This page gives you the facts and mechanisms for the reduction of carbonyl compounds (specifically aldehydes and ketones) using sodium tetrahydridoborate (sodium borohydride) as the reducing agent.

The reduction of aldehydes and ketones by sodium tetrahydridoborate

Sodium tetrahydridoborate (previously known as sodium borohydride) has the formula NaBH₄, and contains the BH₄⁻ ion. That ion acts as the reducing agent.

There are several quite different ways of carrying out this reaction. Two possible variants (there are several others!) are:

- The reaction is carried out in solution in water to which some sodium hydroxide has been added to make it alkaline. The reaction produces an intermediate which is converted into the final product by addition of a dilute acid like sulphuric acid.
- The reaction is carried out in solution in an alcohol like methanol, ethanol or propan-2-ol. This produces an intermediate which can be converted into the final product by boiling it with water.

In each case, reduction essentially involves the addition of a hydrogen atom to each end of the carbon-oxygen double bond to form an alcohol. Reduction of aldehydes and ketones lead to two different sorts of alcohol.

The reduction of an aldehyde

For example, with ethanal you get ethanol:

\[
\text{CH}_3\text{CHO} + 2[\text{H}] \rightarrow \text{CH}_3\text{CH}_2\text{OH}
\]

Notice that this is a simplified equation - perfectly acceptable to examiners. The H in square brackets means "hydrogen from a reducing agent". In general terms, reduction of an aldehyde leads to a primary alcohol. A primary alcohol is one which only has one alkyl group attached to the carbon with the -OH group on it. They all contain the grouping -CH₂OH.

The reduction of a ketone

For example, with propanone you get propan-2-ol:

\[
\text{CH}_3\text{C}═\text{O} + 2[\text{H}] \rightarrow \text{CH}_3\text{CH}(_2)\text{CH}_2\text{OH}
\]

Reduction of a ketone leads to a secondary alcohol. A secondary alcohol is one which has two alkyl groups attached to the carbon with the -OH group on it. They all contain the grouping -CHOH.
The simplified mechanisms

The BH₄⁻ ion is essentially a source of hydride ions, H⁻. The simplification used is to write H⁻ instead of BH₄⁻. Doing this not only makes the initial attack easier to write, but avoids you getting involved with some quite complicated boron compounds that are formed as intermediates.

\[
\begin{align*}
\delta^+ & \quad \delta^- \\
\text{C} & \quad \text{O} \\
\quad & \quad \cdot\text{H}
\end{align*}
\]

The reduction is an example of nucleophilic addition. The carbon-oxygen double bond is highly polar, and the slightly positive carbon atom is attacked by the hydride ion acting as a nucleophile. A hydride ion is a hydrogen atom with an extra electron - hence the lone pair.

The mechanism for the reduction of ethanal

In the first stage, there is a nucleophilic attack by the hydride ion on the slightly positive carbon atom. The lone pair of electrons on the hydride ion forms a bond with the carbon, and the electrons in one of the carbon-oxygen bonds are repelled entirely onto the oxygen, giving it a negative charge.

What happens now depends on whether you add an acid or water to complete the reaction.

Adding an acid:

When the acid is added, the negative ion formed picks up a hydrogen ion to give an alcohol.

Adding water:

This time, the negative ion takes a hydrogen ion from a water molecule.
The mechanism for the reduction of propanone

As before, the reaction starts with a nucleophilic attack by the hydride ion on the slightly positive carbon atom.

Adding an acid:

The negative ion reacts with a hydrogen ion from the acid added in the second stage of the reaction.

Adding water:

This time, the negative ion takes a hydrogen ion from a water molecule.

Contributors

Jim Clark (Chemguide.co.uk)