# Electronegativity

## Purpose:

To investigate the nature of the bond formed by two atoms and to explore a variety of models that are used to classify and describe such bonds.

## Getting Ready:

Visit the **Electronegativity** simulation at The Physics Classroom website:

https://www.physicsclassroom.com/Physics-Interactives/ChemistryElectronegativity

Navigational Path:

www.physicsclassroom.com ➔ Physics Interactives ➔ Chemistry ➔ Electronegativity

## Background:

The great 20th century Chemist Linus Pauling described electronegativity as "the power of an atom in a molecule to attract electrons to itself." The electronegativity of two interacting atoms determines the nature of the attraction or bond between them. In some cases, the two interacting atoms will attract the valence electrons with equal strength such that they are best described as being shared between them. In other cases, the two atoms will attract the valence electrons with unequal forces such that their bond is best described as a transfer of an electron from one atom to the other. And finally, there are cases such that the valence electrons are released *to the cloud* that is shared by a network of surrounding atoms. These three ideal cases are referred to, in order, as **covalent bonds**, **ionic bonds**, and **metallic bonds**. The goal of this activity is to understand some models that are used to predict the nature of the bond as being covalent, ionic, or metallic.

## Model #1: Bond Type Depends on Elements' Location on the Periodic Table

1. The simplest model of categorizing the bond formed by two atoms involves the use of the elements' location on the periodic table (PT). We will develop a model based on evidence from the simulation that suggests that the location of an element on a PT affects the types of bonds they form. Use the simulation to complete the table.

| | **Element #1** | | **Element #2** | | **Circle *Closest* Bond Type** | | |
|---|---|---|---|---|---|---|---|
| a. | **Li** | Circle: Metal<br>Nonmetal | **F** | Circle: Metal<br>Nonmetal | Covalent | Ionic | Metallic |
| b. | **Na** | Circle: Metal<br>Nonmetal | **Na** | Circle: Metal<br>Nonmetal | Covalent | Ionic | Metallic |
| c. | **Cl** | Circle: Metal<br>Nonmetal | **O** | Circle: Metal<br>Nonmetal | Covalent | Ionic | Metallic |
| d. | **Na** | Circle: Metal<br>Nonmetal | **Cl** | Circle: Metal<br>Nonmetal | Covalent | Ionic | Metallic |
| e. | **C** | Circle: Metal<br>Nonmetal | **H** | Circle: Metal<br>Nonmetal | Covalent | Ionic | Metallic |
| f. | **Mg** | Circle: Metal<br>Nonmetal | **Mg** | Circle: Metal<br>Nonmetal | Covalent | Ionic | Metallic |

2. Are any of the bonds purely covalent? or purely ionic? _______________ Explain.

3. Complete the statements below to generate three rules for predicting whether a bond is covalent, ionic, or metallic based on the identity of the two elements as being two metals, two nonmetals, or a metal-nonmetal combination.

   Rule #1: Two nonmetals form a(n) ________________ (ionic, covalent, metallic) bond.

   Rule #2: Two metals form a(n) ________________ (ionic, covalent, metallic) bond.

   Rule #3: A metal and a nonmetal form a(n) ________________ (ionic, covalent, metallic) bond.

4. Use the simulation to find at least three metal-nonmetal combinations that break Rule #3 stated above. Record your data at the right. (NOTE: do not use the hydrogen element in your investigation.)

   Explain how your data provide evidence that is contrary to Rule #3.

| Metal Element | Nonmetal Element | % Ionic Character |
|---|---|---|
| | | |
| | | |
| | | |

**Model #2: Electronegativity Differences**

5. Tap on several atoms and note the electronegativity values of metals and nonmetals. Alternatively, visit our Periodic Table of Electronegativity Values page. Record electronegativity (EN) values of the following elements:

**Electronegativity Values of Selected Elements**

| **Li**<br>metal | **Be**<br>metal | **B**<br>metalloid | **C**<br>nonmetal | **N**<br>nonmetal | **C**<br>nonmetal | **O**<br>nonmetal | **F**<br>nonmetal | **Cl**<br>nonmetal | **Br**<br>nonmetal |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

6. Complete the following statements:

   a. Metals have _______________ (lower, higher) EN values than nonmetal elements.

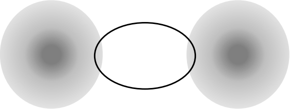
   b. EN values __________ (↑, ↓) when moving down a column of the PT.

   c. EN values __________ (↑, ↓) when moving left to right across a row of the PT.

   d. Differences in EN values are greatest the ________________ (further apart, closer together) that two elements are on the PT.

7. As Linus Pauling noted, electronegativity is the power of an atom to attract electrons to itself. Since bonds are the result of an atom's attraction for another atom's valence electrons, it would make since that the nature of a bond would have something to do with electronegativity. Analyze these three bonds. Record the electronegativity values of each element. Draw the location of the shared electrons. Draw the so-called dipole moment vector; include the arrowhead and the +/- signs. Indicate the percent ionic character.

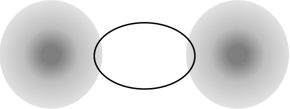
**_____% Ionic**



**F** **F**

**EN=____** **EN=____**

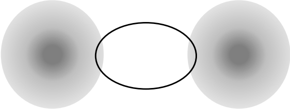
**_____% Ionic**



**N** **F**

**EN=____** **EN=____**

**_____% Ionic**



**Li** **F**

**EN=____** **EN=____**

8. Answer the following questions regarding the Li-F, N-F, and F-F bond.

a. In which bond are the electrons shared most equally between atoms? _____________

b. In which bond are the electrons being taken away rather than shared? _____________

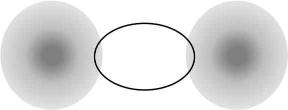
c. Which bond does not have a dipole moment vector? _____________

d. The shared $e^-$s are positioned closer to the atom with ___________ (greatest, smallest) EN.

e. As the difference in EN value increases, the bond becomes _________ (more, less) ionic.

9. A bond such as Li-F is often called an **ionic bond**; electrons are transferred from one atom to the other. A bond such as F-F is called a **nonpolar covalent bond**; electrons are shared equally among the two atoms. These are two extremes along the spectrum of bonds. A bond like N-F, an *intermediary* to the two extremes, is called a **polar covalent bond**; electrons are shared among the atoms, but a bit unequally due to the difference in electronegativity. Explore and provide one more example of each type of bond. For each, record the electronegativity values, draw the location of the shared electrons and draw the so-called dipole moment vector (with include the arrowhead and the +/- signs).

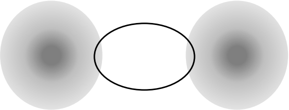
**Ionic**



**Li** **F**

**EN=____** **EN=____**

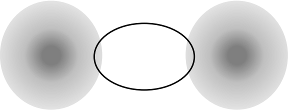
**Polar Covalent**



**N** **F**

**EN=____** **EN=____**

**Nonpolar Covalent**



**F** **F**

**EN=____** **EN=____**

10. A dipole exists when the center of + and – charge in a bond is located at separate locations. Analyze the four dipole moment vectors above and complete these sentences:

a. The dipole vector points from the ____________ to the ____________ electronegative element (insert least and most into the blanks).

b. The + pole is located near the _____________ (least, most) electronegative element.

c. The - pole is located near the _____________ (least, most) electronegative element.

11. Review your part e answer to Question #8. Some have attempted to use differences in EN value to classify bonds as nonpolar covalent, polar covalent, and ionic. One common classification scheme is to say any bond with an EN difference of 0.5 to 1.7 is polar covalent. An EN difference less than 0.5 is nonpolar covalent and an EN difference greater than 1.7 is ionic. Use EN values and this classification scheme to fill in the table.

| | **Bond** | **Diff. in EN Value** | **Bond Classification** | **Typical Comp'd** | **m.p. (°C)** | **b.p. (°C)** | **For Q#12 (Comp'd Type)** |
|---|---|---|---|---|---|---|---|
| a. | Na-F | | | NaF | 993 | 1695 | |
| b. | B-H | | | $BH_3$ | NA* | -78** | |
| c. | C-Cl | | | $CCl_4$ | -23 | 77 | |
| d. | Na-Cl | | | NaCl | 801 | 1413 | |
| e. | K-O | | | $K_2O$ | 740 | 1445 | |
| f. | C-H | | | $CH_4$ | -183 | -162 | |
| g. | Mg-Cl | | | $MgCl_2$ | 714 | 1413 | |
| h. | Mg-O | | | MgO | 2800 | 3600 | |
| i. | Ca-P | | | $Ca_3P_2$ | 1400 | NA*** | |
| j. | Al-P | | | AlP | 1100 | NA*** | |

* Polymerizes **Approximation *** Decomposes before boiling

12. Compounds consisting of covalently bonded atoms are referred to as **molecular compounds**. While there are exceptions, they are generally gases or liquids at room temperature and have relatively low melting and boiling points. Compounds consisting of only ionic bonds usually form **ionic compounds** with relatively high melting and boiling points. Based on the m.p. and b.p. data above, fill in the last column – **molecular** or **ionic** compound type.

13. Using the EN differences and the classification system in Question #11, you classified 10 bonds in the table. And based on m.p. and b.p. data, you classified compounds containing these bonds as ionic or covalent. Do any of your ionic compounds (last column) contain only covalent bonds? ____________ What does this finding suggest regarding the value of a model that classifies a bond into one of three categories based solely on differences in electronegativity between the bonded atoms?

## Model #3: Electronegativity and Electronegativity Difference

A third model for thinking about classifying bonds is based on the premise that the bond type depends on both the EN difference and the average EN value of the bonded atoms. The model is based on the so-called van Arkel-Ketelaar Triangle. One variation of the triangle is shown below. The three bonding extremes are listed at the corners of the triangle. The electronegativity is listed along the lower edge of the triangle. The 20 elements of the simulation (minus Group 18 and plus Cs and Fr) are listed along the axis. To identify the location of a bond on the triangle, two diagonal lines parallel to the triangle's opposite sides are constructed, beginning from the EN value of the elements along the bottom edge. The intersection point of these lines is the location of the bond. The bond falls into one of three (four, if you count semi metallic) categories – ionic (**I**), covalent (**C**), and metallic (**M**).

Based on this model:

- For two elements whose average EN value is 1.9, the difference in EN would need to be just approximately 0.8 or higher to be considered ionic.
- For two elements whose average EN value is 2.0, the difference in EN would need to be just approximately 1.4 or higher to be considered ionic.
- For two elements whose average EN value is 2.6, the difference in EN would need to be just approximately 2.2 or higher to be considered ionic.
- For two elements whose average EN value is 2.8, the bond that they form would always be covalent.
- While these are distinct cut-offs that vary with average EN values, there is still a spectrum or range of ionic character for any bond classification.