

EXTENSION ACTIVITY
GENERAL CHEMISTRY

IONIC BONDING

Activity Directions

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This activity will serve as practice for the topics covered in the Ionic Bonding game. This activity is best used in conjunction with not only the tutorial levels, but also supplementary learning resources such as course lectures, textbook reading, etc. Questions labeled “Lock It In” are simply opportunities for you to solidify what you have accomplished in each task and help ensure you meet each objective.

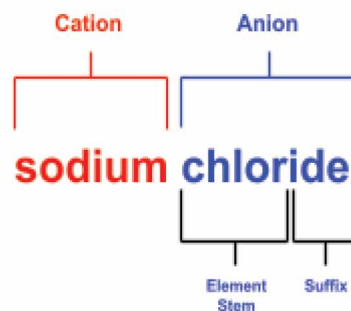
1. Log into Collisions and navigate to the Ionic Bonding Game.
2. Play the Tutorial levels, if you haven't done so already.
3. Exit the levels and enter the Ionic Bonding sandbox.
4. Follow all instructions as written below. Be sure to reference your course's textbook, lecture notes, etc. as needed.



OBJECTIVE 1

Demonstrate an understanding of ionic compound nomenclature and ionic ratios for main group elements.

Ionic bonds form as a result of electrostatic attraction between cations and anions. As a result, ionic compounds are given two-part names that acknowledge both the cation and anion. The name of the cation appears first, while the anion name appears second. Metals (cations) will simply keep their element name. However, with nonmetals (the anions) the suffix -ide is added to the element stem name. Take the compound NaCl as an example:



TASK 1: Complete the table below by creating each compound in the sandbox and by using the information provided in the text above.

Compound Name	Chemical Formula	Charge of Each Cation	Number of Individual Cations in Formula Unit	Charge of Each Anion	Number of Individual Anions in Formula Unit	Cation-Anion Ratio
potassium bromide						
	MgCl ₂					
aluminum oxide						
	Li ₃ N					
calcium sulfide						



LOCK IT IN: Does the nomenclature used here for main group ionic compounds reflect the number of individual ions in the formula unit? Explain.



OBJECTIVE 1

Demonstrate an understanding of ionic compound nomenclature and ionic ratios for main group elements.

Ionic compound nomenclature with polyatomic ions is straightforward except that the names of the polyatomic ions must be memorized or obtained from a reference source. Once again, the cation will appear first in the name, while the anion will appear second without name modification (e.g. ammonium chlorate - NH_4ClO_3). Below is a table of the polyatomic ions available in the Ionic Bonding Sandbox. Use them to complete Task 2.

Ion Name	Chemical Formula
nitrate	NO_3^-
hydroxide	OH^-
ammonium	NH_4^+
phosphate	PO_4^{3-}
sulfate	SO_4^{2-}
carbonate	CO_3^{2-}

TASK 2: Complete the table below by creating each compound in the sandbox and by using the information provided in the text above.

Compound Name	Chemical Formula	Charge of Each Cation	Number of Individual Cations in Formula Unit	Charge of Each Anion	Number of Individual Anions in Formula Unit	Cation-Anion Ratio
	$\text{Al}_2(\text{SO}_4)_3$					
sodium nitrate						
ammonium carbonate						
	$\text{Ca}(\text{OH})_2$					
	$\text{Mg}(\text{NO}_3)_2$					

LOCK IT IN: Does the nomenclature used here for compounds containing polyatomic ions reflect the number of individual ions in the formula unit? Explain.



OBJECTIVE 1

Demonstrate an understanding of ionic compound nomenclature and ionic ratios for main group elements.

Ionic compound nomenclature becomes more involved when considering the transition metals. Take a look at the iron (Fe) and copper (Cu) ions in the sandbox. You will notice that there are two possible charges for iron ions and two possible charges for copper ions. The existence of multiple ion charges is a very common characteristic of transition metals. As such, special nomenclature rules exist to keep track of them.

- Many transition metal ions have outdated common names that use the stem of the element name and either the ending -ic or -ous. The Latin name is sometimes used in place of the stem of the element name (e.g. Co^{3+} —cobaltic and Co^{2+} —cobaltous). Although these names are not often used formally anymore, they are still rather common in industrial and medical settings. It is thus helpful to at least recognize them. Examples include stannous fluoride used in toothpaste and ferrous sulfate given as a medication for anemia.
- The Stock system now provides what is considered the preferred and formal name for the transition metal ions. In this system, the metal is named and followed by the roman numeral for the charge of the ion in parentheses (e.g. the Fe^{2+} ion is iron (II) in the Stock system).

Element	Ion	Ion Common Name	Ion Stock System Name
Iron	Fe^{2+}	ferrous	iron (II)
	Fe^{3+}	ferric	Iron (III)
Copper	Cu^{+}	cuprous	copper (I)
	Cu^{2+}	cupric	copper (II)
Tin	Sn^{2+}	stannous	tin (II)
	Sn^{4+}	stannic	tin (IV)
Lead	Pb^{2+}	plumbous	lead (II)
	Pb^{4+}	plumbic	lead (IV)
Cobalt	Co^{2+}	cobaltous	cobalt (II)
	Co^{3+}	cobaltic	cobalt (III)
Chromium	Cr^{2+}	chromous	chromium (II)
	Cr^{3+}	chromic	chromium (III)



OBJECTIVE 1

Demonstrate an understanding of ionic compound nomenclature and ionic ratios for main group elements.

TASK 3: Complete the table below by creating each compound in the sandbox and by using the information provided in the text above.

Compound Name (Stock system name)	Chemical Formula	Charge of Each Cation	Number of Individual Cations in Formula Unit	Charge of Each Anion	Number of Individual Anions in Formula Unit	Cation-Anion Ratio
iron (II) sulfate						
	CuCl_2					
	Cu_2SO_4					
copper (II) phosphate						
	$\text{Fe}(\text{NO}_3)_3$					



LOCK IT IN:

Which name—
Common or Stock
System—would
be most useful in
determining the
chemical formula
of a substance with
which you are not
familiar? Why?



OBJECTIVE 2

Demonstrate an understanding of how the periodic table can be used to determine ionic ratios.

As you have probably already seen, the periodic table is a powerful tool for predicting properties of elements. One of these properties, particularly for the main group elements, is the ability to predict the charge of an element's ion using its group/family. This is possible because elements in the same group/family have the same number of valence electrons and will respond similarly to satisfy the octet rule. As you can see in the periodic table below, most of these families have special names, some of which are more commonly encountered (e.g. alkali metals) than others (e.g. pnictogens).

Periodic Table of the Elements

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16	Group 17	Group 18
Alkali metals	Earth metals	Transition metals						Pnictogens		Chalcogens		Halogens		Noble gases			
Lanthanides																	
Actinides																	

Periodic Table Families in *Chemistry* by Rice University, [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

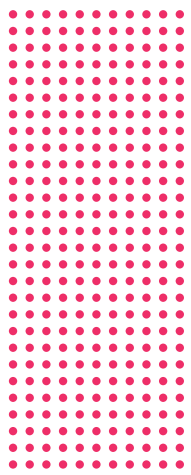
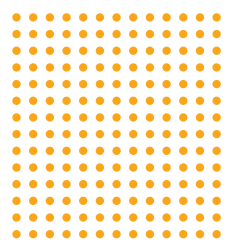


OBJECTIVE 2

Demonstrate an understanding of how the periodic table can be used to determine ionic ratios.

Periodic Table of the Elements

Period	Group 1																	18
1	1 H 1.008 hydrogen																	2 He 4.003 helium
2	3 Li 6.94 lithium	4 Be 9.012 beryllium											5 B 10.81 boron	6 C 12.01 carbon	7 N 14.01 nitrogen	8 O 16.00 oxygen	9 F 19.00 fluorine	10 Ne 20.18 neon
3	11 Na 22.99 sodium	12 Mg 24.31 magnesium	3	4	5	6	7	8	9	10	11	12	13 Al 26.98 aluminum	14 Si 28.09 silicon	15 P 30.97 phosphorus	16 S 32.06 sulfur	17 Cl 35.45 chlorine	18 Ar 39.95 argon
4	19 K 39.10 potassium	20 Ca 40.08 calcium	21 Sc 44.96 scandium	22 Ti 47.87 titanium	23 V 50.94 vanadium	24 Cr 52.00 chromium	25 Mn 54.94 manganese	26 Fe 55.85 iron	27 Co 58.93 cobalt	28 Ni 58.69 nickel	29 Cu 63.55 copper	30 Zn 65.38 zinc	31 Ga 69.72 gallium	32 Ge 72.63 germanium	33 As 74.92 arsenic	34 Se 78.97 selenium	35 Br 79.90 bromine	36 Kr 83.80 krypton
5	37 Rb 85.47 rubidium	38 Sr 87.62 strontium	39 Y 88.91 yttrium	40 Zr 91.22 zirconium	41 Nb 92.91 niobium	42 Mo 95.95 molybdenum	43 Tc [97] technetium	44 Ru 101.1 ruthenium	45 Rh 102.9 rhodium	46 Pd 106.4 palladium	47 Ag 107.9 silver	48 Cd 112.4 cadmium	49 In 114.8 indium	50 Sn 118.7 tin	51 Sb 121.8 antimony	52 Te 127.6 tellurium	53 I 126.9 iodine	54 Xe 131.3 xenon
6	55 Cs 132.9 cesium	56 Ba 137.3 barium	57-71 La-Lu * lanthanum series	72 Hf 178.5 hafnium	73 Ta 180.9 tantalum	74 W 183.8 tungsten	75 Re 186.2 rhenium	76 Os 190.2 osmium	77 Ir 192.2 iridium	78 Pt 195.1 platinum	79 Au 197.0 gold	80 Hg 200.6 mercury	81 Tl 204.4 thallium	82 Pb 207.2 lead	83 Bi 209.0 bismuth	84 Po [209] polonium	85 At [210] astatine	86 Rn [222] radon
7	87 Fr [223] francium	88 Ra [226] radium	89-103 Ac-Lr ** actinide series	104 Rf [267] rutherfordium	105 Db [270] dubnium	106 Sg [271] seaborgium	107 Bh [270] bohrium	108 Hs [277] hassium	109 Mt [276] meitnerium	110 Ds [281] darmstadtium	111 Rg [282] roentgenium	112 Cn [285] copernicium	113 Uut [285] ununtrium	114 Fl [289] flerovium	115 Uup [288] ununpentium	116 Lv [293] livermorium	117 Uus [294] ununseptium	118 Uuo [294] ununoctium



Atomic number → **1**

Symbol → **H**

Atomic mass → **1.008**

Name → **hydrogen**

Color Code	
 Metal	Solid
 Metalloid	Liquid
 Nonmetal	Gas

Periodic Table of the Elements in *Chemistry* by Rice University, [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)

IONIC BONDING - EXTENSION ACTIVITY



OBJECTIVE 2

Demonstrate an understanding of how the periodic table can be used to determine ionic ratios.

TASK 4: Find an element available in the sandbox for each of the element families listed in the table below and record the charge of its ion.

Element Family	Ion Example	Ion Charge
Alkali Metal		
Alkaline Earth Metal		
Pnictogens (Nitrogen Family)		
Chalcogens (Oxygen Family)		
Halogens (Fluorine Family)		



LOCK IT IN:
Fill in the subscripts for this compound using the ratios you determined.

The compound below represents a generic alkali metal chalcogenide.



The compound below represents a generic alkaline earth metal halide.



TASK 5: Using what you learned about the charges of the ions in different element families, determine what cation-anion ratio would form between any elements of the families in the table below. The alkali metal halides have already been done for you.

		Anion		
		Halogen	Chalcogen	Pnictogen
Cation	Alkali Metal	1:1		
	Alkaline Earth Metal			



OBJECTIVE 3

Demonstrate an understanding of how ionic bonding is an energetically favorable process.

It is important to remember that ionic bonding is the result of two key processes: the transfer of an electron(s) from one atom to another and the resulting electrostatic attraction between the now oppositely charged particles. As such, two key concepts immediately become important—**ionization energy** and **electron affinity**. Ionization energy describes the amount of energy required to remove an electron from an atom in the gaseous state. Electron affinity describes the amount of energy either required or released to add an electron to an atom in the gaseous state. Considering this, one would assume that the formation of ionic bonds occurs when the ionization energy of one atom is less than the amount of energy released when the atom with which it bonds accepts an electron. Let's see if this is true.

TASK 6: Complete the fifth column of the table by determining the sum of ionization energies and electron affinities of the elements in each reaction by adding the two together. Signs are important here! The last column will remain empty until Task 7. Also, remember that in some cases the number of electrons exchanged is more than one, so you will sometimes have to also consider second ionization energies and electron affinities.

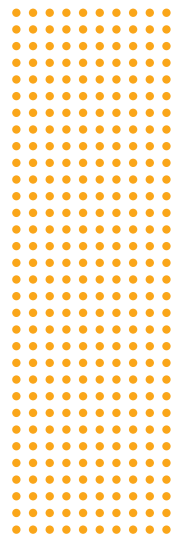
Compound	Synthesis Reaction	Metal Ionization Energy (kJ/mol)	Nonmetal Electron Affinity (kJ/mol)	IE + EA (kJ/mol)	Endothermic or Exothermic?
lithium bromide (LiBr)	$\text{Li(s)} + \frac{1}{2} \text{Br}_2(\text{g}) \rightarrow \text{LiBr(s)}$	+ 520	— 325		
potassium fluoride (KCl)	$\text{K(s)} + \frac{1}{2} \text{F}_2(\text{g}) \rightarrow \text{KF(s)}$	+ 419	— 328		
calcium oxide (CaO)	$\text{Ca(s)} + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{CaO(s)}$	First: + 590 Second: + 1145	First: —142 Second: + 844		
magnesium chloride (MgCl ₂)	$\text{Mg(s)} + \text{Cl}_2(\text{g}) \rightarrow \text{MgCl}_2(\text{s)}$	First: + 738 Second: + 1451	— 349		



OBJECTIVE 3

Demonstrate an understanding of how ionic bonding is an energetically favorable process.

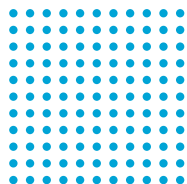
TASK 7: In the case that a reaction releases energy, it is considered **exothermic**. If the reactions you saw in Task 6 were exothermic, then the sum of their ionization energies and electron affinities would be negative, indicating that energy is released by the reaction. In the case that a reaction requires an input of energy, it is considered **endothermic**. If the reactions you saw in Task 6 were endothermic, then the sum of their ionization energies and electron affinities would be positive, indicating that energy input is required to complete the reaction. Use this information to complete the last column of the table in Task 6 and determine which type of reaction is predicted by ionization energies and electron affinities alone.



LOCK IT IN:

It turns out that the formation of ionic compounds in general, including the ones in Task 6, are very exothermic reactions. Considering this information, do the concepts of ionization energy and electron affinity alone explain the formation of ionic bonds? Explain your answer.





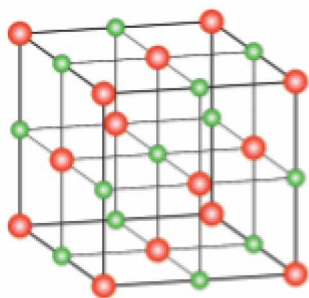


OBJECTIVE 3

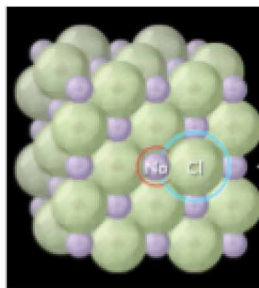
Demonstrate an understanding of how ionic bonding is an energetically favorable process.

TASK 8: Leave the sandbox and go to level 3 in the ionic bonding game. Click the menu button and choose “Restart level”. Build the first compound from the table in Task 6 — lithium bromide. Drag the formula unit into the correct section of the bottom panel of the game screen. In the space below, describe what appears immediately **after** the game checks and confirms the compound you created.

That structure that is shown is known as a **crystal lattice**. This arrangement of ions is crucial to understanding how a process that would be endothermic based on electron transfer alone is actually exothermic. As you saw with lithium bromide in the game, ions created as a result of electron transfer coalesce to form a network of alternating cations and anions. As these oppositely charged ions approach each other, their potential energy decreases and is released as heat. This released energy is known as the **lattice energy** and is so large that it outweighs the endothermicity of the electron transfer and makes the entire process of ionic bond formation exothermic.



Left: This generic crystal lattice shows alternating cations and anions. Formation of structures like this one releases energy.



Right: Sodium chloride (NaCl) crystal lattice as depicted in the Ionic Bonding game.

Ion Lattice by Prolineserver, [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)



LOCK IT IN:

In your own words, use the terms endothermic and exothermic to explain why ionic bond formation releases energy.



OBJECTIVE 4

Demonstrate an understanding of how Lewis structures can represent the formation of ionic compounds.

Lewis structures are a useful tool commonly used in chemistry to simply depict the valence electrons found around atoms and ions. As such, Lewis structures can also be used to show how atoms interact with one another in order to fulfill the **octet rule** that states that atoms generally prefer to have a full set of valence electrons. Such a state would be represented on a Lewis structure either by showing either 4 pairs of dots surrounding the atom or no dots surrounding the atom. Arrows can also be used to show how valence electrons move between atoms. Lewis structures are particularly useful for depicting the covalent bonds of molecules, but are also used for ionic compounds.



Sodium Atom
Lewis Structure



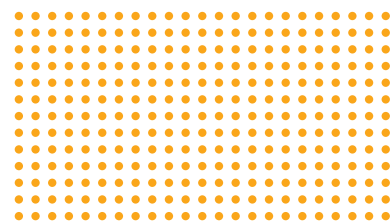
Sodium Ion
Lewis Structure



Chlorine Atom
Lewis Structure



Chloride Ion
Lewis Structure





OBJECTIVE 4

Demonstrate an understanding of how Lewis structures can represent the formation of ionic compounds.

TASK 9: Use the sandbox to create a compound that matches the Lewis structures in the first column of the table. Record the details about that compound in the remaining columns of the table. Note: Multiple correct answers are possible for each reaction.

Lewis Structure Synthesis Reaction	Total # of Electrons Transferred	Resulting Cation-Anion Ratio	Resulting Compound Name	Resulting Chemical Formula
$X \cdot \longrightarrow \cdot \ddot{Y} : \longrightarrow X^+ [:\ddot{Y}:]^-$				
$\begin{array}{c} \cdot \ddot{Y} : \\ \cdot \ddot{Y} : \\ \cdot X \end{array} \longrightarrow X^{2+} 2[:\ddot{Y}:]^-$				
$\cdot X \quad \cdot \ddot{Y} : \longrightarrow X^{2+} [:\ddot{Y}:]^{2-}$				
$\begin{array}{c} \cdot \ddot{Y} : \\ \cdot \ddot{Y} : \\ \cdot \ddot{Y} : \\ \cdot X \end{array} \longrightarrow 2X^{3+} 3[:\ddot{Y}:]^{2-}$				
$\begin{array}{c} \cdot X \\ \cdot X \\ \cdot X \end{array} \begin{array}{c} \cdot \ddot{Y} : \\ \cdot \ddot{Y} : \\ \cdot \ddot{Y} : \end{array} \longrightarrow 3X^{2+} 2[:\ddot{Y}:]^{3-}$				



OBJECTIVE 5

Demonstrate an understanding of the role of electronegativity in ionic bond characterization.

Another key concept in chemical bonding is **electronegativity**. Electronegativity describes the tendency of an atom to attract shared electrons towards itself. The difference in electronegativity between two bonded elements can help reveal whether the bond is ionic or covalent (covalent bonds are covered in their own game). Metals tend to have very low electronegativities while nonmetals tend to have higher ones. Ionic bonds, which form between metals and nonmetals, are thus characterized by large differences in electronegativities between the bonding elements. The exact electronegativity difference that characterizes each bond type varies depending on source, demonstrating how bonds are never purely ionic. However, the values used here are broadly representative of the variation. Also note that there are exceptions to the general electronegativity difference patterns. Some compounds with relatively low electronegativity differences between elements are classified as ionic, while others with relatively large differences are classified as covalent. As with many areas in chemistry, gray areas do exist.

Pauling Electronegativities of the Elements

Group (vertical)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period (horizontal)																		
1	H 2.20																	He
2	Li 0.98	Be 1.57											B 2.04	C 2.55	N 3.04	O 3.44	F 3.98	Ne
3	Na 0.93	Mg 1.31											Al 1.61	Si 1.90	P 2.19	S 2.58	Cl 3.16	Ar
4	K 0.82	Ca 1.00	Sc 1.36	Ti 1.54	V 1.63	Cr 1.66	Mn 1.55	Fe 1.83	Co 1.88	Ni 1.91	Cu 1.90	Zn 1.65	Ga 1.81	Ge 2.01	As 2.18	Se 2.55	Br 2.96	Kr 3.00
5	Rb 0.82	Sr 0.95	Y 1.22	Zr 1.33	Nb 1.6	Mo 2.16	Tc 1.9	Ru 2.2	Rh 2.28	Pd 2.20	Ag 1.93	Cd 1.69	In 1.78	Sn 1.96	Sb 2.05	Te 2.1	I 2.66	Xe 2.60
6	Cs 0.79	Ba 0.89	*	Hf 1.3	Ta 1.5	W 2.36	Re 1.9	Os 2.2	Ir 2.20	Pt 2.28	Au 2.54	Hg 2.00	Tl 1.62	Pb 2.33	Bi 2.02	Po 2.0	At 2.2	Rn 2.2
7	Fr 0.7	Ra 0.9	**	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo
Lanthanides	*	La 1.1	Ce 1.12	Pr 1.13	Nd 1.14	Pm 1.13	Sm 1.17	Eu 1.2	Gd 1.2	Tb 1.1	Dy 1.22	Ho 1.23	Er 1.24	Tm 1.25	Yb 1.1	Lu 1.27		
Actinides	**	Ac 1.1	Th 1.3	Pa 1.5	U 1.38	Np 1.36	Pu 1.28	Am 1.13	Cm 1.28	Bk 1.3	Cf 1.3	Es 1.3	Fm 1.3	Md 1.3	No 1.3	Lr 1.291		

Electronegativity Values, [CC BY-SA 3.0](https://creativecommons.org/licenses/by-sa/3.0/)



OBJECTIVE 5

Demonstrate an understanding of the role of electronegativity in ionic bond characterization.

Electronegativity Difference	Bond Type
0 to 1.7	Covalent
> 1.7	Ionic unless between two nonmetals

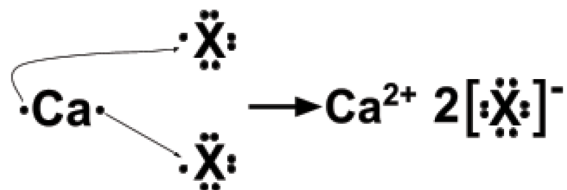
TASK 10: Use the electronegativity values and bond type table provided above to identify each substance in the table below as either ionically or covalently bonded. Make any ionically bonded substance in the sandbox to practice.

Chemical Formula of Substance	Electronegativity of First Element	Electronegativity of Second Element	Electronegativity Difference	Ionic or Covalent?
Cs ₂ S				
KF				
CO				
NO				
MgO				



CLOSURE

CLOSURE: Below is a Lewis structure for a substance with an anion of unknown identity. Use the sandbox to identify two ion candidates for the missing anion "X". Once you have done this, write the name and chemical formula for each compound before calculating the electronegativity difference between the elements in the two compounds you identify.



Possible Identity of X (name and chemical formula)	Compound Name	Compound Chemical Formula	Electronegativity Difference

