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Application of Experimental Inquiry Teaching Mode in Cultivating Students' Chemistry Key Competency

—the Experimental Inquiry of the Oxidation of Nitric Acid

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***Abstract*—Based on the high school chemistry classroom, this paper has taken the nitric acid oxidation as an example and adopted the experiment inquiry teaching mode to cultivate students' chemistry key competency. Taking the copper and nitric acid reaction experiment as the study carrier, according to the relationship between the reactants and the products of the two reactions of the copper and nitric acid and the copper and dilute nitric acid, the paper has connected five related reactions in series, which are copper and concentrated nitric acid, nitrogen dioxide and water, copper and dilute nitric acid, nitric oxide and oxygen, nitrogen dioxide and sodium hydroxide. Thus, the teaching design of experimental inquiry can fully implement the cultivation of five chemistry key competencies for students.**

Keywords—Experimental inquiry; Chemistry key competency; Nitric acid; Copper

I. INTRODUCTION

Since the reform of the new curriculum, inquiry teaching mode has gradually become an important teaching mode in the middle schools of China. Especially, the experimental inquiry teaching mode, with its intuitive, image, strong awareness of inquiry and other characteristics, has been gradually attached importance to become one of the important methods of middle school chemistry teaching. And its function can not be replaced and underestimated as for improving the teaching quality, the development of students' key competency[1].

With the further advancement of the new curriculum reform, the ministry of education of the People's Republic of China recently revised the "chemistry key competency " in the curriculum standards for ordinary high school chemistry (2017 edition) issued in 2018. This concept integrated many requirements together, such as the learning of chemical knowledge and skills, the construction of chemical ideas, the development of scientific inquiry and problem-solving ability, the formation of innovative consciousness and social responsibility. The concept established four levels to make specific requirements for Senior High School Chemistry Teaching in China from the perspectives of "macro identification and micro analysis", "change concept and balance thought", "evidence reasoning and model cognition", "scientific inquiry and innovation consciousness", "scientific attitude and social responsibility"[2]. The proposal of "chemistry key competency" has aroused a wide discussion in the field of education. How to cultivate students' chemistry key competencies has become an urgent problem to be solved in Senior High School Chemistry Teaching. In the development of chemical science history, it was not difficult to find that chemical experiment played a unique role in stimulating students' interest in learning, recognizing problems, verifying hypotheses and providing teaching situations. Therefore, it was very advantageous to cultivate students' chemistry key competency using the experimental inquiry teaching mode, which coincides with the view of cultivating students' chemistry key competency in the new curriculum standard.

The oxidizability of nitric acid was one of the key teaching contents of high school chemistry, which played a connecting role between the teaching contents of "REDOX reaction principle" and "formation of periodic table of elements". The experiment of the reaction of copper with nitric acid was an important carrier to explore the oxidizability of nitric acid, which could not only enhance the students' cognition for the oxidizability of nitric acid, but also aroused their interest in the experiment and cultivate their chemistry key competency.

However, in Chemistry 1 (2007 edition) Textbook,[3] which was adopted by most secondary schools, no experimental device was designed to introduce the oxidization of nitric acid. Instead, it was proposed that "nitric acid can also produce a similar reaction" by analogy with concentrated sulfuric acid and copper, making students' cognition of this reaction vague. Therefore, in this paper, experimental inquiry teaching mode was adopted in the teaching design of the oxidizability of nitric acid, and the experimental equipment was innovated, which provided a carrier for the exploring the oxidizability of nitric acid and realizing the cultivation of the students' chemistry key competency. Based on the relevant literature [4-6], the designs of all the above have completed the learning activity proposal, which is to explore the nature of concentrated, dilute nitric acid, on page 16 in General High School Chemistry Curriculum Standards 2017 edition.

II. Teaching Design

A. Creating situations

In this section, combined with human exploration of nitric acid and its history, the students were guided to go further study on the basic principles of nitric acid and metal reaction. The slide of the excerpt of "Guangqi Xu's handwriting" [7] was shown to arouse students' curiosity about what kind of material strong water was. The purpose was to introduce nitric acid and lead students to understand that nitric acid can react with metals except for gold. In this design, students can experience the opposites and unity of the relationship between natural science and humanities, understand the excellent traditional Chinese culture, and develop the chemistry key competency of "scientific attitude and social responsibility".

B. Establishing assumptions

In this section, based on the theory of the zone of proximal development, the students' cognitive conflict was established. Applying the teaching method of consolidating the previous knowledge and introducing the new knowledge, the teacher can guide the students to analyze the phenomenon that copper was soluble in nitric acid by reviewing the metal activity sequence. Whereupon, the problem was put forward that copper could not exchange with acid to release hydrogen but could be dissolved in nitric acid, which would make students have a cognitive needs and arouse the learning enthusiasm of students. After that, the teacher would provide the teaching frame to guide the students to analyze the valence of nitric acid, and to confirm that the valence of nitrogen in nitric acid was the highest valence (+ 5), which made nitric acid show a strong oxidation property, and then guessed the reaction between copper and nitric acid. In the end, the students used the above analysis to establish the hypothesis that copper could react with nitric acid by oxidation-reduction, and then designed the experimental schemes with the form of group cooperation, exchanged and displayed the schemes, collected the evidence. After each group presented the experimental plan, the teacher raised a question that whether the change of nitric acid concentration could cause the change of reaction products to stimulate the students to think further. The purpose of this design was to cultivate the students' ability of independent thinking and cooperative learning, and improve the chemistry key competency of "scientific inquiry and innovation consciousness".

C. Experimental inquiry

After summarizing and evaluating the experimental schemes designed by the students, an optimized design scheme was put forward and the integrated micro-experimental innovative device was displayed, which was designed according the optimized design scheme in this section. Using this device the experimental process of the oxidation of nitric acid would be explored. In the exploring process, based on the oxides of nitrogen the students have learned, they can infer which substances the red-brown gas, colorless gas and blue solution observed in the experiment are, write down the chemical equation, and thus establish the connection between macroscopic phenomena and microscopic essence, which can be implemented into the symbolic representation. To help students form the experimental inquiry thinking of "hypothesis establishment -- evidence collection -- hypothesis verification", and cultivate the key competency of "macro identification and micro analysis", "evidence reasoning and model cognition" in chemistry. By comparing different experimental phenomena of copper reaction with concentrated and dilute nitric acid, students can understand the relationship between quantitative change and qualitative change in the chemical reaction, so as to cultivate the key competency of "change concept and balance thought" in chemistry.

D. Summarizing

This section was a summary of the previous experimental study. Through the experimental study, the students were led to conclude that the oxidation of nitric acid was due to the presence of five-valent nitrogen and the oxidation of nitric acid is stronger than that of dilute nitric acid. So the key points were clear and the difficulties were broken. Finally, after students understand the application of nitric acid in production and life, they can deepen their understanding of nitric acid, strengthen their consciousness of green chemistry. Thereupon, the chemistry key competency of "scientific attitude and social responsibility" was performed.

III. The Intention of Experiment Design

In this paper, the oxidation experiment device of nitric acid was innovated, and the reaction apparatus was made up of 3 mL cellophane bottle, reversed rubber stopper, infusion tube and 1 mL syringe. The integrated micro-experimental device was shown in Fig. 1. In Fig. 1, bottle a and bottle b each contained a spiral copper sheet with a width of 4 mm and a length of 4 cm. A syringe filled with 1 mL concentrated HNO_3 was inserted into bottle a. A 3 mL distilled water was added into bottle b. Bottle c filled with air was connected to a syringe which containing a 1 mL NaOH solution. Bottles of a, b and c were connected in series with infusion tubes.

In this experimental device, the five related reactions were linked in series which were copper with concentrated nitric acid, nitrogen dioxide with water, copper with dilute nitric acid, nitric oxide with oxygen and nitrogen dioxide with sodium hydroxide. The design principle was based on the property relations between reactants and products in the two reaction of copper with concentrated nitric acid and copper with dilute nitric acid, the evidence-reasoning model was also built. The design of the scheme could commendably mobilize students' active exploration and thinking, train students' logical thinking ability, and achieve the goal of cultivating students' chemistry key competency disciplines.

The specific design intentions of the five related reactions in the series involved in the experiment are as follows:

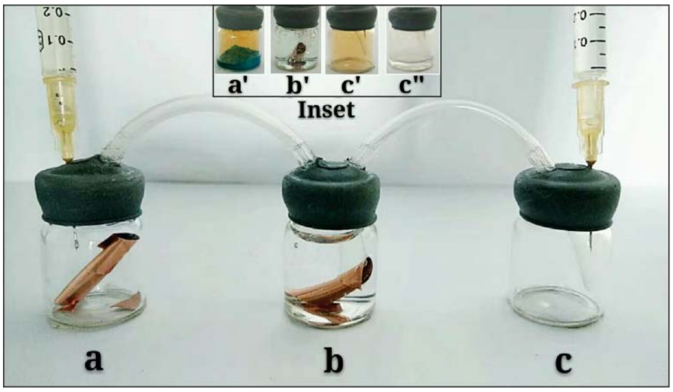

Fig. 1. The integrated micro-experimental device for five reactions. The inset showed the color change of the solutions in the bottles after a period of reaction.

A. Design of Reaction of Copper with Concentrated Nitric Acid

Copper reacted with concentrated HNO_3 in bottle a. At the beginning, the 0.2 mL concentrated HNO_3 in the syringe which connected with the bottle a was continuously and slowly pushed into the bottle. This time, a large amount of reddish brown gas was produced rapidly in bottle a. There were bubbles on the surface of the copper sheet. The color of the solution was blue-green and the reaction was violent. However, the solution gradually turned blue by the amount of nitric acid increasing (see inset a′ in Fig. 1). The appearance of reddish brown gas proved the generation of NO_2; the solution turning blue indicated the formation of $Cu(NO_3)_2$. So it could be concluded that Cu was oxidized by concentrated HNO_3, the chemical reaction equation was $Cu + 4HNO_3 = Cu(NO_3)_2 + 2H_2O + 2NO_2\uparrow$. This step-by-step design guided students to infer products from experimental phenomena, draw reasonable conclusions from analyzing evidences, and write chemical equations. Thus, it was implemented that the cultivation of the two chemistry key competencies, "macro identification and micro analysis" and "evidence reasoning and model cognition".

B. Design of Reaction of Copper with Dilute Nitric Acid

Since the students have already learned before about that NO_2 reacts with water to produce HNO_3 and NO, and the NO_2 in this experiment was just the product of the reaction of Cu with concentrated HNO_3 in bottle a, the red-brown gas (NO_2) coming from bottle a was then introduced into bottle b. The red-brown gas would fully contact and react with distilled water to produce dilute nitric acid (see bottle b in Fig. 1).In this step, it was observed that the reddish-brown gas changed to colorless after being introduced into the bottle b, and there were a large number of colorless bubbles in the inlet port of the bottle b. These indicated that the NO_2 reacted with water. Based on previous knowledge, students could deduce by themselves that the resulting solution in bottle b was dilute HNO_3 forming from the reaction of NO_2 and water, the colorless bubbles were NO, and the chemical equation was $3NO_2 + H_2O = 2HNO_3 + NO$. this design can not only help the students to review and consolidate the knowledge that the reaction between NO_2 and water, but also can train their inferential capability by observing the change of gas color. Such an arrangement could further develop students' inquiry consciousness and the chemistry key competencies which were "macro identification and micro analysis" and "evidence reasoning and model cognition".

When the NO_2 was put into the bottle b for a period of time, the solution of dilute HNO_3 in bottle b reached enough concentration to react with copper. After 1 minute of reaction, colorless bubbles began to adhere to the surface of the copper sheet in bottle b, and with the passage of time, the number of colorless bubbles increased, and the solution gradually changed from colorless to blue (see inset b′ in Fig. 1). This indicates that copper has reoxidation and reduction reaction with newly generated dilute nitric acid, the resulting blue solution is copper nitrate solution, and the colorless gas should be nitric oxide (further verification experiments were designed after the nitric oxide generated here). The reaction in bottle b is: $3Cu + 8HNO_3(dilute) = 3Cu(NO_3)_2 + 4H_2O + 2NO\uparrow$. This design could direct students to observe the relationship between quantitative change and qualitative change in the chemical reaction, and fully implement the chemistry key competency of "change concept and balance thought".

C. Validation Design of Nitric Oxide

In order to prove the colorless gas produced in bottle b was NO, the experimental scheme could be designed according to the color change of the reaction between NO and O_2. Therefore, the colorless gas generated in the bottle b was introduced into a small bottle filled with air (see bottle c in fig. 1), and after 8 seconds the color of the gas changed to red brown (see inset c′ in fig. 1). This means that the gas produced in the bottle b was exactly NO, and the reaction in the bottle c was $2NO + O_2 = NO_2$. This design could not only review the relationship between NO and NO_2, but also arouse students' interest in exploration and cultivate students' the chemistry key competency of "scientific inquiry and innovative consciousness".

D. Exhaust Gas Treatment Design

As the final product in bottle c was a poisonous and irritating gas, and it was also one of the causes of acid rain, the design of the tail gas treatment should be completed at the end of the experiment. Therefore, the exhaust gas of NO_2 was absorbed by NaOH solution. When the solution of NaOH in the syringe was slowly pushed into the bottle c, the reddish-brown color was gradually faded, a colorless solution was left in the bottle (see inset c″ in fig. 1).The colorless solution was a mixture of $NaNO_3$ and $NaNO_2$, and the chemical equation was $2NO_2 + 2NaOH = NaNO_2 + NaNO_3 + H_2O$. This reaction was an expansion, the design purpose was to deepen students' understanding of disproportionate reaction. It is very necessary and important to cultivate students' safety consciousness and the concept of green chemistry. This experiment design carried adequately out the cultivation of the chemistry key competency of "scientific attitude and social responsibility" for students.

IV. CONCLUSIONS

In this paper, the teaching design of the oxidization of nitric acid was carried out by using the teaching mode of experimental inquiry. The teaching design was based on the experiment of the reaction between copper and nitric acid.

According to the nature relationship between reactants and products, the experimental equipment for the reaction of copper with nitric acid was designed in an integrated, miniature and green way. The cultivation of five chemistry key competencies for student were carried out adequately.

A. *Visual experiment to implement "macro identification and micro analysis"*

In our design, the vial and infusion tube used in the experiment were small and transparent, which increased the visibility of the experiment. It made it possible to observe clearly the red brown NO_2, the colorless NO, and the change of the color between the two gases during the experiment. It was helpful for students to speculate on the reaction products, write chemical equation correctly, and carry out symbol representation.

B. *Comparative experiment to implement "change concept and balance thought"*

The experimental device designed by us was convenient for students to compare the experimental phenomena in the reaction of copper with concentrated and dilute nitric acid, which could deepen students' understanding that the change of the concentration of reactants would result in the change of the species of the products. Furthermore, it was clarified that the influence of the concentration of nitric acid on the oxidation of nitric acid. The students were guided to analyze the chemical problems from the philosophical point of view and to further understand the relationship between quantitative change and qualitative change in chemical reaction.

C. *Integrative experiment to implement "evidence reasoning and model cognition"*

The experimental device was designed according to the logical relationship between the properties of reactants and products. Five reactions, which were reactions of Cu and concentrated HNO_3, Cu and diluted HNO_3, NO_2 and H_2O, NO and O_2 and the absorption of NO_2 tail gas, were designed as a whole and completed at one time. Such an integrated design presented a strong logic, which could help students to understand the oxidation of HNO_3 and the properties relationship between NO, NO_2 and HNO_3, and to construct a reasonable knowledge model system of nitric acid oxidizability by evidence independently. The design purposes were to train the students' logical thinking ability and inferential capability, to cultivate their interest in inquiry.

D. *Microscale experiment to implement "scientific inquiry and innovation consciousness"*

The experiments in this paper were designed with miniaturization of instruments and microquantization of drugs, which not only reduced the risk of experiments but also saved the dosage of drugs. It not only ensures the safety of the experiment, but also saves the economic expense and lightens the environmental burden.The replacement of experimental supplies and the improvement of the connection mode of experimental devices can stimulate students' innovative thinking and enhance their awareness of innovation.

E. *Green experiment to implement "scientific attitude and social responsibility"*

Greening design of tail gas treatment was carried out in this experiment. The injection of NaOH absorbent prevented from the NO_2 escaping into the air, avoided environmental pollution and fostered the students' sense of social responsibility. In addition, the reversed rubber stopper used in the experiment could encase the mouth of the penicillin bottle, which prevented the separation between the bottle body and the bottle stopper and the splash of concentrated HNO_3 causing by the rapid formation of a large amount of NO_2 gas in the reaction of Cu and concentrated HNO_3. So, the design of the reversed rubber stopper further avoided the dangerous occurrence and environmental pollution. This innovation could not only improve the safety of the experimental system, but also worked together with the tail gas treatment design, which fully reflected the concept of green chemistry.

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