

CATALITIC VOLCANO¹⁾

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Abstract. The lecture demonstration of the decomposition of H_2O_2 in the presence of Mn(IV) oxide with a proof of the products of the reaction is presented in an entertaining way with the smoking and shrinking water bottle. Designed are several three minutes reaction time presentations, which can demonstrate the reaction rate factors: catalyst, surface area, concentration, and temperature. The materials and the reaction changes can be used for an introduction, or review of some chemistry topics: state and changes of matter, collision theory, activation energy, catalysis, redox reactions, exothermic and decomposition reactions, evaporation, condensation, enthalpy, entropy, classification and recycling of polymers. With a suitable explanation the demonstrations or a part of them can be shown to all grades of students and the general public to inspire science and chemistry in particular.

Keywords: chemistry demonstrations, high school, college general chemistry, reaction rate factors, decomposition exothermic reactions

Introduction

Decomposition reactions – the opposite of synthesis (combination) reactions, are presented in all schemes of classification of reactions, and are studied from high school to university. Particularly, the decomposition of hydrogen peroxide, $2\text{H}_2\text{O}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$ is given as an example in the chemistry literature and many variations of demonstrations are presented in schools, colleges and universities, at science centers, for scouts, at a lecture time, at magic shows, on You Tube, books, magazines, and conferences. H_2O_2 decomposes slowly at room temperature, and the rate of disproportionation is higher in the presence of different catalysts: MnO_2 ²⁾ (Shakhashiri, 1985; Sarquis & Sarquis, 1995), KMnO_4 (Sarquis & Sarquis, 1995), KI (Summerlin & Ealy, 1985; Perkins, 2011), FeCl_3 (Trujillo et al., 2005), enzymes (Summerlin et al., 1988; Lozanov, 2009; Kimbrough et al., 1997).

Lecture demonstrations are given in a short time. The aim of the designed demonstrations is to show how the decomposition of H_2O_2 in the presence of the catalyst MnO_2 can be used to demonstrate the factors affecting the rate of chemical reactions-catalyst, surface area of the catalyst, concentration of the catalyst and the reactant, and reactant's temperature; to be shown in about three minutes with a small polyethylene (PETE)

water bottle, and how the changes in the demonstration can be addressed to different chemistry topics. The reaction rate is measured by the amount of products produced in a given time period.

Applications

State and changes of matter, collision theory, activation energy, catalysis, exothermic and decomposition reactions, evaporation, condensation, enthalpy, entropy, rate of reactions, polymers – all these are possible applications.

Materials

Hydrogen peroxide, H_2O_2 (5%, 7%, 10%, 12%, 15%, 30%); Manganese (IV) oxide, MnO_2 ; Balloons; Polyethylene water bottles, 500 ml; Wooden splints; Matches/cigarette lighter; Beakers-250 ml, 400 ml.

Preparation

The different concentrations of H_2O_2 are prepared by dilution of 30% H_2O_2 . Wide mouth PETE bottles with attached to the caps 60 ml disposable syringes, Fig. B.3 are made by inserting the tips of the syringes into drilled holes, and glued with a hot gun.

Presentation

Part A:

20 ml of 30% H_2O_2 is placed in PETE water bottle, which doesn't fit into a 250 ml beaker, **Fig. A, A1**. 0.5 g MnO_2 is added, and after bubbling starts, a glowing wooden splint is inserted into the bottle, **A.2**. If it does not light up, it is inserted again, until it is lighted up, **A.3**. When the white smoke starts coming out of the bottle, the glowing splint is brought close to the bottle's mouth, **A.4**, or further, **A.5**, and kept there until smoke is released, **A.6**. The bottle shrinks and falls to the bottom of the beaker, **A.5** and the burning wooden splint goes off, **A.6**. The reaction time is less than three minutes. **A.7** is a comparison by volume between the shrunken (**A.6**) and the regular PETE bottles.

Part B:

(1) Balloons with 0.4 g MnO_2 are attached to three small PETE water bottles, containing 20 ml of 5%, 10%, and 20% H_2O_2 , Fig. **B.1**. Balloons expand to different sizes. (2) Under the above conditions to the bottles is added one drop of a liquid detergent and the changes in sad's volume is shown in three minutes time period, Fig. **B.2**. (3) The syringes contain 20 ml of 7% (left bottle), respectively, 10% H_2O_2 (right bottle), and 0.7 g MnO_2 . Time period: 30", 60", 90" and 10', **Fig. B. 3**. For stability the bottles are placed into 400 or 600 ml beakers.

Part C:

(1) The bottles contain 20 ml 10% H_2O_2 and 0.4 g MnO_2 **Fig. C.1**, with different size of the catalyst's particles-crystal shiny powder, left bottle, and fine dull powder, the right bottle. (2) The PETE bottles contain 20 ml 15% H_2O_2 and the attached balloons are with 0.2 g, 0.4 g and 0.8 g MnO_2 (left to right), reaction time 10", 60" and 120", **Fig. C.2**. After 60" the balloons are removed and the bottles are shown after 15', 5' and 2.5' reaction time. The bottles decrease volumes with 4%, 10% and 17% respectively.

Part D:

The bottles contain 20 ml 15% H_2O_2 , 0.4 g MnO_2 at temperatures 0 °C (at left), 20°C (at right), **Fig.D**, and reaction time 10" and 150".

Safety and disposal

Hydrogen peroxide is caustic to the skin, and needs to be handled with care. Wear gloves and goggles. It can be disposed of in the sink with water. Manganese dioxide can be recovered by filtration, or disposed of as a solid in a solid waste container.



A.1

A.2

A.3

A.4

A.5

A.6

Fig. A: 20 ml 30% H_2O_2 , 0.5 g MnO_2



A.7 : 33% less volume

120''

180'' reaction time, s

5%

10%

20%

5%

10%

20% H₂O₂

Fig. B.1: 20 ml 5%, 10%, 20% H_2O_2 ; 0.4 g MnO_2



5%

10%

20%

5%

10%

20%

5%

10%

0% H₂O O_2

10''

120''

180'' reaction time, s

Fig. B.2: 20 ml 5%, 10%, 20% H₂O₂; 0.4 g MnO₂; 1 drop detergent

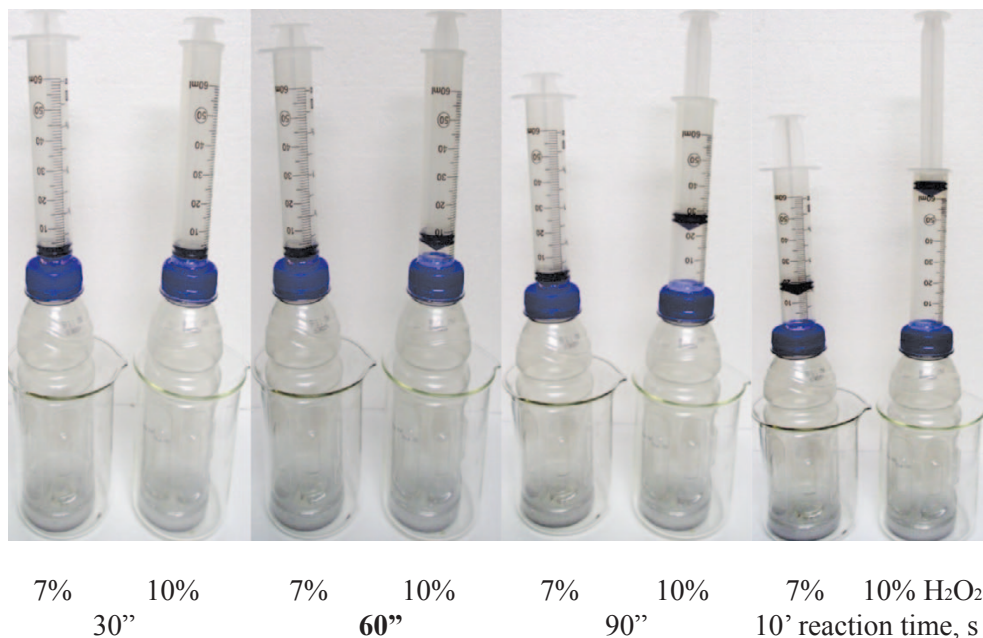


Fig. B.3: 20 ml 7%, 10% H₂O₂; 0.7 g MnO₂



MnO₂-crystals (left bottle), MnO₂- grinded fine powder (right bottle)

Fig. C.1: 20 ml 10% H₂O₂, 0.4 g MnO₂, 30'' reaction time



0.2 g	0.4 g	0.8 g	0.2 g	0.4 g	0.8 g	0.2 g	0.4 g	0.8 g	MnO ₂
10"			60"			120"			reaction time, s

Fig. C.2: 20 ml 15% H₂O₂



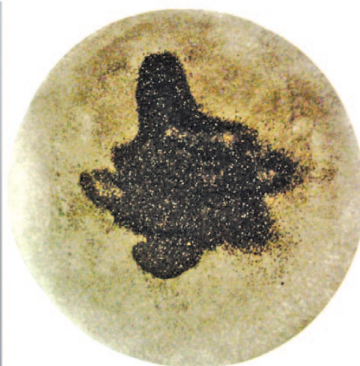
0.2 g	0.4 g	0.8 g MnO ₂
15'	5'	2.5' reaction time, min
4%	10%	17% less bottle's volume

Fig. C.2.1: 20 ml 15% H₂O₂



0 °C 20 °C 0 °C 20 °C temperature
10'' 150'' reaction time, s

Fig. D: 20 ml 15% H_2O_2 , 0.4 g MnO_2



MnO_2 , regenerated by gravity filtration

Explanation

The decomposition reaction of H_2O_2 in the presence of the catalyst MnO_2 to water and oxygen is exothermic (energy is released-negative enthalpy: the energy required to break the bonds in the reagent is less than the energy released by the bond formation of the products). More heat is evolved and a product produced with increasing the concentrations of the reactant H_2O_2 and the catalyst. The hot plastic bottle shrinks in all directions: in the blowing process PETE sheets are placed perpendicularly to each other,

and with the produced heat in the reaction, the stretched and oriented macromolecules are coming to their more relaxed state, Fig. A.5, A.6. The heat energy from the hot bottle flows to the beaker and to the surrounding air. The process is spontaneous and entropy increases. MnO_2 is heterogeneous catalyst-it's in a different phase from the reactant H_2O_2 , being catalyzed. The manganese ion from manganese oxide behaves as a Lewis acid-it coordinates to one of the two oxygen atoms (coordinate covalent bond) and draws electron density from it. The bond between the two oxygen $-\text{O}-\text{O}-$ weakens and it breaks. The surface area of the solid MnO_2 affects the reaction rate-the smaller the particles of the solid (only the molecules on solid surface can react with another chemical reagent), the higher the rate of the reaction. Increasing the temperature results in increase of the average kinetic energy of the molecules, and a larger fraction of their collisions. The "smoke" coming out from the bottles is a stream of condensed water and oxygen and the products of the reaction are proofed with a glowing wooden splint, Fig. A₃-A₆.

NOTES

1. The demonstration was presented as a poster at the ChemED 2011 (Biennial International Educational Meeting), July 24-28, 2011, Kalamazoo, MI, USA.
2. <http://www.chem.umn.edu/services/lecturedemo/info/genie.htm>

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