Polar Bonds

Unit: Intermolecular Forces

MA Curriculum Frameworks (2016): HS-PS1-2, HS-PS1-3

Mastery Objective(s): (Students will be able to…)

- Calculate the electronegativity difference between atoms in a bond.
- Identify polar bonds based on electronegativity differences.

Success Criteria:

- Bonds are correctly identified as polar or non-polar based on electronegativity difference.

Tier 2 Vocabulary: polar

Language Objectives:

- Explain how electrons are distributed unevenly in polar bonds.

Notes:

polar: anything with two sides that are opposite with respect to something. For example, a battery is polar because it has a positive and negative end.

polar bond: a covalent bond that has opposite partial charges on each side (one side partially positive and one side partially negative), because of unequal sharing of electrons.

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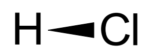
For example: The bond between H and Cl in the H-Cl molecule is a polar bond.

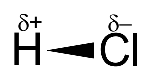
The bond is polar because hydrogen and chlorine share a pair of electrons, but the sharing is not equal. Chlorine has an electronegativity of 3.16, but hydrogen has an electronegativity of only 2.2. This means the electrons spend more time with chlorine than with hydrogen.

One way to show a polar bond is by using a wedge-shaped bond, which is wider on the side where the electrons spend the most time. The HCl molecule would look like this:



The wedge is narrower on the H side and wider on the Cl side because the chlorine atom has the electrons more of the time.

It is also common to label atoms in the structure with partial charges. The lower-case Greek letter "delta" (δ) is used to mean "partial". A partially positive charge would be shown as $\delta+$ and a partially negative charge would be shown as $\delta-$, as in the following example:



In the above example, hydrogen has a partial positive charge, and chlorine has a partial negative charge.

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Bond Type and Bond Character

bond type: whether we define a bond as ionic or covalent. This depends on several factors, but for the purposes of this class, it just depends on which types of elements the bond is joining.

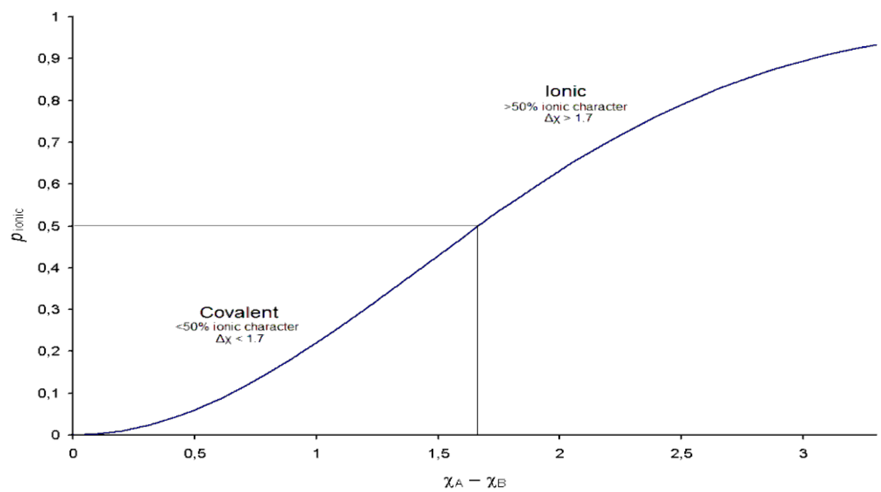
- covalent bond: between two nonmetals
- ionic bond: between two ions (usually a metal & nonmetal)
- metallic bond: between two metals

bond character: what a bond *acts like*, based on how equally the electrons are shared. This depends on the electronegativities (χ) of the two elements. In simplest terms, the larger the difference between the two electronegativities ($\Delta\chi$) the greater the extent to which the electrons are associated with one element more than the other.

American chemist Linus Pauling developed the following formula for calculating bond character based on the electronegativity difference between the elements sharing the bond:

$$\%\text{ ionic character} = 1 - e^{-\frac{1}{4}(\chi_A - \chi_B)^2}$$

The following is a graph of Pauling's formula:



Notice that an ionic character of 0.5 (50 %) would result from an electronegativity difference of approximately 1.7. Therefore, we can define a bond as being primarily ionic in character if the electronegativity difference between the two atoms in the bond is 1.7 or more.

A bond that is less than 50 % ionic is said to be primarily covalent in character.

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However, even covalent bonds can have measurably unequal sharing. it takes a relatively small difference to create a measurable bond polarity. The lower boundary is defined by the polarity of a C—H bond, which has no observable polarity under most conditions. The difference between the Pauling electronegativity of carbon (2.55) and hydrogen (2.20) is 0.35, so $\Delta\chi = 0.35$ is chosen to be the maximum electronegativity difference for a nonpolar bond. This represents about 3 % ionic character.

These values are summarized in the following table:

Electronegativity Difference ($\Delta\chi$)	**% Ionic Character**	**Bond Character**
0.35 or less (C—H)	< 3 %	nonpolar covalent
between 0.35 and 1.7	3 %–50 %	polar covalent
1.7 or more	> 50 %	ionic

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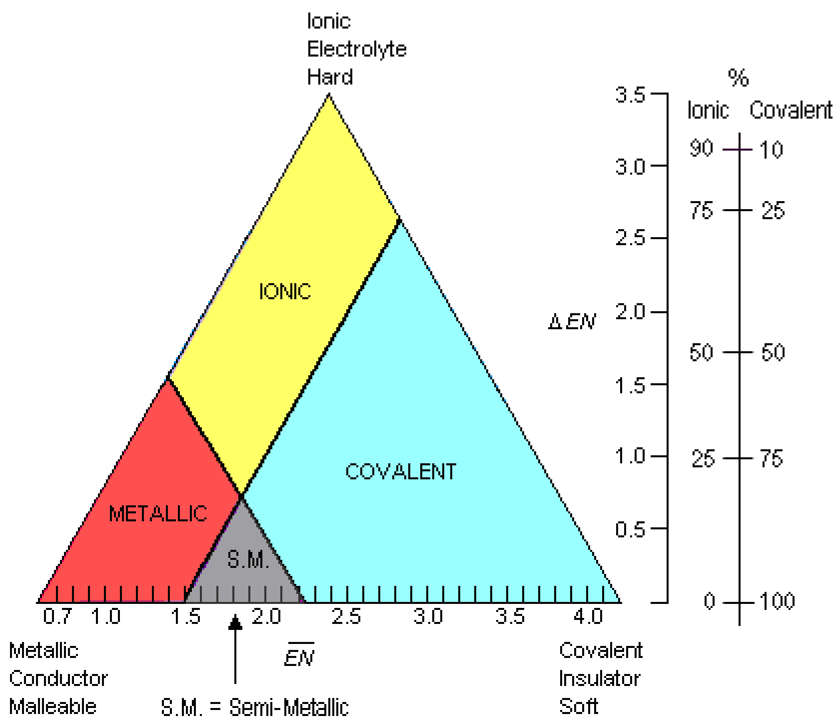
Bond Triangle

As it turns out, looking only at the difference between the electronegativities of the elements in a chemical bond is not always a good predictor of bond character. For example, metallic bonds behave neither like ionic nor covalent bonds, and electronegativity difference could not predict metallic bond character. The idea of a triangular region, with covalent, ionic, and metallic bonds in each of the corners has been around since the 1920s. The modern bond triangle was developed by two chemists: the Dutch chemist Anton Eduard van Arkel published a bond triangle in 1941 that placed compounds with in specific positions around the triangle. In 1947, the Dutch chemist J. A. A. Ketelaar published a significant paper expanding on van Arkel's ideas. Bond triangles are often called van Arkel-Ketelaar triangles after these two chemists.

American chemist William Jensen quantified the van Arkel-Ketelaar triangle in a 1995 paper, in which he plotted the average of the two electronegativities on the *x*-axis, and the difference between the two electronegativities on the *y*-axis.

The following bond triangle, which gives reasonably good predictions of the nature of various chemical bonds based on each atom's electronegativity, was published by the chemistry department at Purdue University:.



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Homework Problems

Complete the table. You will need to look up electronegativity values (χ) from in "Table Z. Selected Properties of the Elements" of your Chemistry Reference Tables, which begins on page 516.

Elements	**Bond Type**	**χ1**	**χ2**	**Δχ**	**Bond Character**
Pb–S	ionic	2.33	2.58	0.25	nonpolar covalent
Ag–Cl					
Cu–C					
C–N					
C–I					
H–O					
Al–Cl					
K–F					
N–H					
N–O					
C–S					
Ba–Cl					
S–O					
Si–H					

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