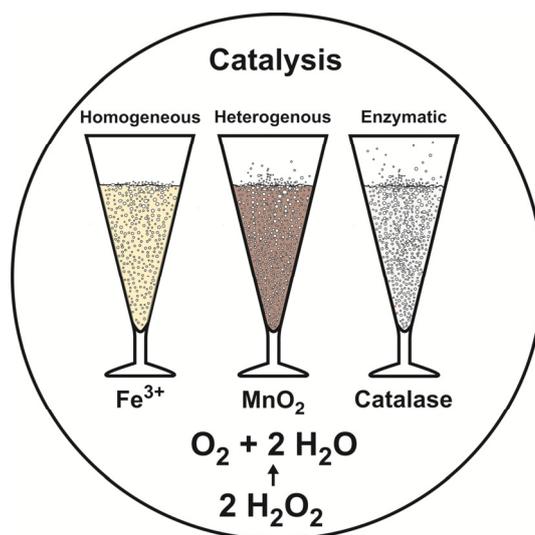


# Decomposition of Hydrogen Peroxide by Various Catalysts



## Equipment:

3 goblets (conical glass cups)  
appropriate measuring cylinders or pipettes  
spatula  
(optional: food grater  
200-mL Erlenmeyer flask  
cheese cloth or cotton tea filter  
glass beaker)

## Chemicals:

hydrogen peroxide solution (6 % w/w)  
iron(III) chloride solution (0.1 M) (acidified with dilute hydrochloric acid)  
manganese dioxide powder  
catalase solution (1 % w/w) or crude potato extract  
(optional: peeled raw potato  
deionized water  
crushed ice)

## Safety:

hydrogen peroxide solution ( $\text{H}_2\text{O}_2$ ):



H302, H318

P102, P280, P305 + P351 + P338, P301 + P312, P501

manganese dioxide ( $\text{MnO}_2$ ):



H272, H302 + H332

iron(III) chloride ( $\text{FeCl}_3$ ):



H302, H315, H318, H317

P280, P302 + P352, P305 + P351 + P338

It is necessary to wear safety goggles and protective gloves, because every contact of the chemicals with eyes or skin should be avoided.

## Procedure:

Preparation: If no catalase solution is available crude potato extract can be used instead: Approx. 20 g of a peeled raw potato are finely grated by means of a food grater. The paste is scraped into a 200-mL Erlenmeyer flask and 25 mL of ice-cooled deionized water are added. The flask is swirled in intervals for about 15 min. Subsequently, the suspension is filtered through a sheet of cheese cloth or a cotton tea filter into a chilled beaker.

Procedure: 20 mL of hydrogen peroxide solution are filled into each of the three goblets.

*Homogeneous catalysis:* 2 mL of iron(III) chloride solution are added to the first goblet.

*Heterogeneous catalysis:* A spatula-tip full of powdered manganese dioxide is added to the second goblet.

*Enzymatic catalysis:* 1 mL of catalase solution or alternatively 2 mL of the filtered clear potato extract are added to the third goblet.

### **Observation:**

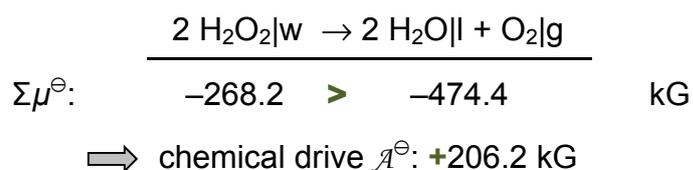
*Homogeneous catalysis:* The color of the solution changes from pale yellow to brownish orange. Additionally, a noticeable evolution of gas can be observed after a while. The pale yellow color returns together with the end of bubbling.

*Heterogeneous catalysis:* A strong effervescence combined with the formation of fog can be observed [therefore, the experiment is also known as “genie in a bottle” (see extra instructions)]. The liquid gets dark because of the finely dispersed black manganese dioxide.

*Enzymatic catalysis:* In the case of the catalase solution a strong evolution of gas takes place, which is combined with the formation of a foam layer and of mist. The reaction catalyzed by the catalase from potato extract is weaker and a distinct foam layer is formed. During all experiments the goblets warm up more or less excessively.

### **Explanation:**

Hydrogen peroxide in aqueous solution exhibits a strong tendency to decompose into water and oxygen (disproportionation):



Necessary chemical potentials ( $T^\ominus = 298 \text{ K}$ ,  $p^\ominus = 100 \text{ kPa}$ ):

Substance	Chemical potential $\mu^\ominus$ [kG]
$\text{H}_2\text{O}_2 \text{w}$	-134.1
$\text{H}_2\text{O} \text{l}$	-237.2
$\text{O}_2 \text{g}$	0

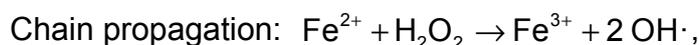
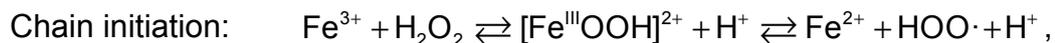
The chemical drive of the reaction is positive, i.e. the reaction should take place spontaneously. The decomposition rate at room temperature is, however, immeasurably small. But the rate can be appreciably increased by the addition of a catalyst.

$\text{Fe}^{3+}$  ions are an example for a *homogeneous catalyst*, i.e. the catalyst is in the same phase as the reaction mixture. The catalytic decomposition of hydrogen peroxide can be essentially explained by two different mechanisms based on the mutual redox transitions  $\text{Fe(III)}/\text{Fe(V)}$  (KREMER-STEIN mechanism) and  $\text{Fe(III)}/\text{Fe(II)}$  (HABER-WEISS mechanism), respectively.

According to the mechanism proposed by KREMER and STEIN an intermediate oxygen complex of iron with oxidation number +V is primarily formed by the reaction of  $\text{Fe}^{3+}$  with  $\text{H}_2\text{O}_2$ . This complex reacts with another  $\text{H}_2\text{O}_2$  molecule to water and oxygen thereby reforming  $\text{Fe}^{3+}$ :



According to the mechanism proposed by HABER and WEISS the  $\text{Fe}^{3+}$  ions initiate a radical reaction, after which the chain reaction consumes the hydrogen peroxide. This mechanism can explain the high reaction rate very well.



A nice special effect concerning the topic “homogeneous catalysis” can be shown with the experiment “Dancing Absinthe” (see extra instructions).

Manganese dioxide is an example for a *heterogeneous catalyst*, i.e. the phase of the catalyst is different from that of the reaction mixture. The surface of solid manganese dioxide provides a particularly favorable environment to catalyze the decomposition, though the mechanism is not understood very well. For increasing the surface area available for contact with the hydrogen peroxide solution a finely graded powder is used. The observed fog (the “genie”) is caused by condensing water vapor mixed with oxygen gas.

*Enzymatic catalysis* takes an intermediate position, because enzymes are proteins, i.e. macromolecules with diameters between 10 and 100 nm, that are colloiddally dispersed in solution and mostly much bigger than the substrate molecules. The cytotoxin hydrogen peroxide is one of the by-products of many cellular reactions. Aerobic cells protect themselves against peroxide by the action of the enzyme catalase. Therefore, catalase is nearly ubiquitous among animal organisms, especially it is found in liver and red blood cells. But catalase also occurs in plant tissues, and is especially abundant in plant storage organs such as potato tubers, corms, and in the fleshy parts of fruits.

The detailed structure of catalase differs from one organism to another, but the general quaternary structure is analogous to hemoglobin in that catalase is tetrameric and each polypeptide chain, composed of more than 500 amino acids, contains an iron-centered porphyrin ring. However, in contrast to hemoglobin, catalase utilizes  $\text{Fe}(\text{III})$ . This iron can formally be oxidized to  $\text{Fe}(\text{V})$  in the oxidation-reduction cycle, however, the processes at the active site of the enzyme are not understood very well. But the incorporation of the iron ions in the porphyrin and in the enzyme protein improves apparently their catalytic activity because the effect of catalase is much stronger than that of the iron ions in solution.

The experiment “Strawberry Ice Cream” represents another nice fun experiment, here to the topic “enzymatic catalysis” (see extra instructions).

### **Disposal:**

Hydrogen peroxide solutions can be disposed of down the drain with running water. Manganese dioxide can be reused after drying.