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- More

2

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Molecular Compounds:
Intermolecular Attractions

In this lesson you will explore weak attractions that exist between molecules.

Key Objectives:

1. Discuss the differences between bonds and intermolecular forces (IMFs).
2. Explain which types of molecules (polar or nonpolar) experience intermolecular forces.
3. List the three main types of intermolecular forces and the types of molecules associated with these forces.
4. Explain how London Dispersion forces are created.
5. Define polarizability.
6. Discuss the factors which impact the strength of London dispersion forces.
7. Rank the general order in strength for intermolecular interactions.

Prerequisite Knowledge:

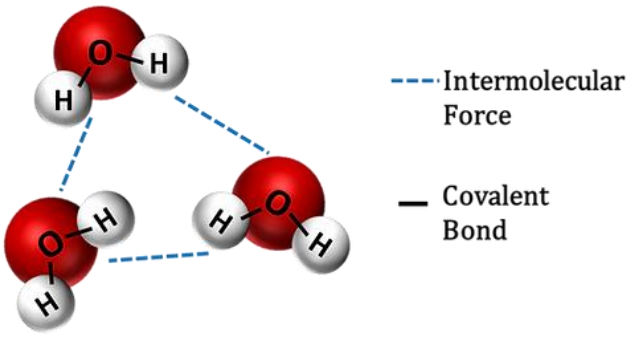
1. Be able to determine if a molecule is polar or nonpolar.
2. Understand the term electronegativity.

PDF Worksheet

Bonds vs Intermolecular Forces

The three main types of bonds are **ionic**, **covalent** and **metallic**. Bonds occur between atoms or ions **within** a crystal or **within** a molecule.

Intermolecular forces are weaker forces of attraction which occur **between** small covalently bound molecules.



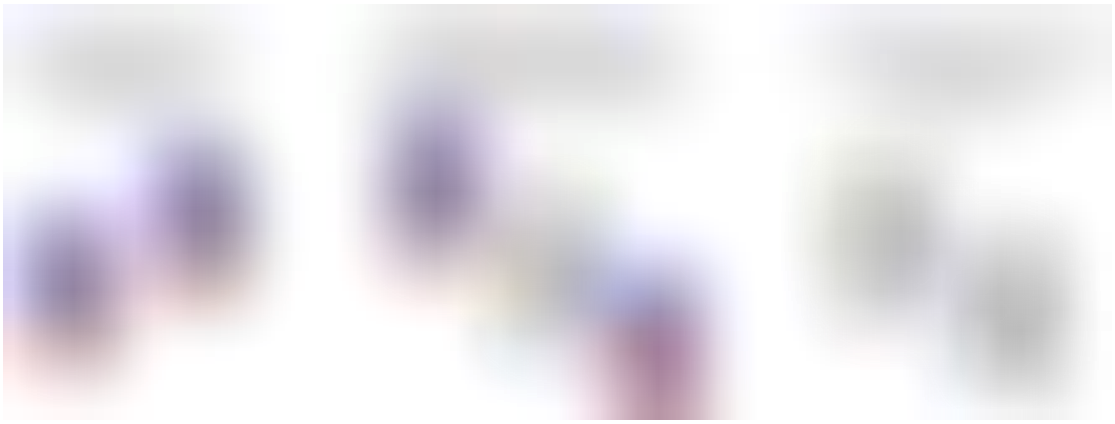
In general, intermolecular forces between molecules are weaker than the ionic, covalent and metallic bonds.

Which molecules experience intermolecular attractions?

Intermolecular forces exist between **all** molecules regardless of polarity.

Attractions exist between:

- adjacent polar molecules
- polar molecules and adjacent non-polar molecules
- adjacent non-polar molecules.



Bonds vs Intermolecular Forces

Bonds occur inside molecules.

Intermolecular Forces occur between molecules.

Intermolecular Forces are weaker than bonds.

ALL molecules experience intermolecular forces

(polar and non polar)

Types of Intermolecular Forces

1. **London Dispersion Forces**
2. **Dipole-Dipole Forces**
3. **Hydrogen Bonds**

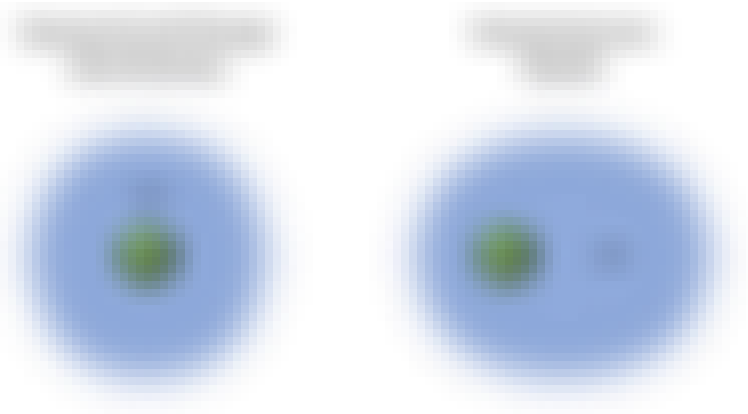
London Dispersion and Dipole-Dipole Forces are collectively called van der Waals Forces after Dutch scientist Johannes Diderik van der Waals.

London Dispersion Forces

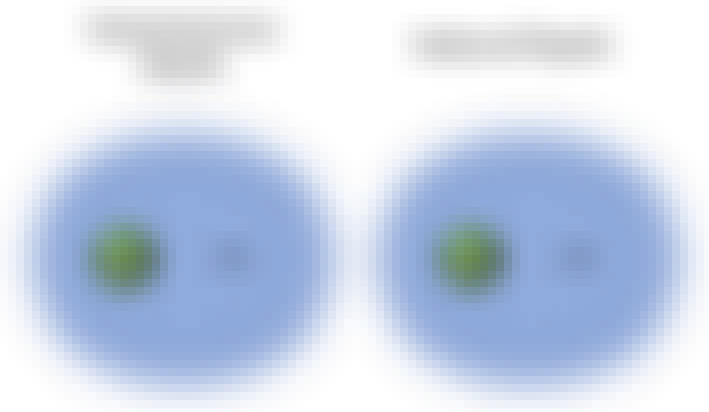
Chemistry is all about the attractions between opposite charges.

But how can **nonpolar,** electrically neutral particles attract one another?

Let's examine Neon. Neon has 10 electrons which, **on average**, are all dispersed symmetrically around the nucleus. However, at any specific moment in time, there exists a probability that more electrons are found on one side of the atom than the other. This creates an **instantaneous dipole** where one end of the atom is slightly negative and the other is slightly positive.



The momentary uneven distribution of electrons within the Ne atom triggers a response from an adjacent Ne atom whose electron density moves toward the net positive regions in the first atom. The **instantaneous dipole** in the first atom **induces a dipole** in an adjacent atom. A subsequent attraction occurs between the dipoles and we give this attraction the name: **London Dispersion Forces**.



London Dispersion forces are the primary and only force experienced by nonpolar molecules and atoms. They result from instantaneous dipoles due to a momentary uneven distribution of electrons within the particle.

All molecules have electron clouds that are able to shift or polarize in response to an external electric field.

Therefore, all molecules experience London Dispersion Forces.

Factors That Impact the Strength of London Dispersion Forces

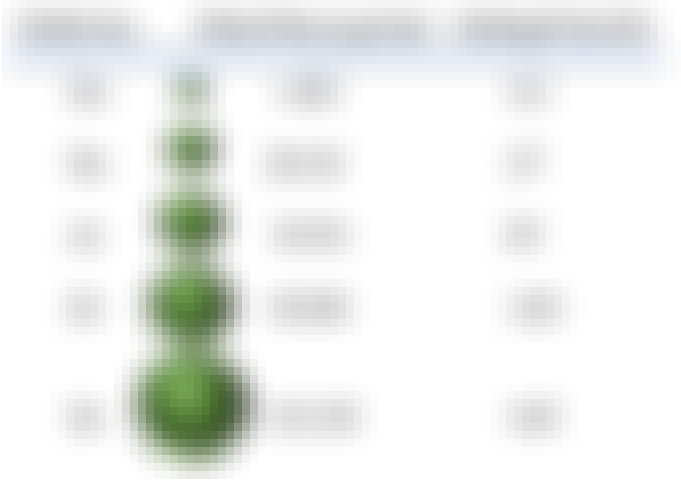
In general, London Dispersion forces are the weakest of all the intermolecular attractions. However, their strength can increase dramatically with several factors.

Polarizability & the Size of the Electron Cloud

The ability of an electron cloud to distort and create a dipole is called **polarizability**.

The size of the electron cloud impacts the strength of the dispersion forces. **Larger electron clouds** have increased polarizability and result in **stronger London dispersion forces**.

Molar mass provides a quick reference for the size of the electron cloud. **Greater molar mass generally results in larger, more polarizable electron clouds and a greater dispersion force**. This leads to higher melting/boiling points since it takes more energy to separate the attracted particles.



Surface Area

An **increase in surface area strengthens London Dispersion forces**. For example, **Pentane** and **2,2-Dimethylpropane** both have the same molar mass (72 g/mol) and the same constituent elements, yet pentane has a higher boiling point. The straight-chain structure of pentane provides for greater contact area between the molecules and stronger London Dispersion Forces.

Gecko Feet

The impact of surface area can be seen in the climbing abilities of a gecko. The tiny hairs on a gecko's foot allow for incredible surface area contact. This creates such strong London Dispersion forces that the gecko can climb up vertical walls even though the hairs themselves are not sticky.

London Dispersion Forces

These attractions result from momentary uneven distributions of electrons that create temporary dipoles within particles.

London Dispersion Forces occur between all molecules regardless of their polarity.

While polar molecules have additional intermolecular attractions, nonpolar molecules experience London Dispersion Forces as their primary and only attraction.

London Dispersion Forces grow stronger with:

1. **Increased polarizability (larger electron clouds)**
2. **Increased surface area contact**

Example One

Which of the following noble gases is the most polarizable?

a. He

b. Ne

c. Ar

d. Kr

e. Xe

Solution:

Example Two

Which of the following compounds would experience the strongest London dispersion forces?

a. C_2H_6

b. CH_4

c. C_4H_{10}

d. C_3H_8

Solution:

Dipole - Dipole Forces

Polar molecules have a permanent dipole moments (permanent slightly positive and slightly negative ends). Because opposite charges attract, the positive end of one molecule is attracted to the negative end of another molecule as shown below. The intermolecular force which is created **between these polar molecules** is called a **Dipole - Dipole Force**.

As the polarity of the molecule increases, so does the strength of the Dipole - Dipole interaction.

Cumulative Forces

Remember that in addition to the dipole-dipole forces between polar molecules, all molecules experience London dispersion forces when their electron clouds additionally polarize in response to an external electric field.

Therefore, all molecules that experience dipole-dipole forces

also experience London dispersion forces.

If molecules are roughly the same mass, then they experience roughly the same amount of dispersion forces.

In that case, the strength of the interaction depends on the polarity of the molecule.

If molecules are vastly different masses, however, the amount of London Dispersion Forces tends to decide the strength of molecular interaction.

Example Three

Which statement best describes a dipole?

a. The combination of two positive but unequal charges located at the center of the particle

b. The combination of two negative charges and equal charges located at the center of the particle

c. The combination of two equal and opposite charges separated by a small distance

Solution:

Example Four

Label all the intermolecular forces each of the substances below would experience.

Solution:

a. H_2

b. HCl

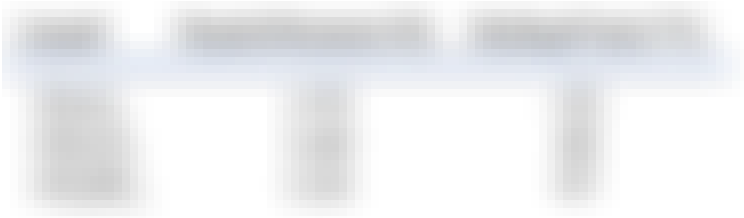
c. NO

d. CO_2

Video Solution

Example Five

The boiling points of three haloalkanes are shown below. Explain the trend in the boiling point data for these three molecules.



Video & Written Solutions

Hydrogen Bonding

The term hydrogen bonding is often very confusing for beginning chemistry students. It is important to realize that a "hydrogen bond" is really just another polar attraction between molecules.

It is not a covalent bond inside a molecule.

Hydrogen Bonding interactions occur between very polar molecules.

Simplified Hydrogen Bonding

Look for H attached to F, O, N

Hydrogen bonding occurs between molecules whose structures include a **Hydrogen** atom directly attached to a **Fluorine, Oxygen or Nitrogen** atom.

This creates very polar molecules which can participate in especially strong dipole-dipole interactions. But why only those elements?

Size

Hydrogen is a very small atom which can get close to similarly small fluorine, oxygen and nitrogen atoms. The close distance creates a large force according to Coulomb's Law.

Charge

Fluorine, Oxygen and Nitrogen also happen to be very electronegative atoms. Their large electronegativities create electron rich areas. More charge density leads to stronger electrostatic forces according to Coulomb's Law.

Question:

Explain why methanol is capable of hydrogen bonding but formaldehyde is not.

Answer:

In methanol, the hydrogen atom is directly attached to the oxygen atom. Formaldehyde, on the other hand, does not have this direct connection between the hydrogen and oxygen atoms. Without this direct connection, formaldehyde is not capable of hydrogen bonding.

Example Six

Samples of which of the molecules below will experience hydrogen bonding interactions?

a. H_2S

b. NH_3

c. HCl

d. HF

e. CH_3CH_2OH

Solution:

Video Solution

Example Seven

When a sample of ammonia, NH_3 is boiled, which of the following processes occur during the boiling process?

a. The N-H bonds within the ammonia molecule are broken apart.

b. Hydrogen bonds within the NH_3 molecule are broken apart.

c. Hydrogen bonds between NH_3 molecules are broken allowing the NH_3 molecules to separate from one another.

Solution:

H-Bond Donors and Acceptors

In order for Hydrogen bonding to occur between the hydrogen on one molecule and fluorine, oxygen, or nitrogen on an adjacent molecule, the electronegative atom (F, O, N) must have a lone pair of electrons that it can donate to the hydrogen.

To establish a hydrogen bond between two molecules, a hydrogen bond donor must be present on the first molecule and a hydrogen bond acceptor must be present on the second molecule.

Molecule One: The Hydrogen Bond Donor

(H - F O N)

A hydrogen bond donor creates a very electropositive hydrogen atom whose electron density has been drawn away from the hydrogen. Look for a hydrogen atom directly attached to either fluorine, oxygen, or nitrogen.

Molecule Two: The Hydrogen Bond Acceptor

(:F :O or :N)

All you need on the second molecule is either a fluorine, oxygen, or nitrogen atom that has a lone pair of electrons it can donate.

This specific interaction can be seen between base pairs in a DNA strand.

Example Eight

Which of the following interactions shows a "hydrogen bond"?

Solution:

Video Solution

Example Nine

Samples of which of the particles below will experience hydrogen bonding interactions with H_2O?

Select all that apply.

a. H_2CO

b. NCl_3

c. HCl

d. HF

e. NH_4^+

Solution:

Video Solution

Example Ten

In general, which of the following intermolecular forces is the weakest?

a. London Dispersion Forces

b. Dipole - Dipole Forces

c. Hydrogen - Bonding Interactions

Solution:

Example Eleven

Which arrow is pointing toward a covalent bond and which arrow is pointing toward a hydrogen bond?

Solution:

Example Twelve

Hydrogen bonding occurs between molecules where hydrogen is bonded to which of the following elements: (Select all that apply)

a. Hydrogen

b. Fluorine

c. Chlorine

d. Oxygen

e. Nitrogen

Solution:

Example Thirteen

Which one of the following compounds is likely to experience London dispersion and dipole-dipole forces as well as hydrogen bonding interactions.

a. H_2

b. NF_3

c. CH_3OH

d. F_2

Solution:

Video Solution

Example Fourteen

Which intermolecular bond is caused by the temporary uneven distribution of electrons?

(a) London dispersion forces

(b) Hydrogen bonding

(c) Dipole to dipole attractions

Solution:

Previous

Menu

Next

- 
- 
-