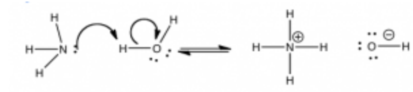
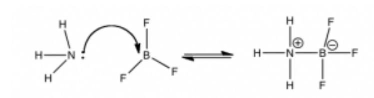
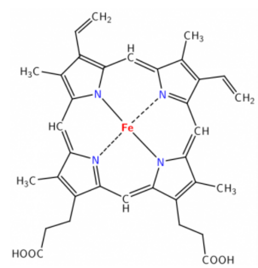
7.3: Lewis Acid-Base Reactions



Although chemists use the Brønsted–Lowry model for any reaction in which a proton is transferred from one atom to another, there is an even broader model. The Lewis model incorporates reactions where there is no proton transfer. Instead of seeing the reaction as a proton transfer, we can look at it from the vantage point of the electron pair that eventually becomes part of the new bond. That is: we can consider an acid-base reaction as the donation of an electron pair (from a base) to form a bond between the donor atom and the proton (or the acid). So, instead of saying water transfers a proton to ammonia, the Lewis model would view the process as ammonia donating a lone electron pair to form a new bond with a proton from a water molecule. This process results in the transfer of a hydrogen from the water to the ammonia molecule (a bond formation event, as shown in the figure). The electrons that were originally bonded to the hydrogen do not disappear. Rather, they are left behind on the oxygen, leading to the generation of a hydroxide ($-OH$) ion. The Lewis acid–base model allows us to consider reactions in which there is no transferred hydrogen, but where there is a lone pair of electrons that can form a new bond.





This figure shows an example of the Lewis acid–base model in the reaction between boron trifluoride (BF_3) and ammonia (NH_3). In this case, the base is the electron pair donor and the acid is the electron pair acceptor. The lone electron pair from NH_3 is donated to boron, which has an empty bonding orbital that accepts the pair of electrons, forming a bond between the N and the B. Even though we use the term "donate", the electron pair does not leave the NH_3 molecule; it changes from a non-bonding pair to a bonding pair of electrons. BF_3 is a Lewis acid, but note that it has no H to donate. It represents a new class of acids: Lewis acids. These include substances such as BF_3 or $AlCl_3$, compounds of periodic table Group III atoms, which have only six electrons in their bonding orbitals. This electron deficiency leaves empty, energetically-accessible orbitals open to accept an electron pair from the Lewis base, the electron pair donor. Other examples of Lewis acids are metal ions, like Fe^{2+}, Fe^{3+}, Mg^{2+}, and Zn^{2+}. All of these elements play a critical role in biological systems via their behavior as Lewis acids. An important example is the heme group of hemoglobin. In the center of this group is a positively-charged iron (Fe) atom. Such positively-charged ions (cations) have empty orbitals that can interact with the lone pair electrons from Lewis bases and form Lewis acid–base complexes. In the case of hemoglobin, the Lewis bases (O_2, CO_2, and CO) interact with Fe to move oxygen into the body from the lungs and move CO_2 from the body to the lungs. It takes a little practice to gain confidence in recognizing Lewis acid–base reactions, but this skill can help us understand many biological and chemical systems.

If we look back over the acid–base theories about acids, we see that the theories become increasingly complex as each subsequent theory subsumes the previous one and extends the range of reactions that can be explained. Neither the Arrhenius nor Brønsted–Lowry theories explain why iron in the heme complexes and oxygen to form the oxygen transport system in our bodies. The Lewis acid–base model, on the other hand, can help explain this as well as the simple reaction between HCl and $NaOH$ (where ^{-}OH is the Lewis base and H^+ is the Lewis acid).

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Questions to Answer

- For the reaction: $HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$, write out (in words and molecular level pictures) what is going on during the reaction in terms of:
  - Arrhenius acid–base theory
  - Bronsted–Lowry acid–base theory
  - Lewis acid–base theory
- Now do the same activity for the reaction of NH_3 and HCl.
- Now do the same activity for the reaction of R_2NH and $AlCl_3$.
- Why do you think we use different models of acid–base reactions?
- Can you describe what would dictate the use of a particular model?