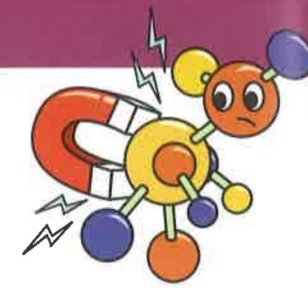


LESSON

# 15 Attractive Molecules

## Attractions Between Molecules

### Think About It

Not everything has a smell. In fact, there are more substances on the planet that we *don't* smell than substances that we *do* smell. If everything around us had a smell, our noses would probably be overwhelmed most of the time.

**Why do some molecules smell while others do not?**

To answer this question, you will explore

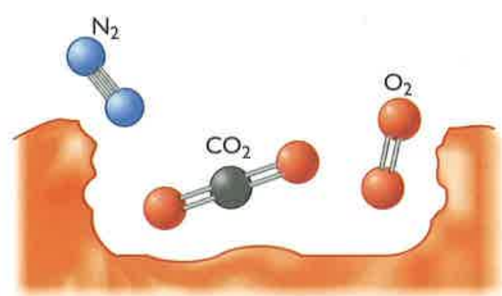
1. Compounds That Do Not Have a Smell
2. Polar Molecules
3. Intermolecular Force

### Exploring the Topic

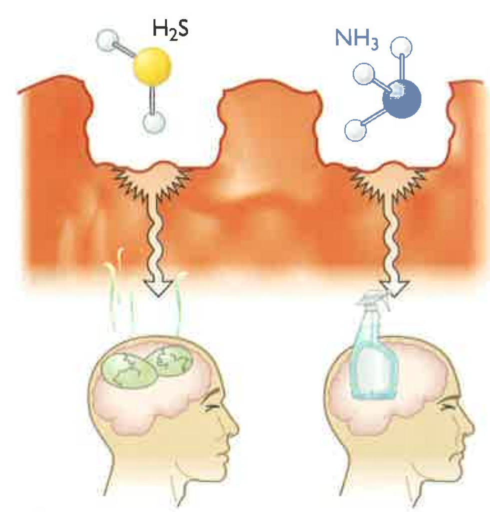
#### 1 Compounds That Do Not Have a Smell

Take a big whiff of air. Perhaps you are able to detect some odors—a freshly mowed lawn, somebody's food cooking. But the air itself does not smell. Small molecules, such as nitrogen, oxygen, carbon dioxide, and water vapor, obviously fit inside the receptor sites. So, why can't we smell them?

Perhaps these molecules are too small to stay docked in a receptor site. But some small molecules do have a smell. Hydrogen sulfide, $H_2S$, smells like rotting eggs and ammonia, $NH_3$, smells pungent.




Some small molecules do not have a smell.




But $H_2S$ and $NH_3$ both have strong smells.

So the molecular size of a compound does not explain whether we can smell it. It turns out that a molecular property called *polarity* is involved.



**PHYSICS CONNECTION**

You take off a wool hat, and all your hair stands on end. This happens because electrons move from your hair to the hat so that each individual hair has a positive charge. Because like charges repel one another, the hairs try to get as far apart as possible, resulting in a bad hair day. Something similar happens when a child slides down a plastic slide.

#### 2 Polar Molecules

When two different materials are rubbed together, some electrons can transfer from one material to the other. The result is an imbalance of positive and negative charges. One material has an excess of positive charge and the other an excess of negative charge. This is known as static electricity.

Suppose that you rub a plastic wand on a piece of cloth. The plastic wand will end up with a charge. In class you tested a number of liquids by holding a charged wand near them and observed that some of the streams bend toward the wand.

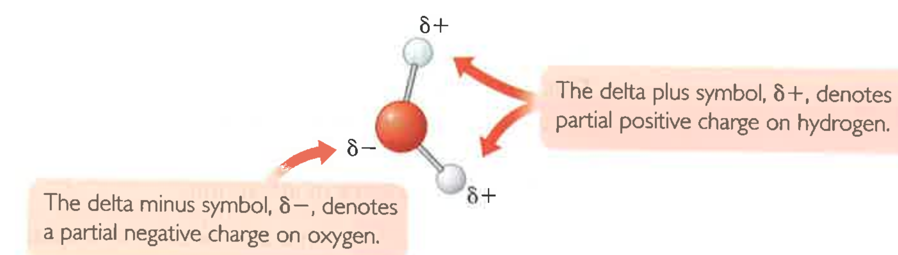
All of the liquids in the first column of the table are attracted to a charged wand. They are made up of **polar molecules.** The liquids in the second column are not attracted to a charged wand; they consist of **nonpolar molecules.**

These molecules are all **polar.** They all have a smell.

| Polar molecules | Nonpolar molecules |
|---|---|
| water<br>vinegar<br>nail polish remover<br>rubbing alcohol<br>antifreeze | mineral oil<br>hexane<br>paint thinner<br>motor oil |

These molecules are all **nonpolar.** They do not have a smell.

Water is a polar molecule. As this illustration shows, there are partial charges at different locations on the water molecule. These **partial charges** are much smaller than the charge on an individual electron or proton. However, the charges are large enough to cause a stream of water to be attracted to a charged wand.

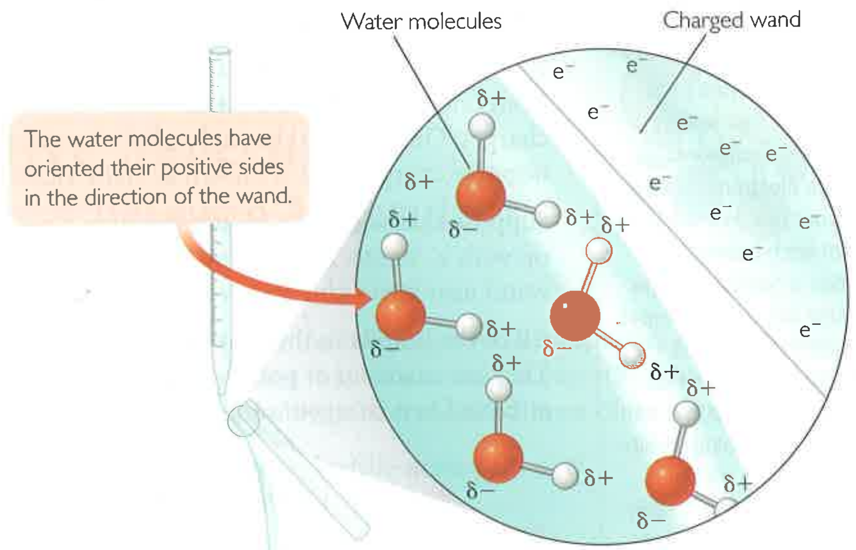



The oxygen atom has a partial negative charge, and the hydrogen atoms each have a partial positive charge.

#### 3 Intermolecular Force

**Explaining the Charged Wand**

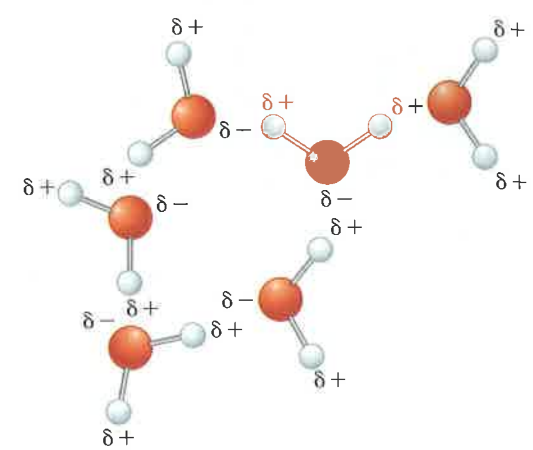
When a wand with a negative charge is placed next to a stream of water, the water molecules orient themselves in space so that their positive ends are lined up in the direction of the wand. As a result, the whole stream of water is attracted to, or pulled toward, the charged wand. The illustration on the next page shows a possible way to depict what happens to the molecules.



Water molecules next to a charged wand

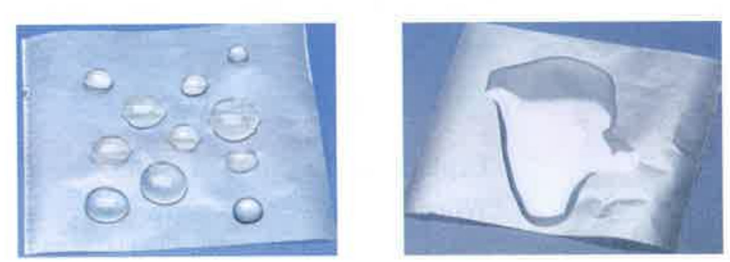
**Intermolecular Behavior**

The partial charges on polar molecules cause more than an attraction to a charged wand. They also cause attractions between molecules. As the molecules in a polar liquid tumble around they tend to align with each other because partial negative charges are attracted to partial positive charges. This attraction between individual molecules is an **intermolecular force.** The prefix *inter* means "between" and the force is a force of attraction.


Water molecules interacting

Intermolecular attractions can be used to explain many observable properties.

*Observation:* Water beads up on waxed paper. Oil spreads out.



*Explanation:* The water molecules are polar, while the oil molecules are nonpolar. The individual water molecules are attracted to each other and "cling together." Individual oil molecules are not attracted to one another to the same extent, and they spread out.

*Observation:* Water is a liquid at room temperature, but methane is a gas at room temperature. They have roughly the same molecular mass.

**LANGUAGE CONNECTION**

The saying "Oil and water don't mix" is one way to remember that a nonpolar substance and a polar substance tend not to dissolve in each other.



*Explanation:* Water is polar and methane is nonpolar. The individual water molecules are attracted to each other and stay together as a liquid. The attractions between methane molecules are much weaker. The methane molecules spread throughout the room as a gas.

*Observation:* Methanol dissolves easily in water. Oil floats on top of water but does not dissolve.

*Explanation:* The polar methanol molecules are attracted to the polar water molecules and go into solution. The nonpolar oil molecules are not attracted to the polar water molecules.

**Key Terms**

polar molecule
nonpolar molecule
partial charge
intermolecular forces

## Lesson Summary

### Why do some molecules smell while others do not?

Molecules can be divided into two classes: polar and nonpolar. Polar molecules are attracted to a charged wand because they have partial charges distributed within the molecule. Nonpolar molecules are not attracted to a charged wand. Polarity is responsible for intermolecular attractions that affect many properties of molecules possibly including smell properties.

## EXERCISES

### Reading Questions

1. Explain in your own words what a polar molecule is.
2. What are intermolecular attractions?

### Reason and Apply

3. **Lab Report** Write a lab report for the Lab: Attraction[…] In your conclusion, explain why some liquids were attra[…] and others were not as well as why some liquids beaded while others did not.

#1,2,4-6

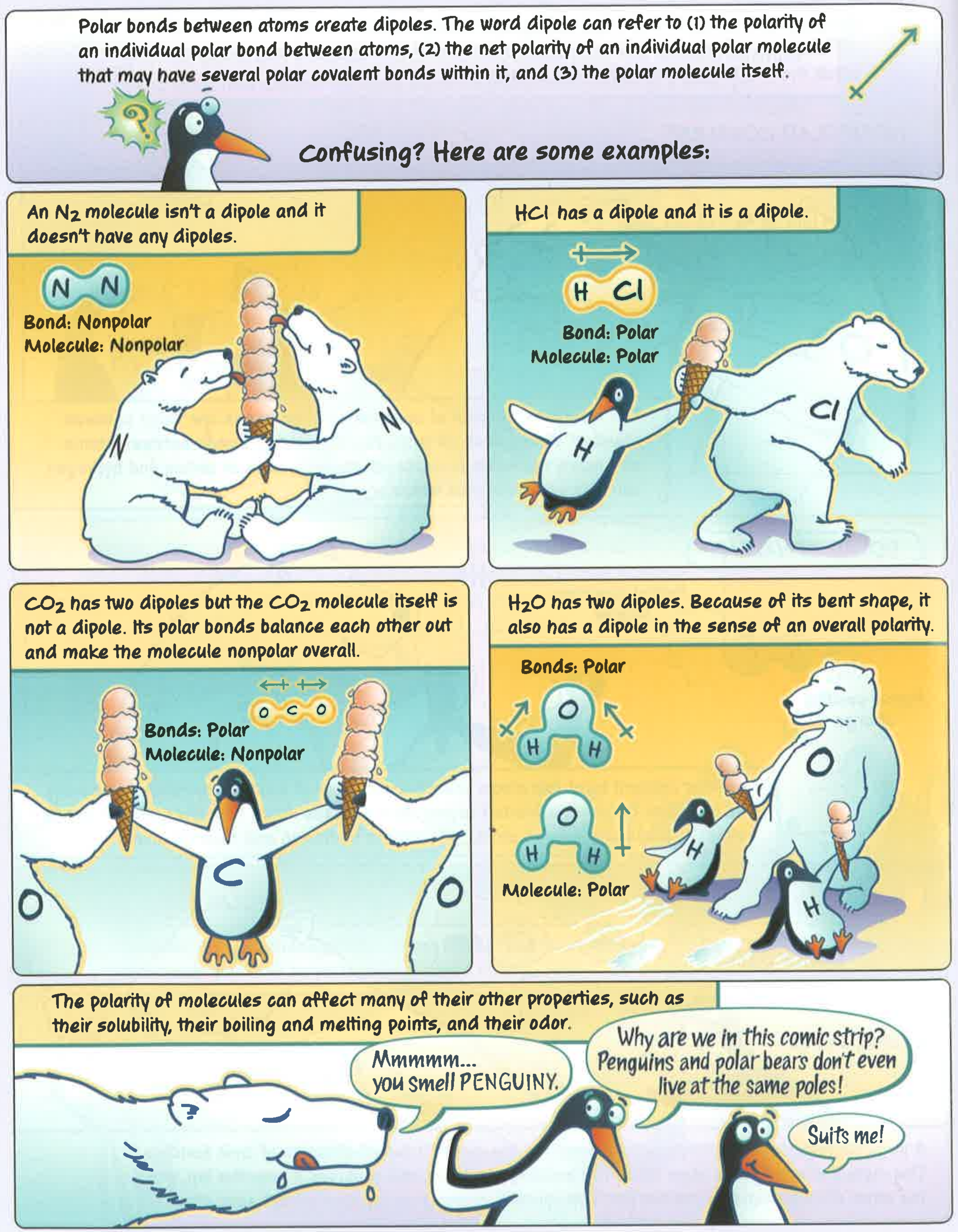
(Title)

**Purpose:** (Explain what you were trying to find out.)

**Procedure:** (List the steps you followed.)

**Results:** (Explain what you observed during the experiment.)

**Conclusions:** (What can you conclude about what you were trying to find out? Provide evidence for your conclusions.)






LESSON

# 16 Polar Bears and Penguins

## Electronegativity and Polarity

### Think About It

Hydrogen chloride, HCl, is a colorless but very toxic gas. Its smell is described as a suffocating, acrid odor. Like most other small molecules that smell, HCl molecules are polar. But what makes an HCl molecule polar? Where do the partial charges come from on the atoms in a polar molecule?

**What makes a molecule polar?**

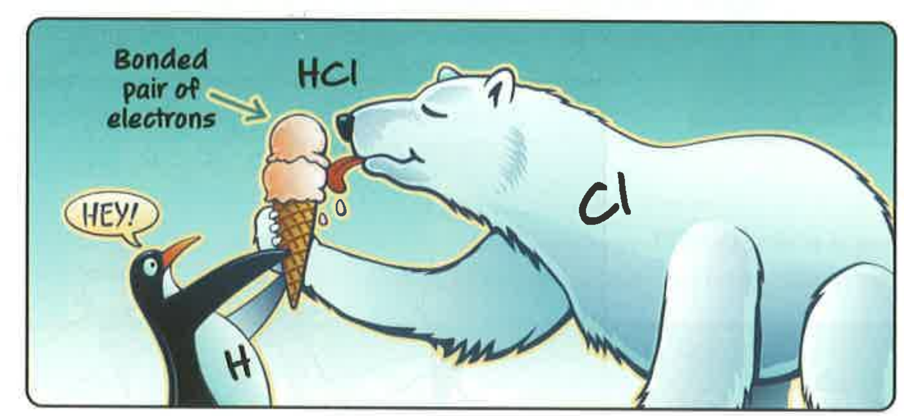
To answer this question, you will examine

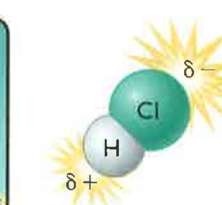
1. Electronegativity
2. Nonpolar Molecules
3. Electronegativity and Bonding

### Exploring the Topic

#### 1 Electronegativity

The hydrogen atom and the chlorine atom in hydrogen chloride, HCl, form a covalent bond by sharing a pair of electrons. This cartoon represents HCl as a penguin and a polar bear. The bonded pair of electrons is represented as two scoops of ice cream. Although the penguin and the polar bear are sharing the ice cream, they are not sharing it equally.




Similarly, the hydrogen atom and the chlorine atom in a hydrogen chloride molecule do not share the bonded pair of electrons equally. The chlorine atom attracts the shared electrons much more strongly than the hydrogen atom does. As a result, the shared electrons spend more time near the chlorine atom than they do near the hydrogen atom. Because of this displacement of the electrons, the hydrogen atom has a partial positive charge and the chlorine atom has a partial negative charge.

The tendency of an atom to attract shared electrons is called **electronegativity.** An atom that has a large electronegativity strongly attracts shared electrons. In this case, the chlorine atom, like the polar bear, is stronger in attracting electrons, so it is more electronegative than the hydrogen atom. The atoms that are more electronegative are the ones that end up with a partial negative charge. The atoms with less electronegativity end up with a partial positive charge. The result is a polar bond.

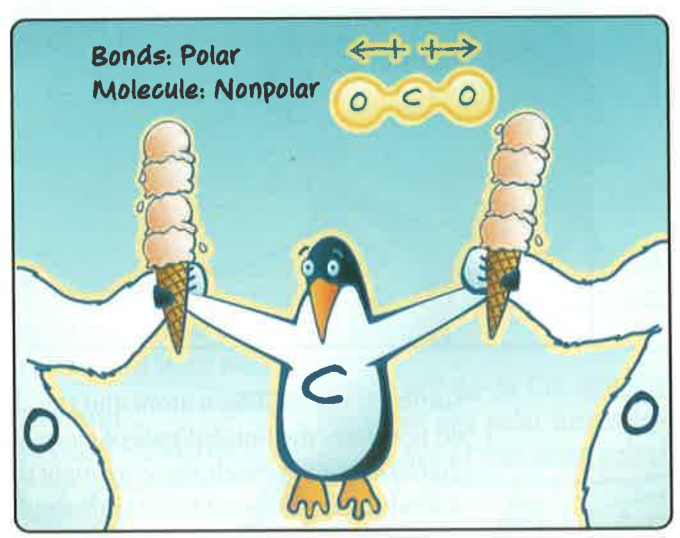
A polar molecule is called a **dipole,** because it has two poles: a positive end and a negative end. A dipole can be shown with an arrow starting at the positive end and pointing to the negative end of the molecule. The polar bond itself is also called a dipole.


## Nonpolar Molecules

When two atoms with identical electronegativities bond together, the attraction of the shared electrons is identical. As a result, the molecule is nonpolar. For example, $H_2$ and $Cl_2$ are both nonpolar molecules. They have no partial charges.


A contest between two polar bears of equal strength or two penguins of equal strength would result in a tie.

There is another way to end up with a nonpolar molecule. Examine the next illustration. Why is carbon dioxide, $CO_2$, a nonpolar molecule?



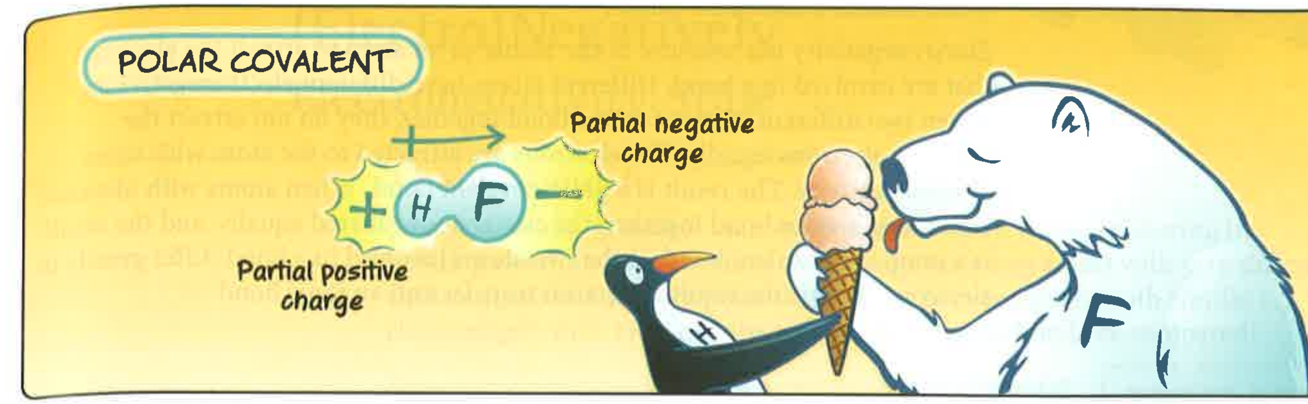

$CO_2$ is a nonpolar molecule.

The two dipoles in $CO_2$ balance each other, and there is no partial positive end to the molecule. So the overall molecule is nonpolar.



## Electronegativity and Bonding

There are two types of covalent bonds: polar covalent bonds and nonpolar covalent bonds. When two atoms with different electronegativities bond together, the result is a polar covalent bond.

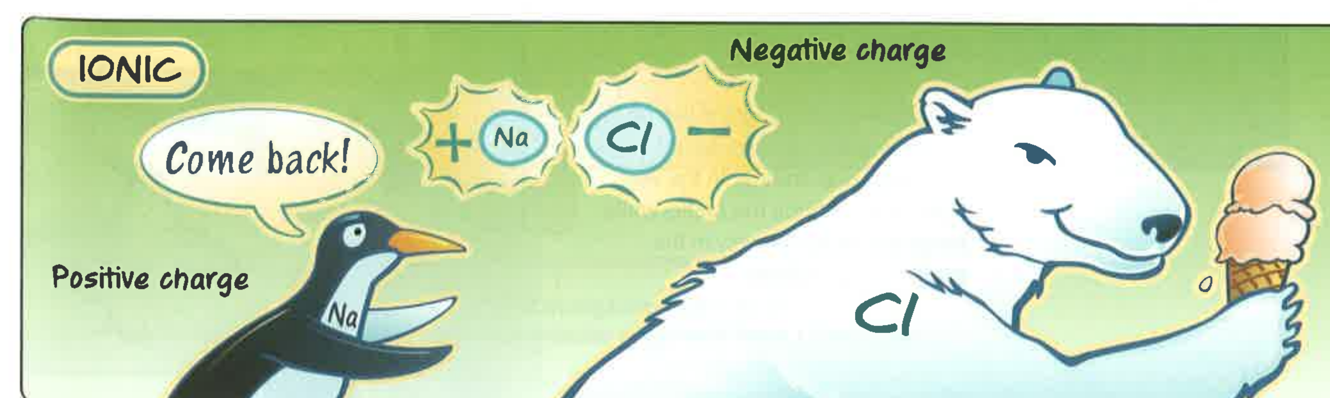



Different electronegativities result in polar bonds.

When the electronegativities of the atoms that bond are identical, the result is a nonpolar covalent bond.


Identical electronegativities result in nonpolar bonds.

If the electronegativities of the two atoms differ greatly, it is possible for electrons to be pulled entirely toward one of the atoms in a bond. The result is an ionic bond.




Extremely different electronegativities result in ionic bonds.

Ionic compounds represent the extreme of polar bonds, in which electrons are transferred to the more electronegative atom in the pair.

**Key Terms**
electronegativity
dipole

## Lesson Summary

### What makes a molecule polar?

Electronegativity is a measure of the ability of an atom to attract the electrons that are involved in a bond. Different atoms have different electronegativities. When two different kinds of atoms bond together, they do not attract the bonding electrons equally. The electrons are attracted to the atom with more electronegativity. The result is a polar covalent bond. When atoms with identical electronegativities bond together, the electrons are shared equally, and the result is a nonpolar covalent bond. If the two atoms involved in a bond differ greatly in electronegativity, the result is electron transfer and an ionic bond.

## EXERCISES

#1-4

### Reading Questions

1. What is the difference between a polar covalent bond and a nonpolar covalent bond?
2. What is the difference between a polar covalent bond and an ionic bond?
3. Explain why carbon dioxide is a nonpolar molecule even though its bonds are polar.

### Reason and Apply

4. Are these molecules polar covalent or nonpolar covalent?
   **a.** $N_2$ **b.** HF **c.** $F_2$ **d.** NO **e.** FCl
5. Using polar bears and penguins, create an illustration showing an ammonia, $NH_3$, molecule. (*Hint:* You may wish to start with a Lewis dot structure.)
6. Is the molecule HOCl polar or nonpolar? Use a Lewis dot structure to explain your thinking.
7. Use electronegativity to explain why some molecules are attracted to a charged wand.

**NATURE CONNECTION**

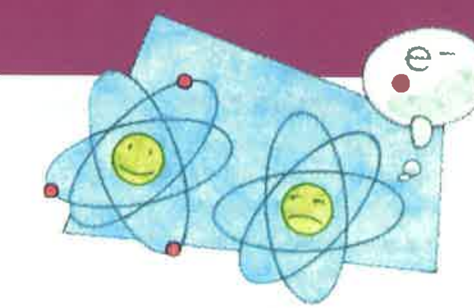
Polar bears and penguins live on opposite poles, so they do not encounter one another in the wild. Polar bears inhabit the Arctic, while penguins live exclusively in the southern hemisphere.



**LESSON 17**

# Thinking (Electro)Negatively

## Electronegativity Scale




### Think About It

Some atoms are "greedier" than other atoms when it comes to sharing the bonding electrons between them. A bond between two atoms with very different electronegativities is more polar than a bond between atoms with similar electronegativities. How can the polarity of different bonds be compared?

**How can electronegativity be used to compare bonds?**

To answer this question, you will explore

1. Electronegativity Scale
2. Diatomic Molecules

### Exploring the Topic

#### 1 Electronegativity Scale

Chemists have assigned each atom a number, called an *electronegativity value.* This number corresponds to the tendency of an atom to attract bonding electrons. By using these numbers, it is possible to compare the polarity of different bonds. The table here shows the electronegativity value for an atom of each element in the periodic table.

Electronegativity scale

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H 2.10 | | | | | | | | | | | | | | | | | He |
| Li 0.98 | Be 1.57 | | | | | | | | | | | B 2.04 | C 2.55 | N 3.04 | O 3.44 | F 3.98 | Ne |
| Na 0.93 | Mg 1.31 | | | | | | | | | | | Al 1.61 | Si 1.90 | P 2.19 | S 2.58 | Cl 3.16 | Ar |
| 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 |
| Rb 0.82 | Sr 0.95 | Y 1.22 | Zr 1.33 | Nb 1.60 | Mo 2.16 | Tc 1.90 | 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 |
| Cs 0.79 | Ba 0.89 | La* 1.10 | Hf 1.30 | Ta 1.50 | W 2.36 | Re 1.90 | Os 2.20 | Ir 2.20 | Pt 2.28 | Au 2.54 | Hg 2.00 | Tl 1.62 | Pb 2.33 | Bi 2.02 | Po 2.00 | At 2.20 | Rn |
| Fr 0.70 | Ra 0.89 | Ac* 1.10 | | | | | | | | | | | | | | | |

* Electronegativity values for the lanthanides and actinides range from about 1.10 to 1.50.

**HISTORY CONNECTION**

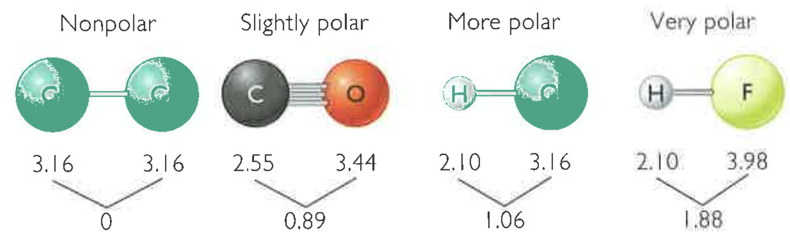
Linus Pauling, inventor of the electronegativity scale, is one of only two people (the other is Marie Curie) to receive Nobel Prizes in two different fields. In 1954, he received the Nobel Prize in Chemistry, and in 1962 he received the Nobel Peace Prize for his work in campaigning against above-ground nuclear testing.

Notice that the values generally increase from left to right and bottom to top. Noble gases are often not assigned values because they generally do not form compounds.

A scale for electronegativity was first proposed by Linus Pauling, in 1932. The scale used today by chemists ranges in value from 4.0 down to 0. The electronegativity scale allows you to compare individual atoms. For example, fluorine, with an electronegativity value of 3.98, attracts shared electrons more strongly than hydrogen, with an electronegativity value of 2.10.

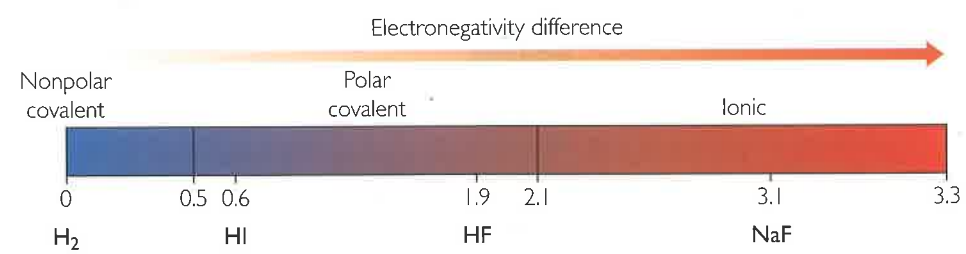
## 2 Diatomic Molecules

The electronegativity scale also allows you to compare the polarity of bonds. In a polar covalent bond, the electrons tend to spend more time around the more electronegative atom. Several substances with only two atoms are shown below. Molecules with two atoms are called **diatomic molecules.** By looking at the numerical difference between the electronegativities of the two atoms, it is possible to compare the polarity of one bond to another. Bonds that have a greater difference in electronegativity between the two atoms are more polar.



Differences in electronegativity

When the difference in electronegativity between the two atoms is very large, the bond is no longer considered covalent. In that case, the electrons are transferred from the less electronegative atom to the more electronegative atom. A cation and an anion form that are attracted to one another in an ionic bond. As shown on the electronegativity scale, when the difference between the electronegativities of two bonded atoms is greater than about 2.1, the bond is considered ionic.

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### Example

**Potassium and Chlorine**

Predict the type of bond you would find between potassium and chlorine.

***Solution***

Use the electronegativity scale to find the electronegativities of potassium, K, and chlorine, Cl. It shows that the values are 0.82 for K and 3.16 for Cl. The difference is 2.34, so the bond is ionic.



**Key Term**
diatomic molecule

## Lesson Summary

### How can electronegativity be used to compare bonds?

Electronegativity values can help you to compare and classify different bonds. If there is no difference in electronegativity between the two atoms the bond is considered nonpolar covalent. The larger the electronegativity difference, the more polar the bond. The electrons in a polar bond tend to spend more time around the more electronegative atom. When the difference between the electronegativities of two bonded atoms is greater than about 2.1, the bond is considered ionic and one atom gives up an electron to the other atom, forming two ions.

## EXERCISES

### Reading Questions

1. Explain how electronegativity values help you to determine the polarity of a bond between two atoms.
2. How can you determine which atom in a covalent bond is partially positive?


### Reason and Apply

3. Consider the following pairs of atoms. Place each set in order of increasing bond polarity. Describe the trend.
   a. Li–F   Na–F   K–F   Rb–F   Cs–F
   b. Mg–O   P–S   N–F   K–Cl   Al–N
4. Place a partial positive or a partial negative charge on each atom in the following pairs of atoms. Describe the trend.
   a. H–B   b. H–C   c. H–N   d. H–O   e. H–F
5. Is hydrogen always partially positive when bonded to another atom? Explain.
6. Name three pairs of atoms with ionic bonds. For each pair show the difference in electronegativity between the two atoms.
7. Name three pairs of atoms with polar covalent bonds. For each pair show the difference in electronegativity between the two atoms.
8. Describe or draw what happens to the electrons in a polar covalent bond, a nonpolar bond, and an ionic bond.
9. What do we mean when we say that bonding is on a continuum?