

THE STRONGER BOND

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Covalent compounds melt at lower temperatures than polar compounds. Does this mean that covalent bonds are weaker than ionic bonds?

We know that ionic or polar compounds such as sodium chloride have melting points close to 1000°C. On the other hand, non-ionic or nonpolar compounds, such as water, hydrochloric acid and chloroform, melt at much lower temperatures. Students often interpret this to mean that ionic bonds are stronger than covalent bonds. This would be true if melting an ionic compound weakens the ionic bond, and melting a nonpolar molecule weakens the covalent bond. But is this really the case?

Which bond is weakened or broken during melting?

We know that ionic or polar solids, like NaCl, are giant lattices held together by strong electrostatic forces between its positive (Na^+) and negative (Cl^-) ions. It is these electrostatic forces that are

weakened during the melting of these solids (see Fig. 1). From the large amounts of energy needed to melt ionic solids, we can infer that these electrostatic forces are very strong.

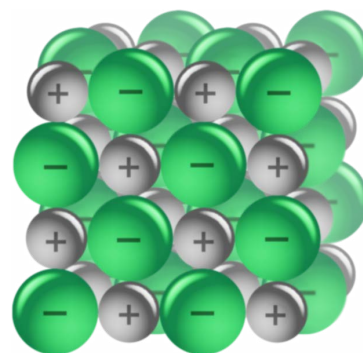


Fig. 1. A schematic representation of an ionic lattice showing the arrangement of positive and negative ions.

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We also know that the atoms in a nonpolar molecule, like HCl, are held by a covalent bond, involving a shared pair of electrons (see Fig. 2). However, the 17 protons in the nucleus of the larger chlorine atom exert a greater attractive force on this shared electron pair than the single proton in the nucleus of the smaller hydrogen atom. This results in a partial negative charge on the chlorine atom and a partial positive charge on the hydrogen atom. The partial negative charge on the chlorine atom attracts the positive charge on the hydrogen atom of a neighbouring HCl molecule. It is these intermolecular interactions that are weakened when HCl is melted or boiled; the covalent bond remains intact.

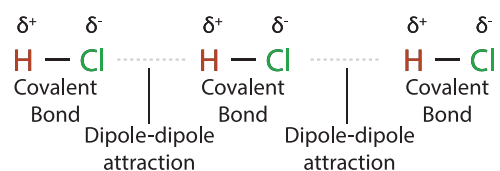


Fig. 2. Depiction of the covalent bond in HCl as well as the permanent dipole interactions between two HCl molecules.

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Thus, the low melting points of nonpolar compounds cannot be used to infer the strength of their covalent bonds. They do indicate, however, that the intermolecular forces in nonpolar compounds are much weaker than the electrostatic forces in polar compounds.

How strong are the intermolecular forces in nonpolar compounds?

To understand this better, let's take a deeper look at the structure of covalent compounds. We know that an electric dipole is created when a pair of electric charges of equal magnitude but opposite signs are separated by a small distance. Nonpolar molecules can form two kinds of dipoles – permanent and temporary.

Permanent dipoles are formed when two elements with differing electronegativities are covalently

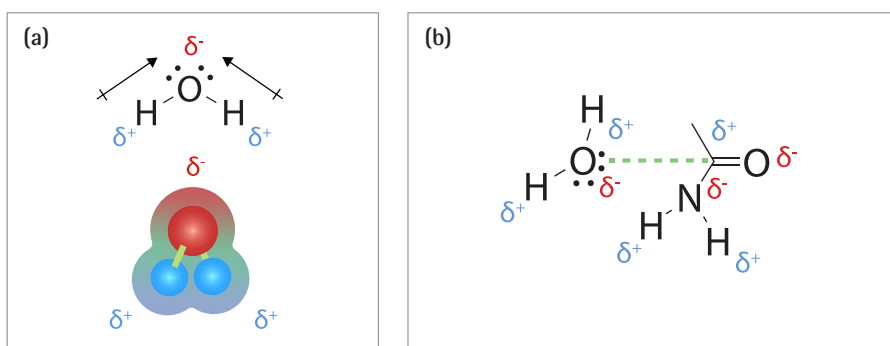


Fig. 3. (a) A permanent dipole is formed in a water molecule due to charge separation. (b) Intermolecular forces between adjacent permanent dipoles are called permanent dipole-permanent dipole interactions.

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bonded, as in the case of HCl. This results in an unequal distribution of electrons within the molecule that then exerts an attractive force on adjacent molecules of the same kind. These are called permanent dipole-permanent dipole interactions (see Fig 3).

Temporary dipoles can be induced in a nonpolar molecule when its electrons are attracted by the positive end of a permanent dipole in its vicinity. These permanent dipole-induced dipole interactions occur between adjacent molecules of different kinds (see Fig. 4a). Temporary dipoles can also be spontaneously formed in nonpolar molecules (see Fig. 4b) when otherwise equally distributed electrons randomly move close enough

to repel each other and shift away from the interaction zone (the region where they are closest to each other). This creates a partial positive charge on one end of the molecule that can then attract electrons from and induce the formation of an instantaneous dipole in a similar or different nonpolar molecule in its vicinity (see Fig. 4c).

In general, instantaneous dipole-induced dipole interactions are weaker than permanent dipole-induced dipole interactions, which are weaker than permanent dipole-permanent dipole interactions. But the intermolecular electrostatic force involved in even a permanent dipole-permanent dipole interaction, the strongest of these interactions, is much weaker than that in ionic compounds. Why? As we have

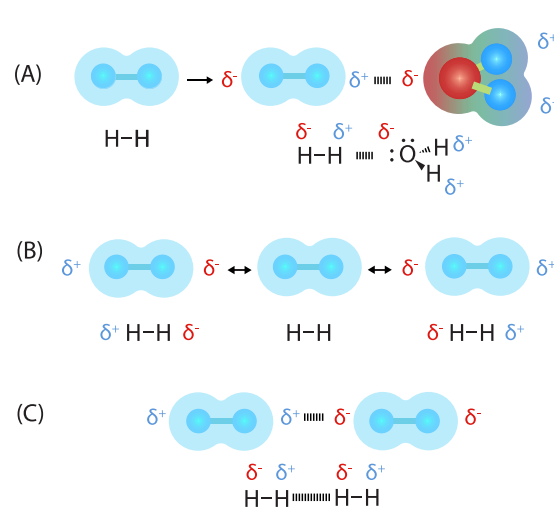


Fig. 4. (a) The permanent dipole in a water molecule induces a dipole in a hydrogen molecule and is then attracted to it. (b) Instantaneous dipoles can form spontaneously in nonpolar molecules, like hydrogen, due to the random motion of shared electrons in its nonpolar bond. (c) Instantaneous dipoles can induce the formation of instantaneous dipoles in other nonpolar bonds, which are then attracted to one another.

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seen in the HCl example, this interaction occurs between the partial positive end of one nonpolar molecule and the partial negative end of its neighbouring molecule. Thus, the force between these molecules is only a fraction of the force between the complete positive and complete negative charge of an ionic compound like NaCl.

How strong is a covalent bond?

Most covalently bonded substances exist as molecules. In diamond, however, each carbon atom is covalently bonded to four other carbon atoms, forming

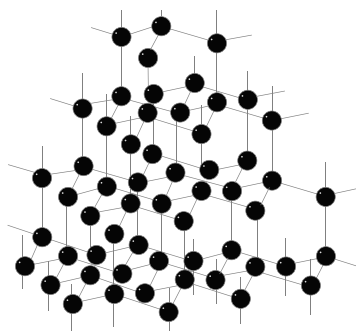


Fig. 5. A schematic representation of the carbon atoms in diamond forming a giant covalent structure. Each atom is covalently bonded with its neighbouring atoms, forming a network of bonds in an arrangement that extends in 3D space.

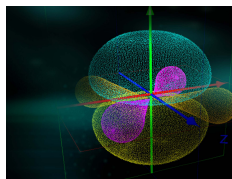
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a giant covalent structure (See Fig. 5). We know that the melting point of diamond is as high as 4000°C. Since diamond is not a molecule, there are no intermolecular interactions to account

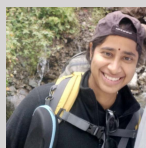
for its melting point. In other words, when diamond melts, its covalent bonds break. From this, we can conclude that covalent bonds are no weaker than ionic bonds.

Key takeaways

- Stronger forces require higher temperatures to weaken them.
- Since ionic solids are held together by strong electrostatic forces, they have high melting points.
- While nonpolar compounds have covalently bonded molecules, melting breaks intermolecular interactions between these molecules. The covalent bond remains intact during this phase change.
- Intermolecular interactions in nonpolar compounds are of three kinds – permanent dipole-permanent dipole, permanent dipole-induced dipole, and instantaneous dipole-induced dipole. Permanent dipole-permanent dipole is the strongest of these interactions.
- The low melting points of nonpolar compounds is because the electrostatic force in even a permanent dipole-permanent dipole interaction is much weaker than the electrostatic force in ionic solids.
- Since very high temperatures are needed to break covalent bonds, these bonds are no weaker than ionic bonds.



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