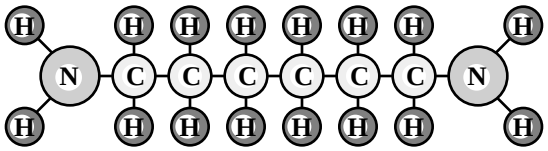
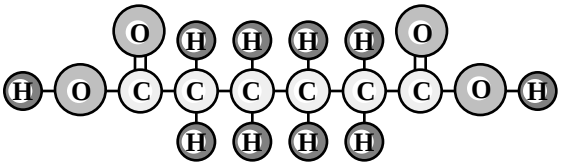
Example 15-9. Energy of formation

How much energy is consumed or evolved when 6,6-nylon is formed? Will the reaction be spontaneous?

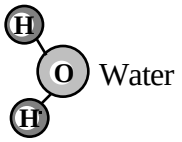
As shown in the book, 6,6 nylon is formed by a condensation reaction between two different monomers, Hexamethylene diamine and Adipic acid. The reaction is shown schematically in the diagram below.



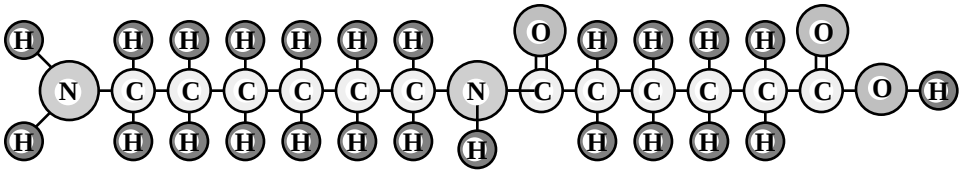
Hexamethylene Diamine



Adipic Acid



Water



6,6 Nylon

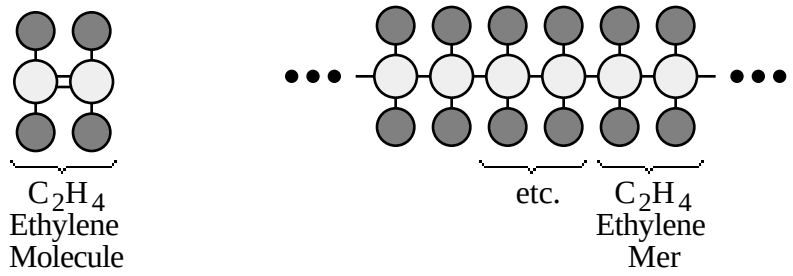
Notice that both ends of the hexamethylene diamine molecule are the same, and that removing one H atom leaves a dangling single bond from the remaining nitrogen. Likewise, both ends of the adipic acid molecule are the same, and removing an OH group leaves a dangling bond from the carbon. In the reaction to form nylon, the H from the hexamethylene diamine and the OH from the adipic acid are removed, combine to form water (H2O), and the exposed bonds are linked together to produce the linear chain of the nylon molecule. Since the other ends of the molecules are unaffected, this process can continue wherever two ends of different molecules come together.

The energy budget for the process can be calculated by adding up the energy of the bonds that must be broken (the N-H bond in the hexamethylene diamine and the O-C bond in the adipic acid), and the new ones which are formed (the C-N bond that constructs the nylon chain, and the O-H bond in the newly formed water molecule). The values below are in kcal./gram-mole.

- $E_{N-H} = 110$ The energy of the nitrogen-hydrogen bond
- $E_{O-C} = 86$ The energy of the oxygen-carbon bond
- $E_{C-N} = 73$ The energy of the carbon-nitrogen bond
- $E_{O-H} = 119$ The energy of the oxygen-hydrogen bond
- $E_{\text{reactants}} = E_{N-H} + E_{O-C}$
  - $\triangle E_{\text{reactants}} = 196$ Total energy consumed in breaking bonds
- $E_{\text{products}} = E_{C-N} + E_{O-H}$
  - $\triangle E_{\text{products}} = 192$ Total energy released in forming bonds
- $\Delta E = E_{\text{reactants}} - E_{\text{products}}$

$\Delta E = 4$ Since E is positive, the reaction will not be spontaneous

It is useful to compare this process, which needs an external source of energy, to the formation of another polymer that does not. Polyethylene is formed by combining C2H4 (ethylene) molecules, as shown in the sketch below. The C2H4 molecule on the left has a carbon-carbon double bond. The process of forming the molecule replaces this double bond with two single bonds, one between the original carbon atoms and another linking the mer to the next one in the chain, as shown on the right.



The energy in the double bond, which must be broken, is 172 kcal/gram-mole. The energy in the single bond is 88 kcal/gram mole. Hence the net energy required is:

$\Delta E = 172 - 2 \cdot 88$

$\Delta E = -4$

In this case, 4 kcal/gram-mole of energy is released in the process of polymerization. Once the process is begun (by supplying the initial energy to break the C=C double bond). The process will continue spontaneously.