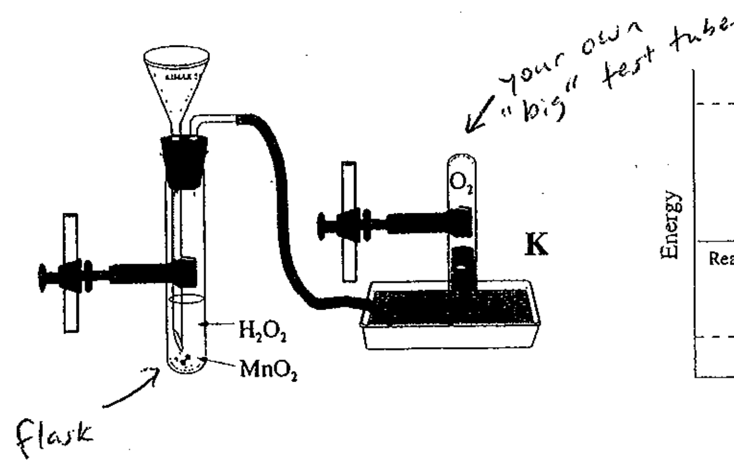
4.3.4 CATALYSTS, REACTION RATES AND ACTIVATION ENERGY

Concepts to Investigate: Reaction rates, catalysts, activation energy, autocatalysts, collision theory.

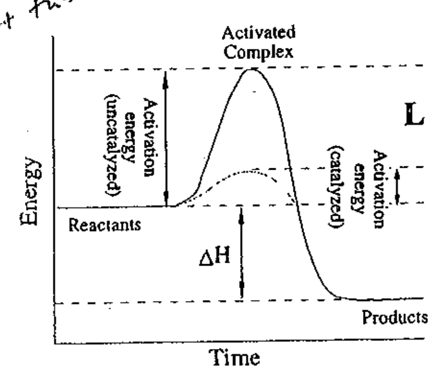
Materials: Part 1: Hydrogen peroxide (H_2O_2) solution from drug store (higher concentrations are available from chemical supply companies and work better, but must be handled with greater caution), apparatus shown in Figure K, manganese dioxide (MnO_2), activated charcoal, calcium carbonate ($CaCO_3$), potassium permanganate ($KMnO_4$), potassium iodide (KI), spatula; Part 2: Sugar cubes, activated carbon (fireplace ash), tongs, ceramic tile or ash tray, match or burner.

Principles and Procedures: A catalyst is a substance that speeds up the rate of a chemical reaction and can be recovered at the end of the reaction in its original form. Often only a trace of a catalyst is sufficient to accelerate a reaction. A catalyst speeds up a reaction by providing a set of elementary steps with more favorable energetics than those that exist in its absence. Catalysts are classified as heterogeneous when the reactants and catalyst are in different phases (for example, solid catalyst and liquid or gas reactants) or homogeneous when the catalyst is in the same phase as the reactants and products.

Catalysts increase the rates of reactions by decreasing the activation energy required to initiate a reaction. According to the collision theory, in order to react, colliding particles must have a total kinetic energy equal to or greater than the activation energy, the minimum amount of energy required to initiate a chemical reaction. If the minimum energy is not available, the particles remain intact and no change results. If the energy is available, the particles enter a transitional structure called an activated complex that results from an effective collision and that persists while old bonds are breaking and new bonds are forming. Figure L shows the energy relationship among reactants, products, activated complex and catalyzed activated complex. Note that the presence of a catalyst (curved dotted line) reduces the activation energy required. As a result, a larger percentage of the collisions occurring in a catalyzed reaction meet the energy requirements to react, and the reaction proceeds more rapidly. In the reaction illustrated, the products are more stable than the reactants, and the reaction is exothermic and is accompanied by a release of heat ($-\Delta H$). The reverse reaction is endothermic. Heat is absorbed and the reactants are more stable than the products. Note that ΔH is positive in an endothermic reaction.



K



L

1. put catalyst in flask
2. pour H_2O_2 in through funnel
3. Collect O_2

Part 1: Catalysts: Hydrogen peroxide is a colorless liquid used as a rocket propellant, disinfectant, and bleaching agent. You may have used a dilute hydrogen peroxide solution to sterilize a wound. Hydrogen peroxide slowly decomposes into water and oxygen:

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

This process can be accelerated by the addition of numerous substances, particularly salts of such metals as iron, copper, manganese, nickel or chromium. It should be noted that these substances accelerate the decomposition of hydrogen peroxide, but are not consumed in the process. Such substances are known as catalysts.

Set up a gas collection device as illustrated in Figure K. Fill the test tube with water, cover the mouth, and invert into a container of water so no water is lost from the tube. Place three grams of manganese dioxide in a ~~large test tube~~ flask and clamp to a support as shown. Insert a stopper assembly equipped with a delivery funnel and bent glass tube as illustrated. Add 50 mL of 3% hydrogen peroxide through the delivery funnel. Collect the test tube of gas, stopper, and set aside. Continue collecting gas in additional tubes until the reaction ceases. Now add more hydrogen peroxide and continue until you have collected 5 test tubes of oxygen. Note that the manganese dioxide is not used up in the reaction. It remains visible in the tube, and promotes the decomposition of hydrogen peroxide repeatedly. Manganese dioxide is therefore considered to be a catalyst, and the reaction can be written:

$$2H_2O_2(aq) \xrightarrow{MnO_2} 2H_2O(l) + O_2(g)$$

Note that the manganese dioxide is written above the arrow, indicating that it is not changed, but only catalyzes the reaction. Unstopper the first tube of gas collected, and test for the presence of oxygen by inserting a glowing splint or smoldering match. Test each of the remaining tubes in the same manner. The flame should glow brightest in the final tube because it contains relatively pure oxygen, while the first tubes may contain some air displaced early in the reaction. Decant the hydrogen peroxide from the reaction flask and add fresh hydrogen peroxide to the old manganese dioxide. Does manganese dioxide continue to promote the production of oxygen?

one test tube each { Repeat this activity using 3 grams each of activated charcoal, potassium permanganate, potassium iodide, and calcium carbonate. Record your results in Table 3. Which of the materials appear to be catalysts?

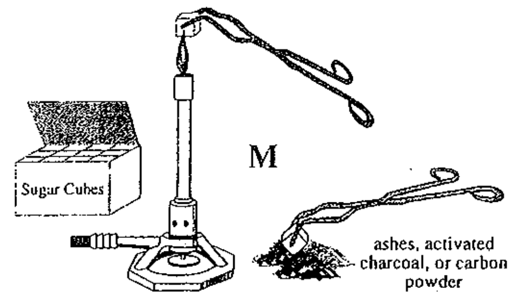
Part 2: Catalysts in combustion: Hold a sugar cube with a pair of tongs above a ceramic tile, ashtray or other fireproof surface, and try to burn it with a match or laboratory burner (Figure M). Since the melting point of sucrose is only 185°C, the sugar cube melts before it

Table 3: Tests for Catalysts

	Rate of Bubbling	*Glowing Splint Test*	*Catalyst?*
manganese dioxide			
activated charcoal			
calcium carbonate			
potassium permanganate			
potassium iodide			

drip on the tile

burns. Dip a second cube in very fine powdered activated charcoal (carbon) or ash from a fireplace or ashtray. When a match is brought to this cube, the cube burns readily. The carbon acts as a catalyst in the combustion of sugar.



Questions

(1) What is the purpose of a catalyst?

(2) Describe in your own words the meaning of "activation energy" and "activated complex."

(3) Although the heat of formation (ΔH = 285.8 kJ/mol) and the free energy change (ΔG = –237.2 kJ/mol) for the reaction of hydrogen and oxygen to form water are quite high, when hydrogen (H_2) and oxygen (O_2) are mixed at room temperature, they do not combine spontaneously to form water (H_2O). Explain.

(4) A catalyst lowers the activation energy for a reaction. Explain.