4.6: Covalent Bonds and Green Chemistry

The nature of covalent bonds is strongly related to green chemistry. Some reasons why this is so include the following:

- High-energy bonds in raw materials require a lot of energy and severe conditions, such as those of temperature and pressure, to take apart in synthesizing
- Especially stable bonds may make substances unduly persistent in the environment.
- Relatively weak bonds may allow molecules to come apart too readily, contributing to reactive species in the atmosphere or in biological systems.
- Unstable bonds or arrangements of bonds may lead to excessive reactivity in chemicals making them prone to explosions and other hazards.
- Some arrangements of bonds contribute to chemical toxicity.

An example of a substance that has a very high bond stability making it an energy-intensive source of raw material is N_2. As mentioned earlier, large amounts of energy and severe conditions are required to take this molecule apart in the synthesis of ammonia, NH_3, the compound that is the basis for most synthetic nitrogen compounds. As discussed with nitrogen in Section 2.5, *Rhizobium* bacteria growing on the roots of leguminous plants such as soybeans convert N_2 to chemically fixed nitrogen. The amount of nitrogen fixed by this totally green route is certainly a welcome addition to the pool of fertilizer nitrogen.

An example of a compound in which especially stable bonds contribute to persistence and ultimate environmental harm is provided by dichlorodifluoromethane, Cl_2CF_2, a chlorofluorocarbon implicated in the destruction of stratospheric ozone (see Chapter 3, Section 3.5, and Chapter 10). The chemical bonds in this compound are so strong that nothing attacks them until the molecule has penetrated many kilometers high into the stratosphere where extremely energetic ultraviolet radiation breaks the C-Cl bond in the molecule. This produces Clatoms that bring about the destruction of protective stratospheric ozone.

A somewhat opposite condition occurs in the case of atmospheric nitrogen dioxide, NO_2, near ground level in the atmosphere. Here the NO bond is relatively weak so that the relatively low-energy ultraviolet radiation ($h\nu$) that is close to the wavelength of visible light and penetrates to the atmosphere at or near ground level can break apart NO_2, molecules:

$$NO_2 + h\nu \rightarrow NO + O \tag{4.6.1}$$

The O atoms released are very reactive and interact with pollutant hydrocarbons, such as those from gasoline, in the atmosphere resulting in the disagreeable condition of photochemical smog.

Some bonding arrangements are notable for instability. These include bonds in which two N atoms are adjacent or very close in a molecule and are bonded with double bonds. Also include dare arrangements in which N and O atoms are adjacent and double bonds are also present.

The presence of some kinds of bonds in molecules can contribute to their biochemical reactivity and, therefore, to their toxicity. An organic compound with one or more C=C double bonds in the molecule is often more toxic than a similar molecule without such bonds.

By avoiding generation, use, or release to the environment of compounds with the kinds of bonds described above as part of a program of green chemistry, the practice of chemistry and the chemical industry can be made much safer. Green chemistry also considers bonds that may have to be protected in chemical synthesis. Often steps must be added to attach protecting groups to bonding groups to prevent their reacting during a step of a synthesis. After the desired step is performed, the protecting groups must be removed to give the final product. Materials are consumed and byproducts are generated by these steps, so the practice of green chemistry attempts to avoid them whenever possible.