You are already familiar with several types of isomeric relationships among organic molecules; constitutional isomers, conformational isomers, enantiomers, and diastereomers. Here is one more. Tautomers are two molecules with the same molecular formula but different connectivity - constitutional isomers, in other words - which can interconvert in a rapid equilibrium. The most common tautomeric relationship in organic chemistry is the **keto-enol** pair.

### 13.1A: Keto-enol tautomerization

When we draw a ketone or aldehyde using the Lewis structure convention, we show a double bond between the carbonyl carbon and the oxygen - this is known as the **keto** form. It turns out that ketones and aldehydes often exist in rapid equilibrium with a tautomeric form known as an **enol**.

\[
\begin{align*}
\text{H}_3\text{C} & \quad \text{C} & \quad \text{CH}_3 \\
\text{O} & \quad & \\
\text{H}_3\text{C} & \quad \text{C} & \quad \text{CH}_2
\end{align*}
\]

**keto** form of acetone \hspace{1cm} **enol** form of acetone

The alpha-protons of carbonyls, as you recall, are somewhat acidic: the pKₐ of acetone, for example, is approximately 19. In the formation of an enol, a base abstracts an α-proton from a carbonyl compound, and that same proton (or a proton on a nearby acid group) is transferred to the carbonyl oxygen. The result is a new functional group that combines both **alkene** and **alcohol** characteristics - hence the term enol. The deprotonated form of an enol is an enolate.

\[
\begin{align*}
\text{R} & \quad \text{O} & \quad \text{H} \\
\text{R} & \quad & \text{R} \\
\text{H} & \quad \text{B} \\
\text{R} & \quad & \text{R}
\end{align*}
\]

**keto** \hspace{1cm} **enolate** \hspace{1cm} **enol**

As a general rule, the keto form of a carbonyl is lower in energy, and thus predominates at equilibrium. Acetone, for example, is present at >99% keto form at equilibrium.

**Exercise 13.1:** Draw all of the possible enol forms of the following aldehydes/ketones. There may be more than one possible enol form.

a. 3-pentanone

b. acetaldehyde (IUPAC name ethaldehyde)
c. cyclohexanone
d. 2-pentanone

Exercise 13.2: Draw three examples of aldehyde or ketone compounds for which there is no possible enol form.

Solutions

There are a few special cases where the enol form predominates at equilibrium: 2,4-pentane dione exists mostly in its enol form (76%), due to the extra stability of the conjugated double bonds that are present in the enol form, and due also to a favorable hydrogen bonding interaction.

![Keto form vs. Enol form](image)

keto form (24%) enol form (76%)

We saw a good example of an enol to keto tautomerization in the last step of the pyruvate kinase reaction (section 10.2F). The enol served as a leaving group in this phosphoryl transfer reaction, after which tautomerization occurred to form the ketone group of pyruvate.

13.1B: Imine-enamine tautomerization

Another common tautomeric relationship in biological organic chemistry is the equilibrium between imines (also known as Schiff bases) and enamines, which are the nitrogen equivalents of enols.

![Imine vs. Enamine](image)

The degradation of serine, for example, involves an enamine to imine tautomerization step, followed by hydrolysis of the imine (section 11.6) to form pyruvate.
As we shall see in a later section, enamines are key intermediates in a very important type of carbon-carbon bond-forming reaction.

**Additional Resources**

*Videos*

- keto-enol tautomerization
- Keto-enol tautomerization video
- Keto enol tautomer video