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What are Van der Waals Forces?

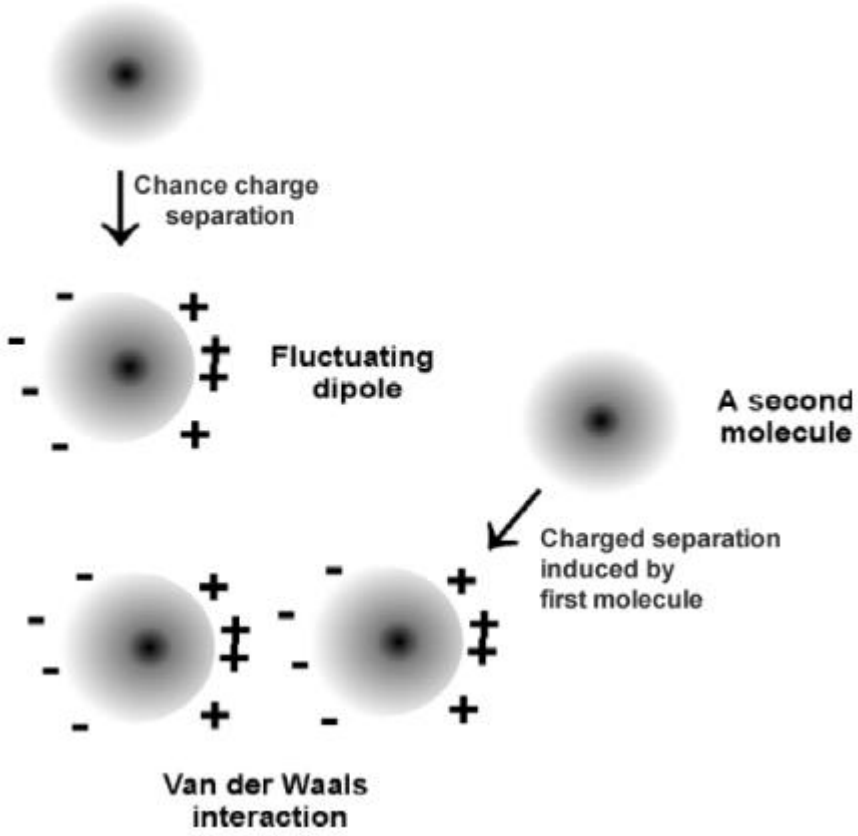
Van der Waals forces are weak intermolecular forces that are dependent on the distance between atoms or molecules. These forces arise from the interactions between uncharged atoms/molecules.

For example, Van der Waals forces can arise from the fluctuation in the polarizations of two particles that are close to each other.

In the group of forces that fall under the category of '***weak chemical forces'***, Van der Waals forces are the weakest. They are known to rapidly vanish when the distance between the interacting molecules increases. The strengths of Van der Waals forces typically ***range from 0.4 kJ.mol^{-1} to 4 kJ.mol^{-1}.***

When the electron density around the nucleus of an atom undergoes a transient shift, it is common for Van der Waals forces to arise. For example, when the electron density increases in one side of the nucleus, the resulting transient charge may attract or repel a neighbouring atom. The nature of these forces is dependent on the distance between the atoms:

- When the distance between the atoms is greater than 0.6 nanometers, the forces are extremely weak and cannot be observed.
- When the distance between the atoms ranges from 0.6 to 0.4 nanometers, the forces are attractive.
- If the interatomic distance is smaller than 0.4 nanometers, the forces are repulsive in nature.



Van der Waals Forces

An illustration detailing the induced formation of a dipole in an atom/molecule due to a fluctuating dipole in another atom/molecule is provided above. The adsorption of gaseous molecules to the surface of an adsorbent and the cohesion of condensed phases can be accounted for by Van der Waals forces.

Characteristics of Van der Waals Forces

- Covalent bonds and ionic bonds are significantly stronger than Van der Waals forces
- These forces are additive in nature, they are made up of several individual interactions
- These forces cannot be saturated
- No directional characteristic can be attributed to these forces
- They are not dependent on temperature (with the exception of dipole-dipole interactions)
- Van der Waals forces are short-range forces. Their magnitude is high when the atoms/molecules in question are close to each other.

Types of Van der Waals Forces

1. Keesom Interactions

Keesom interactions can arise due to the following interactions (all of which are electrostatic in nature):

- The electrostatic interaction between the charges in ionic molecules.
- Interaction between dipoles in polar molecules.
- Quadrupole interactions in the molecules whose symmetry is lower than cubic.

- Interaction between permanent multipoles.

These forces are named after the Dutch physicist Willem Hendrik Keesom. It is important to note that Keesom interactions only originate from the interactions between two permanent dipoles and are temperature dependent.

2. Debye Forces

Debye forces are caused by the interactions between permanent dipoles and other atoms/molecules, which results in the formation of induced dipoles. For example, an induced dipole can be formed from the repulsive forces between electrons (belonging to a molecule) and a permanent dipole.

Unlike Keesom interactions, Debye forces are not dependent on temperature. These forces are named after the Dutch-American physical chemist Peter Debye.

3. London Dispersion Forces

London dispersion forces arise due to the interactions between an instantaneous dipole and an atom/molecule. These forces are named after the German physicist Fritz London and are also known as instantaneous dipole – induced dipole forces.

These forces are believed to be the weakest of all Van der Waals forces. The strength of the London dispersion force between two atoms/molecules depends entirely on the polarizability of the atom/molecule.

Factors Affecting Van der Waals Forces

1. Number of Electrons Held by the Atoms/Molecules

While traversing down a group in the modern periodic table, the atomic radii of the elements increase along with the number of electrons held by their respective nuclei. The presence of a relatively large number of electrons (along with the additional space for these electrons to disperse over) contributes to the formation of temporary dipoles. The greater the number of (instantaneous) dipoles formed, the greater the strength of the Van der Waals force.

An example of this relationship can be observed in the significantly different boiling points of xenon and neon – the boiling point of xenon is -108°C whereas the boiling point of neon is -246°C. The lower boiling point of xenon can be explained by the stronger dispersion forces experienced by its atoms.

2. Shape of the Molecule

Long, unbranched molecules tend to feature stronger dispersion forces than branched, short-chain molecules. For example, the structural isomers butane and isobutane (2-methyl propane) have different boiling points despite having the same chemical formulae. The boiling point of butane is -0.5°C and that of isobutane is -11.7°C.

The difference in the boiling points of these isomers can be accounted for by the stronger Van der Waals forces in the unbranched butane molecules (and the weaker Van der Waals forces in the short, branched isobutane molecules).

Applications of Van der Waals Forces

- It is widely believed that Geckos exploit Van der Waals forces to hang on to smooth surfaces with only their toes.

- The attractive forces that arise between the spatulae of the Gecko's footpads and the smooth surface enable the lizard to effectively climb these surfaces. Similar biological designs can be observed in some spiders.

Frequently Asked Questions

Are Hydrogen Bonds a Type of Van der Waals Force?

The term 'Van der Waals force' is used to describe any dipole-dipole interactions in atoms/molecules. Since hydrogen bonds involve interactions between permanent dipoles, they can be considered as a type of Van der Waals force (and would fall under the category of Keesom Interactions). However, hydrogen bonds are stronger than other types of Van der Waals forces (such as Debye forces and London dispersion forces).

What Causes Van der Waals Forces to Arise?

Van der Waals forces can develop due to the following types of interactions:

- Interaction between two permanent dipoles (as in hydrochloric acid, for example)
- Interaction between a permanent dipole and an uncharged atom/molecule (causes the formation of an induced dipole)
- Interaction between an instantaneous dipole and an uncharged atom/molecule (the instantaneous dipole induces the formation of a dipole in the uncharged species)