5.8: The Energetics of Chemical Reactions

Many of the chemical reactions that we have discussed in this chapter occur with the generation of significant amounts of light and heat. A prime example is the synthesis reaction between zinc and sulfur, described by the equation shown below.

$$\mathbf{Zn}\ (s) + \mathbf{S}\ (s) \rightarrow \mathbf{ZnS}\ (s)$$

Initially, both elements are present as fine powders. They are mixed (carefully) and the mixture is stable sitting of the laboratory bench. When the mixture is touched with a heated metal rod, however, a violent reaction occurs (the reaction is termed ***exothermic***; producing heat) and zinc sulfide is formed as the product. The reaction is obviously favorable, so why does it need heat to start the reaction? This concept can be understood by considering a **reaction coordinate diagram** for a simple one-step reaction.

In a reaction coordinate diagram, the y-axis corresponds to energy. The initial and final "energy wells" represent the ground-state energies of the reactants and products, and the path connecting them describes the energy changes that occur in the course of the reaction.

Looking at the reaction coordinate diagram for the zinc sulfide reaction, the reactants sit at an initial energy level that is characteristic and unique for each element or compound. Likewise, zinc sulfide sits at a lower overall energy level; that means that the conversion from the elements to the compound is **favorable** and that heat is *liberated* during the reaction. If the energy level of the products was *higher* than the reactants, the reaction would be *unfavorable* and heat would be *absorbed* during the reaction (the reaction is said to be **endothermic**; consuming heat).

Why, then, does the zinc sulfide reaction need energy input before the reaction begins? The answer lies in the curved path that connects the reactants and products in the reaction coordinate diagram. In order for the zinc-sulfur mixture to react, enough energy must be put *into* the system so that the energy level of the reactants equals the highest hill in the diagram. Once that point is reached, the reactants can "tumble down" the energy hill and form the more stable products (with the evolution of all of the excess energy as heat, light, etc.).

The top of the energy hill in a reaction coordinate diagram is called the **transition state** (or activated complex). In modern chemical theory, the transition state is the energy maximum corresponding to the processes of bond-making and bond-breaking. The energy required to go from the reactants to the transition state is the **activation energy**. Reactions that occur with little requirement for heat simply have a small activation energy. The magnitude of the activation energy controls the *rate* of a reaction and the *difference* in energy between the reactants and the products controls the equilibrium distribution of the products and reactants in a reversible reaction. We will return to these concepts when we address reaction rates and equilibrium later in the book.