Photocatalysis for the Environment

What is the main purpose of a real scientist? I believe that the purpose is to create a very comfortable atmosphere for all people and to enhance their life to a greater extent. The scientist must contribute to a maximum extent to fulfill this purpose.

Recently, there have been several TV and newspaper reports about photocatalysis. We have recognized that this technology is becoming more and more popular recently. For example, if we visit an electrical appliance shop, we soon realize the appearance of several products based on photocatalysis. For example, indoor air-cleaning systems based on photocatalytic systems have become very familiar in the market. These air cleaners contain special filters made from photocatalytic materials, which remove contaminants, such as those that cause bad odors, and bacteria from the indoor air, when it flows through these photocatalytic filters. That is the reason why these photocatalytic products have become very popular.

What is photocatalysis? This is our main subject. Catalysis is a phenomenon in which the properties of the catalyst material remain the same before and after the chemical reaction; however, the reaction proceeds faster in the presence of the catalyst. If this catalytic reaction happens only under irradiation, then it is called photocatalysis. This is similar to the reactions in the photosynthetic process in plants. In the case of photosynthesis, the reaction between carbon dioxide and water is enhanced under solar light to produce starch and oxygen. This reaction does not occur outside the plant, even under intense light. The chlorophyll in the plant absorbs light and enhances the photosynthetic reaction to produce starch and oxygen. However, the chlorophyll does not undergo any chemical change in this reaction. So, chlorophyll acts as photocatalyst.

In the case of photocatalysis, titanium dioxide works as photocatalyst, similar to the chlorophyll in plant photosynthesis. Titanium dioxide is not a special material. It is widely used as a pigment in paint. However, photocatalytic reactions occurring in the paint under solar light are not desirable, because the organic binder is decomposed. In contrast, photocatalytic reactions are very important for self-cleaning applications, for example.

What is the origin of titanium dioxide photocatalysis? The study of reactions under light is the origin. About 40 years ago, when I was a graduate student, I used a titanium dioxide single crystal in the rutile form for my experiments. I cut the cylindrically shaped titanium dioxide single crystal to form a slice and heated it in a reducing hydrogen atmosphere to induce conductivity in order to use it as an electrode. I examined the electrochemical behavior of this electrode in an electrochemical cell under irradiation with a 500 W xenon lamp. I found the evolution of gas bubbles at the electrode under irradiation. The gas evolution stopped when the irradiation was stopped. I also observed the flow of current from the electrode only when the gas evolution was observed under light. As the electrolyte in my experiment was water, I assumed the gas evolved at the electrode to be oxygen, due to the photocatalytic oxidation of water. Even after a long exposure of the titanium dioxide electrodes in this experiment, the surfaces of the electrodes did not change at all. I also confirmed the absence of any change in the weight after the photocatalytic experiment.

The gas evolved in the above reaction was confirmed to be oxygen, which was produced from water but not from the titanium dioxide. We assumed that the reaction in our experiment was water electrolysis. However, the potential applied in our experiment was not positive enough for water electrolysis, but the reaction happened, due to the irradiation of the electrode. This means that water electrolysis is possible, even at a negative applied potential, if the titanium dioxide electrode is irradiated. We named this reaction "the photosensitized electrooxidation reaction."

By using this photoelectrochemical phenomenon, we constructed a wet-type solar cell by coupling a titanium dioxide anode with a platinum electrode, which acted as a cathode. The results obtained from this experiment were published in the journal 'Nature'. Under irradiation with a xenon lamp, the oxygen evolution reaction occurred at the titanium dioxide anode, while hydrogen evolution was observed at the platinum cathode. While this reaction was in progress, electrical current was generated through a resistor connected between the electrodes. This means that we can construct a wet type solar cell.

By using this wet type solar cell, we started to produce hydrogen, which is a clean energy source, under solar light. To produce a large volume of hydrogen, we used a large area titanium dioxide electrode by heating titanium metal sheets on a gas burner to produce an oxide layer of one micrometer thickness. We could produce about 7 liters of hydrogen by irradiating one square meter area of titanium dioxide layer electrode in our solar cell on a fine summer day. However, we found that the calculated energy conversion efficiency was only 0.4%. Although this value is very small, the material cost is also very low in this system. This is a very interesting subject.

However, the photocatalysis phenomenon, which evolved from this fundamental photoelectrochemical behavior, has become very popular in recent days. Originating from this concept, the antibacterial effect and the deodorizing effect have become popular in indoor air purification. Also, the decomposition of oily dirt on the surfaces of the lighting units of highway tunnels became possible. Photocatalysis is a very nice system to make a clean atmosphere. Recently, we have also found another unique property of titanium dioxide, namely superhydrophilicity. This technology has been applied to the side-view mirrors of automobiles. Now, even on rainy days, safe driving is assured, due to this superhydrophilic effect.

Photocatalysis has two unique properties. One is the strong photocatalytic oxidation power, and the other is superhydrophilicity. Therefore, titanium dioxide photocatalysis has two key components. One is titanium dioxide, and the second is irradiation. When titanium dioxide is irradiated, these two properties operate simultaneously. The first aspect of photocatalysis is the very strong oxidation power, which means that any chemical approaching the surface of titanium dioxide decomposes very easily under light. Any organic compounds at the surface decompose into carbon dioxide and water. However, in this case, the extent of the reaction is limited by the number of photons. Therefore, the temperature in this reaction does not increase as it does in the case of the combustion reaction. The photocatalytic reaction occurs at room temperature.

Another unique property of titanium dioxide is superhydrophilicity. Normally, the surface of titanium dioxide becomes fogged when water condenses on it. However, after irradiation, the water droplets on the surface do not keep their spherical shape but become flat on the surface, thereby forming a uniform film. If oil is already on the surface, the water falling on the irradiated surface penetrates under the oil and removes it easily. By using this behavior, we can achieve an anti-fogging glass with self-cleaning properties. This technology is already being applied to side-view mirrors of automobiles in order to have safe driving.

Just recently, photocatalysis has been applied in many fields. Deodorizing, antibacterial, antifogging, and self-cleaning effects have become very attractive. Also, the photocatalytic effect has been extended to water treatment and the corrosion protection of steel. Very recently, visible light-responsive photocatalysis is becoming an active research field. If we succeed in applying this behavior, photocatalysis can be applied in even wider fields.