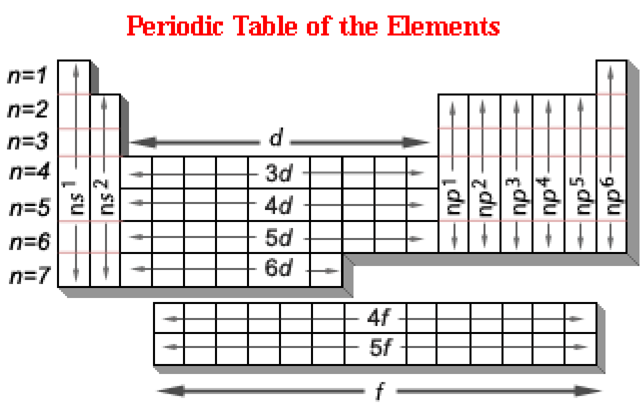
LEARNING OBJECTIVE:	
1.7.A	Explain the relationship between trends in atomic properties of elements and electronic structure and periodicity.
ESSENTIAL KNOWLEDGE:	
1.7.A.1	The organization of the periodic table is based on the recurring properties of the elements and explained by the pattern of electron configurations and the presence of completely or partially filled shells (and subshells) of electrons in atoms. *Exclusion Statement: Writing the electron configuration of elements that are exceptions to the aufbau principle will not be assessed on the AP Exam.*
1.7.A.2	Trends in atomic properties within the periodic table (periodicity) can be qualitatively understood through the position of the element in the periodic table, Coulomb's law, the shell model, and the concept of shielding/effective nuclear charge. These properties include: a. Ionization energy b. Atomic and ionic radii c. Electron affinity d. Electronegativity.
1.7.A.3	The periodicity (in 1.7.A.2) is useful to predict/estimate values of properties in the absence of data.
EQUATION(S):	
	N/A

NOTES:

The periodic table is arranged in order from lowest atomic number (# of protons) to highest. The blocks of the periodic table correspond to the s/p/d/f groups for the electron configuration.



https://socratic.org/questions/what-is-the-electron-configuration-for-francium

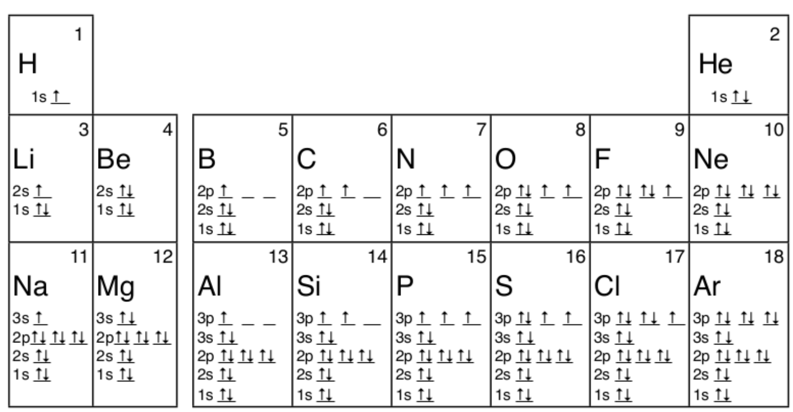


Elements that have the same valence electron configuration tend to have similar chemical properties.

http://nobel.scas.bcit.ca/wiki/index.php/File:Ptable_econfig.gif#filelinks

Most, if not all, periodic trends can be explained by the arrangement of the electrons and the number of protons in the atoms, and applying Coulomb's Law.

https://chem.libretexts.org/Under_Construction/Purgatory/Essential_Chemistry_(Curriki)/Unit_1%3A_Atomic_and_Molecular_Structure/1.4%3A_Electron_Configuration_and_Orbital_Diagrams



KEY TERMS:

COULOMBIC ATTRACTION/ ELECTROSTATIC INTERACTIONS

The positive-negative attraction which takes place when you have two charged particles in close proximity.

- Increases with increase in charge
- Increases with decrease in distance between particles

Coulombic Attraction is the electrostatic attraction between two charged particles. Often when discussing periodic trends the charged particles are the nucleus (specifically the total number of protons) and the electrons. Often we are referring to the outermost electrons, the valence electrons.

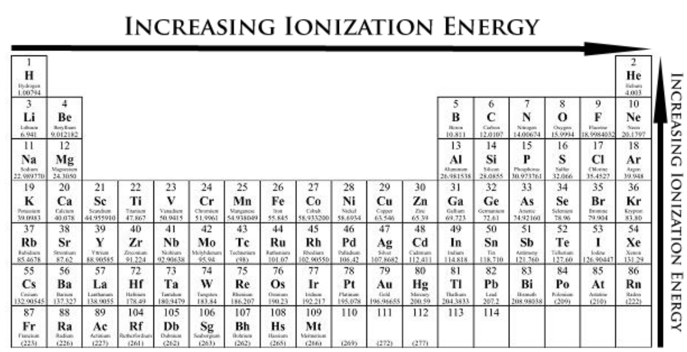
Coulomb's law states that the attraction between two charged particles is proportional to the magnitude of the charge and inversely proportional to the distance between them. To make this simpler, the larger the charge, the more attractive forces between the particles. The further away the particles are from each other, the weaker the attraction.

EFFECTIVE NUCLEAR CHARGE AND ELECTRON SHIELDING

The effective nuclear charge is the net positive charge experienced by valence electrons. It can be approximated by the equation: $Z_{eff} = Z - S$, where Z is the atomic number and S is the number of electrons in orbitals that are closer to the nucleus.

THE SHELL MODEL

The shell model describes the arrangement of the electrons within an atom, as described by the electron configuration from the aufbau principle. The first shell is closest to the nucleus and would have the greatest Coulombic attraction for the nucleus as it is the closest and there is no electrons that are shielding the nucleus from the first shell. The subsequent shells (which overlap) have lower Coulombic attraction due to the greater distance from the nucleus and the decrease in effective nuclear charge due to the shielding of the innermost electrons.



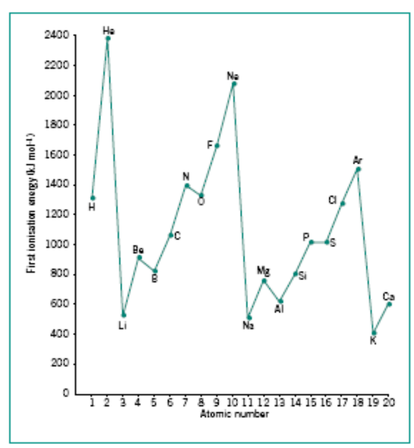
PERIODIC TRENDS

A) FIRST IONIZATION ENERGY

The energy required to remove the outermost (highest energy) electron from the gas from of a neutral atom in its ground state.

First Ionization energy ***decreases*** as you move down a group. Electrons are further from the nucleus and therefore have a lower Coulombic attraction. Additionally, the inner shells of electrons ***shield*** or block the protons force of attraction, so that outermost electrons do not feel as much of the nuclear force. This results in the outer electrons being even easier to remove.

First Ionization energy ***increases*** as you move across a period on the periodic table, from left to right. As you move across the period the atomic radius is smaller and there is an increase in protons in the nucleus. Both factors result in greater Coulombic attraction, which in turn means that it will require more energy to remove the first electron.
https://wps.pearsoned.com.au/ibcsl/89/22896/5861561.cw/content/index.html



There are a few places where the ionization doesn't appear to follow a trend. You can see this on the graph between Be and B or between N and O. These are actually for two slightly different reasons.
https://useruploads.socratic.org/N5qKJ5fTLiJK3MXQAifQ_Ionization_Energy_Trend_IK.png

Be and B exception (s^2 to s^2p^1)
Be = $1s^2\ 2s^2$
B = $1s^2\ 2s^2\ 2p^1$
When the first electron is removed from the boron, B, atom, the electron is being removed from the 2p orbital. Since the 2p orbital is further away from the nucleus it takes less energy to remove it, even though there are more protons in the atom.

N and O exception(s^2p^3 to s^2p^4)
N = $1s^2\ 2s^2\ 2p^3$
O = $1s^2\ 2s^2\ 2p^4$
When the first electron is removed from oxygen it takes less energy (despite the increase in protons) than from nitrogen because the electrons in oxygen are sharing the $2p_x$ orbital and therefore have greater electron-electron repulsions making it easier to remove one electron.

The second ionization energy is the energy to remove a second electron from the atom and so on for each successive electron.

By examining the successive ionization energies for an element, we can determine how many valence electrons there are in that element. When all of the valence electrons have been removed, you will see a large "jump" in the ionization energy values. This "jump" is due to the fact that the core electrons are closer to and less shielded from the nucleus and therefore it requires more energy to remove them.

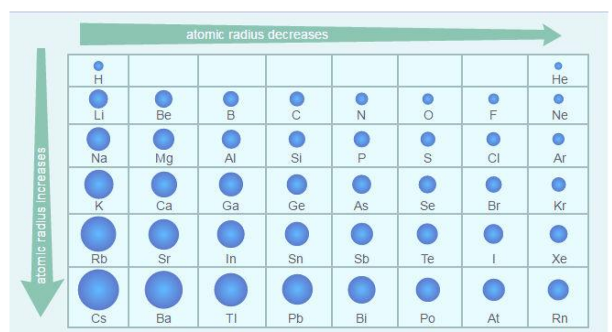
Ionization Energy Number	Enthalpy (kJ/mole)
1st	738
2nd	1451
3rd	7733
4th	10543
5th	13636
6th	18020
7th	21711
8th	25658
9th	31646
10th	35457
11th	169988

For example:
Magnesium, Mg, has the electron configuration: $1s^2\ 2s^2\ 2p^6\ 3s^2$ and we can see that it has 2 valence electrons.
https://www.webelements.com/magnesium/atoms.html

You can see that there is a big jump between the 2nd and 3rd ionization energies and again between the 10th and 11th ionization energies. This shows when electrons are being removed from a shell that is closer to the nucleus.

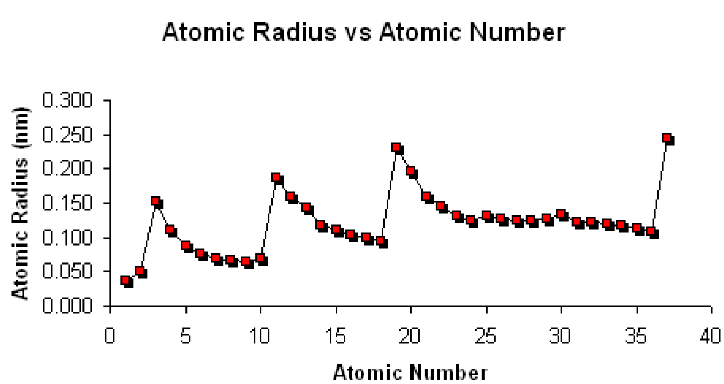
B) Atomic Radius

The **atomic radius** of a chemical element is a measure of the size of its **atoms**, usually the mean or typical distance from the center of the nucleus to the boundary of the surrounding cloud of electrons.



Atomic Radii ***increases*** as you move down a column as there are more electron shells.

https://byjus.com/chemistry/atomic-radius-in-periodic-table-in-basic-chemistry/



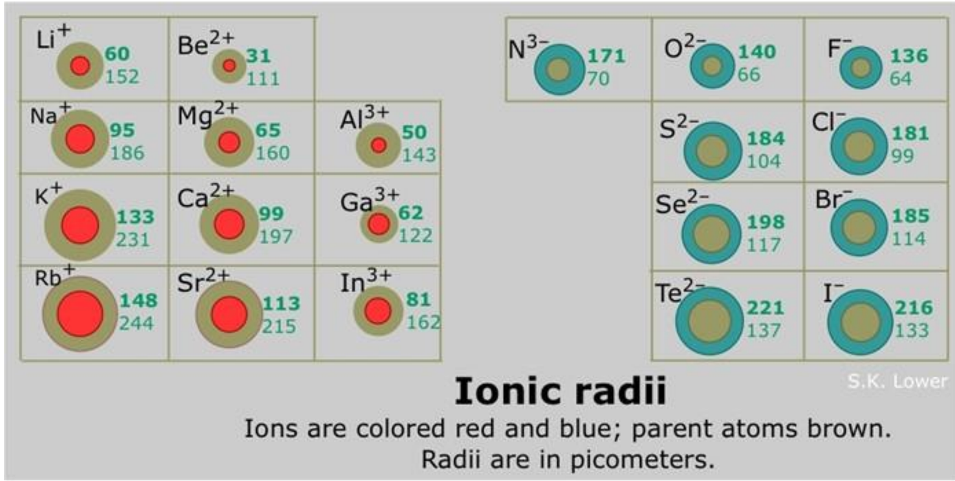
Atomic Radii ***decreases*** as you move across a period on the periodic table, from left to right. Electrons are being added to the same energy level. At the same time, protons are being added to the nucleus. Increasing the number of protons gives a ***higher effective nuclear charge***. In other words, there is a stronger force of attraction pulling the electrons closer to the nucleus. This results in a smaller atomic radius, as with greater numbers of protons there is more pull on the electrons.
https://www.geocities.ws/junebug_sophia/atmRad.gif

Ionic Radius

The trends for ionic radii are similar to those of atomic radii, except that cations and anions are different from each other.

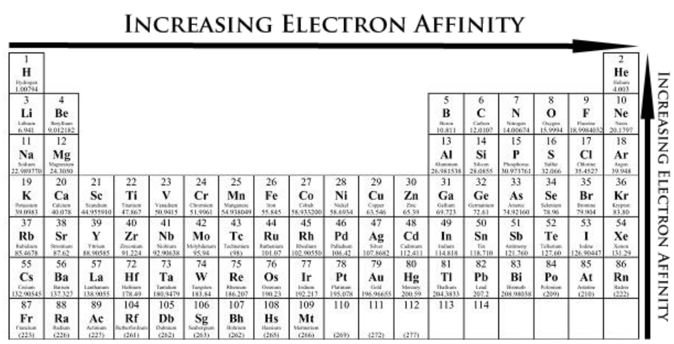
Cations are always smaller than the parent atoms because they have lost their valence shell. This causes them to be smaller. They also decrease in size because the nuclear attraction is now acting on fewer electrons, so they are drawn in toward the nucleus due to the greater attraction. Additionally, there are fewer electron-electron repulsions.

Anions, on the other hand, are always larger than the parent atom. Electrons are added to the same valence shell; however, there are greater electron-electron repulsions so the ion increases in size.
https://slideplayer.com/slide/8861824/



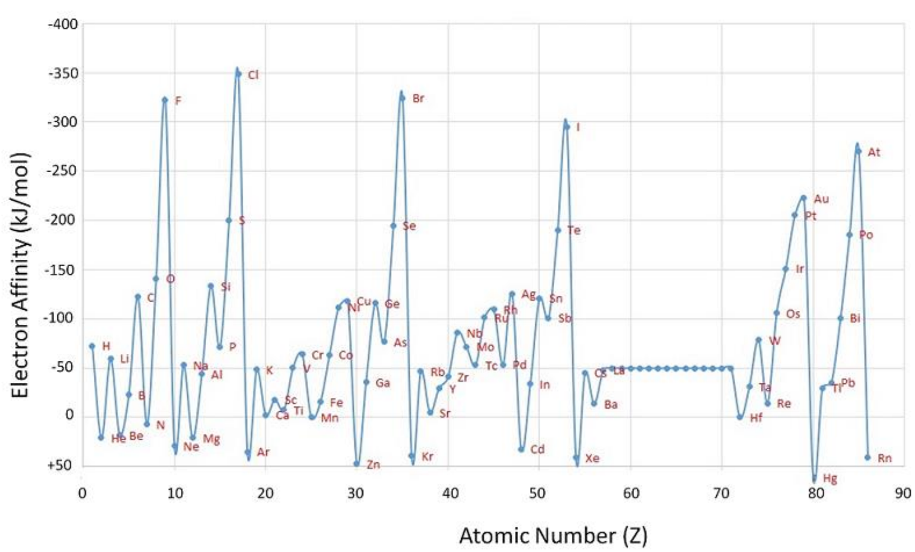
C) Electron Affinity

Electron affinity is the amount of energy involved when an electron is accepted by a gaseous atom to form a negative ion. In other words, the neutral atom's likelihood of gaining an electron. The values tend to be negative to show the energy is released as electrons are added to the atoms.
In general, the electron affinity increases from left to right on the periodic table. This is caused by the filling of the valence shell of the atom; a Group 17atom releases more energy than a Group 1 atom when it gains an electron, indicating that it is more stable.

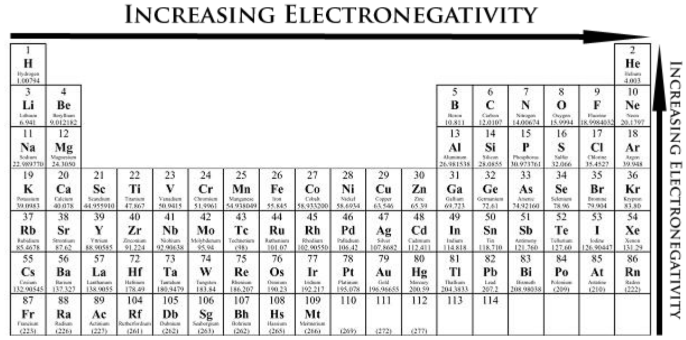


https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Physical_Properties_of_Matter/Atomic_and_Molecular_Properties/Electron_Affinity

A trend of decreasing electron affinity when moving down the groups in the periodic table might be expected. The additional electron will be entering an orbital farther away from the nucleus. Since this electron is farther from the nucleus it is less attracted to the nucleus and would release less energy when added. However, a clear counterexample to this trend can be found in Group 2 and inspecting the entire periodic table, it turns out that the proposed trend only applies to Group 1 atoms.



D) ELECTRONEGATIVITY



Electronegativity is a measure of the ability of an atom (or group of atoms) to attract shared electrons.

Electronegativity **decreases** as you move down a column, as there is a greater distance from the nucleus and more electron shielding.

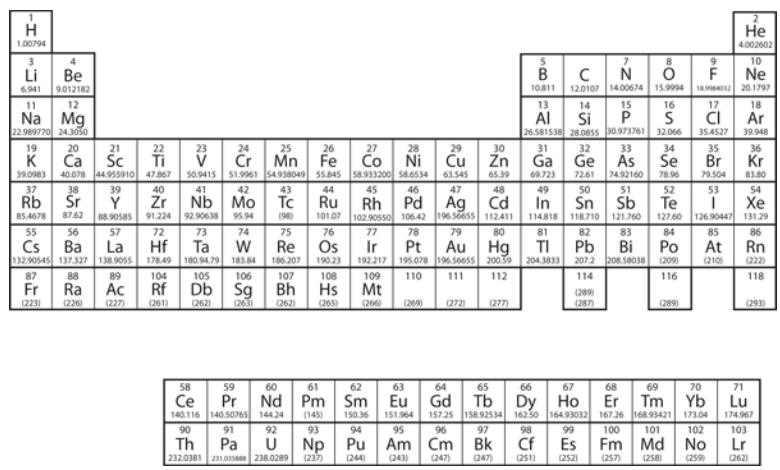
Electronegativity **increases** as you move across a period on the periodic table from left to right. This is because the atomic radius is decreasing while the number of protons (and effective nuclear charge) is increasing.

Fluorine is the most electronegative element.

Example	Difference in electronegativity	Type of Bond
H-H	No difference – Electrons are shared equally	Nonpolar covalent bond
H-Br	Slight difference in values – Electrons are shared unequally	Polar covalent bond
NaCl	Large difference in values – Electrons are not shared, they are transferred	Ionic Bond

REMEMBER:
Stating a trend is not EXPLAINING a trend. Explanations of trends should never be in terms of the location of the periodic table.

I DO:



Choose the atom with:

a) Higher first ionization energy (Na or Li)

Higher first ionization energy (F or O)

b) Larger atomic radius (Na or Li)

Larger atomic radius (F or O)

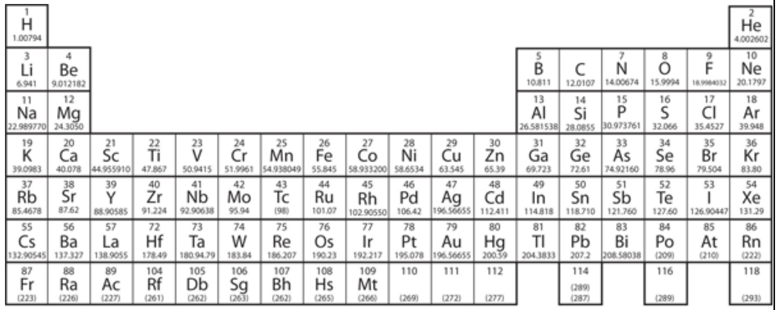
c) Higher electronegativity (Na or Li)

Higher electronegativity (F or O)

WE DO:

Rank the following from smallest to largest atomic/ionic radius.

a) Na^+, Na, Na^-
b) C, N, O
c) Cl, Ar, K
d) Be, Mg, Ca



SCAN ME

YOU DO:

1) On the basis of their position on the periodic table, determine which element in the pair would have a larger atomic radius
   a) P or S
   b) Cl or Br
   c) Sr or Sc

2) Based on the successive ionization energies for the following element "X", predict the formula that would be formed when "X" reacts with chlorine, Cl.

Ionization Energy Number	Enthalpy (kJ/mole)
1^{st}	577
2^{nd}	1820
3^{rd}	2740
4^{th}	11600
5^{th}	14841

3) The first ionization energy for potassium, K, is 419 kJ/mol and the second ionization energy for calcium, Ca, is 1145 kJ/mol. Using concepts from this unit explain why they are different even though they are isoelectric (have the same number of electrons).
   $K_{(g)} \rightarrow K^+_{(g)} + e^-$
   $Ca^+_{(g)} \rightarrow Ca^{2+}_{(g)} + e^-$

4) Element X has an electron configuration of $1s^22s^22p^63s^1$, while element Z has an electron configuration of $1s^22s^22p^5$.
   a) Which element would have greater first ionization energy?
   b) Which element would have a larger radius?
   c) Which element would have higher electronegativity?
   d) Which element would form an ion that has a larger radius?
   e) Which element would release more energy when it gains an electron?

5) Predict two elements that would have properties similar to:
   a) Chlorine

   b) Sodium

   c) Calcium

6) Nitrogen is in column 5A of the periodic table, which is called the pnictogens. When nitrogen reacts with iodine it forms nitrogen triiodide, NI_3, which is a contact explosive that explodes with a snap releasing clouds of purple iodine vapor. Select another pnictogen and predict the formula of the compound that would be formed with a reaction with bromine.

7) Based on the given electron configurations, group together the elements that would have similar chemical properties.
   a) $1s^2 2s^2 2p^6 3s^1$
   b) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
   c) $1s^2 2s^2 2p^5$
   d) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2$
   e) $1s^2 2s^1$
   f) $1s^2 2s^2 2p^6 3s^2 3p^5$

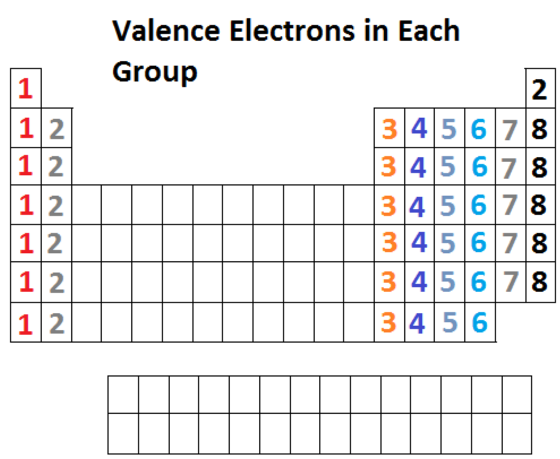
TOPIC: 1.8 VALENCE ELECTRONS AND IONIC COMPOUNDS

LEARNING OBJECTIVE:	
1.8.A	Explain the relationship between trends in the reactivity of elements and periodicity.
ESSENTIAL KNOWLEDGE:	
1.8.A.1	The likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of elements.
1.8.A.2	Elements in the same column of the periodic table tend to form analogous compounds
1.8.A.3	Typical charges of atoms in ionic compounds are governed by their location on the periodic table and the number of valence electrons.
EQUATION(S):	
	N/A

NOTES:

An ionic bond always involves the transfer of electrons from the least electronegative species to the most electronegative. Traditionally, ionic compounds are described as being between a metal and a nonmetal. Based on electron configuration, elements will either lose or gain electrons in order to have a complete s^2p^6 outer valence shell. This loss or gain of electrons leads to the formation of positive or negative ions. Ionic compounds are held together by an electrostatic force.

In order to maintain neutrality, the number of electrons lost must equal the number of electrons gained. Because the number of electrons lost or gained is based on electron configurations, elements in the same group will form the same M_nNm_n analogous compounds. For example, all group I metals (Lithium – Cesium) will have the following format when combined with any group VII halogen (Fluorine – Astatine): LiF or LiCl. Any group II metal, when combined with a group VII halogen, would be CaF_2 or $MgCl_2$. Again, these analogous structures are because of the need to maintain neutrality. Nonmetals only want to gain enough electrons to fill their octet. Metals only want to give away enough electrons to have a pseudo-noble gas configuration.



http://kinga2.weebly.com/unit-3-periodic-table.html

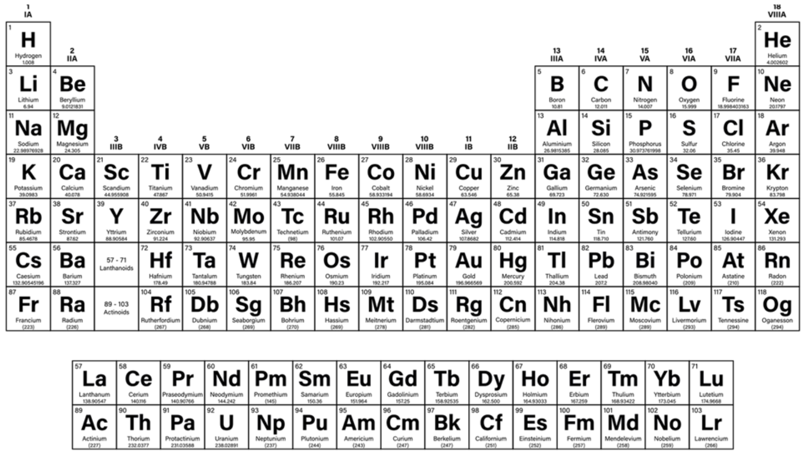
I DO:

Calcium reacts with a certain element to form a compound with the general formula CaX_2. What would be the most likely formula for a compound formed between sodium and element X?

A) NaX_2
B) Na_2X
C) Na_2X_2
D) NaX

WE DO:

Element 117 was recently discovered and is named Tennessine. Assuming that periodic trends are followed, write the noble gas electron configuration and predict the formula when it forms an ionic compound with Mg.

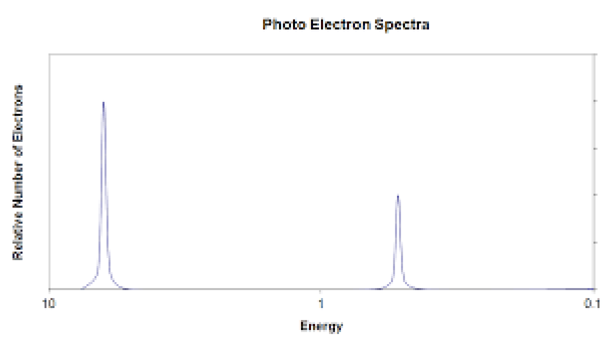


YOU DO:

1) Which of the following has the same number of electrons as Cl^{-1}?
   a) F^{-1}
   b) S
   c) Al^{3+}
   d) K^{+}

2) KCl dissolves in water, forming a solution able to conduct electricity. Which of the following would behave similarly?
   a) $PbCl_2$
   b) LiK
   c) LiCl
   d) $SrCl_2$

3) The complete photoelectron spectrum for an element is shown. What oxide compound would it most likely form?
   a) XO_2
   b) X_2O
   c) XO
   d) X_2O_2



4) Identify the correct electron configuration for the aluminum ion.
   a) $1s^22s^22p^6$
   b) $1s^22s^22p^63s^23p^1$
   c) $1s^22s^22p^63s^23p^6$
   d) $1s^22s^22p^63s^2$

