1.8: Interactions Between Helium Atoms and Hydrogen Molecules

Now let's take a look at a couple of real systems. We begin by considering interactions between the simplest atoms, hydrogen (H) and helium (He), and the simplest molecule, molecular hydrogen (H_2). A typical hydrogen atom consist of one proton and one electron, although some contain one or two neutrons and form "isotopes" known as deuterium and tritium, respectively. A hydrogen molecule is a completely different chemical entity: it contains two hydrogen atoms, but its properties and behavior are quite different. Helium atoms have 2 protons and 2 neutrons in their nuclei, and 2 electrons in their electron clouds. We will consider more complicated atoms and molecules after we discuss atomic structure in greater detail in the next chapter. One advantage of focusing on molecular hydrogen and helium is that it also allows us to introduce, compare, and briefly consider both van der Waals interactions (due to IMFs) and covalent bonds; we will do much more considering later on.

When two atoms of helium approach each other LDFs come into play and a attractive interaction develops. In the case of He the drop in potential energy due to the interaction is quite small, that is, the stabilization due to the interaction, and it does not take much energy to knock the two atoms apart. This energy is delivered by collisions with other He atoms. In fact at atmospheric pressures, Helium is never a solid and liquid He boils at $\sim 4\text{ K}\,(-268.93^\circ\text{C})$, only a few degrees above absolute zero or $\sim 0\text{ K}\,(-273.15^\circ\text{C})$.[30] This means that at all temperatures above $\sim 4\text{ K}$ there is enough kinetic energy in the atoms of the system to disrupt the interactions between He atoms. The weakness of these interactions means that at higher temperatures, above 4 K, helium atoms do not "stick together". Helium is a gas at temperatures above 4 K.

Now let us contrast the behavior of helium with that of hydrogen (H). As two hydrogen atoms approach one another they form a much more stable interaction, about 1000 times stronger than the $He-He$ London dispersion forces. In an $H-H$ interaction the atoms are held together by the attraction of each nucleus for both electrons. The attractive force is much stronger and as the atoms get closer this leads to a larger drop in potential energy and a minimum for the two interacting hydrogen atoms that is much deeper than that for $He-He$. Because of its radically different stability the $H-H$ system gets a new name; it is known as molecular hydrogen or H_2 and the interaction between the H atoms is known as a covalent bond. In order to separate a hydrogen molecule back into two hydrogen atoms, that is, to break the covalent bond, we have to supply energy.[31] This energy can take several forms: for example, energy delivered by molecular collisions with surrounding molecules or by the absorption of light both lead to the breaking of the bond.

Each H can form only a single covalent bond, leading to the formation of $H-H$ molecules, which are often also written as H_2 molecules. These $H-H$ molecules are themselves attracted to one another through LDFs. We can compare energy associated with the $H-H$ covalent bond and the H_2-H_2 IMF. To break a $H-H$ covalent bond one needs to heat the system to approximately 5000 K. On the other hand to break the intermolecular forces between separate H_2 molecules, the system temperature only needs to rise to $\sim 20\text{ K}$; above this temperature H_2 is a gas. At this temperature the IMFs between individual H_2 molecules are not strong enough to resist the kinetic energy of colliding molecules. Now you may ask yourself, why does H_2 boil at a higher temperature than He? Good question! It turns out that the strengths of LDFs depend on several factors including shape of the molecule, surface area, and number of electrons. For example the greater the surface areas shared between interacting atoms or molecules the greater the LDFs experienced and the stronger the resulting interaction. Another factor is the ability of the electron cloud to become charged, a property known as polarizability. You can think of polarizability as the floppiness of the electron cloud. As a rough guide, the further away from the nucleus the electrons are, the more polarizable (floppy) the electron cloud becomes. We will return to this and related topics later on. As we will see, larger molecules with more complex geometries, such as biological macromolecules (proteins and nucleic acids), can interact through more surface area and polarizable regions, leading to correspondingly stronger interactions.

At this point, you are probably (or should be) asking yourself some serious questions, such as, why don't helium atoms form covalent bonds with one another? Why does a hydrogen atom form only one covalent bond? What happens when other kinds of atoms interact? To understand the answers to these questions, we need to consider how the structure of atoms differs between the different elements, which is the subject of the next chapter.

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Questions to Answer

- Can you draw a picture (with about 20 helium atoms, represented as circles) of what solid helium would look like if you could see it?
- How would that differ from representations of liquid helium or gaseous helium?

- Now make a similar drawing of H_2. Does this help explain the higher melting point of H_2?

Question to Ponder

- How do the properties of solids, liquids, and gases differ?
