A Classroom Experiment on Discoloration of Basic Phenolphthalein Solution for Demonstration of Reaction Kinetics

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A classroom experiment to observe discoloration of aqueous dye solution is described. Phenolphthalein gradually discolors from purplish-red to colorless under strongly basic condition (pH > 12). The reaction rate of this discoloration is represented by a pseudo-first-order kinetics equation, so that this reaction can be a good example for the demonstration of reaction kinetics. The demonstration can be carried out in a classroom by using a portable colorimeter and connected to a computer. The time-course of the discoloration is observed by using a projector and a screen equipped in the classroom, so that students can follow the progress of the discoloration. The data can be used to solve additional exercise problems.
Key words: phenolphthalein, discoloration, reaction kinetics, colorimeter, classroom experiment

1. INTRODUCTION

Kinetics of chemical reaction is one of the key concepts in chemistry. Understanding of reaction kinetics is hence essential for students of chemistry class. However, many students do not smoothly understand reaction kinetics; following of many complicated kinetics equations is quite difficult for many students of introductory chemistry class. In such case, demonstration of chemical reaction by classroom experiment will help understanding (Fig. 1). For this purpose, observation of the progress of chemical reaction using a hand-held colorimeter is suitable. It can usually be carried out without severe conditions such as high temperature and high pressure in many cases. In addition, chemical reactions indicating color change are attractive for many students. In this work, basic phenolphthalein (PP) solution was used as a sample. PP gradually discolors from purplish-red to colorless under strongly basic condition (pH > 12) [1–3]. This reaction is shown in Fig. 2. The reaction rate of this discoloration is represented by a pseudo-first-order kinetic equation, so that this reaction can be a good example for the demonstration of reaction kinetics.
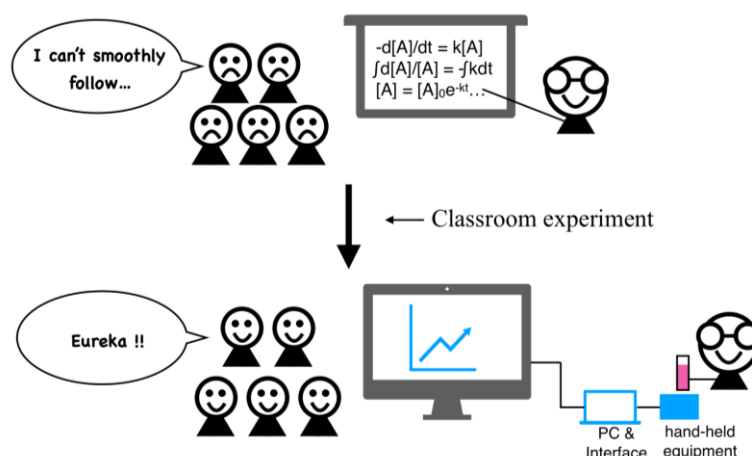

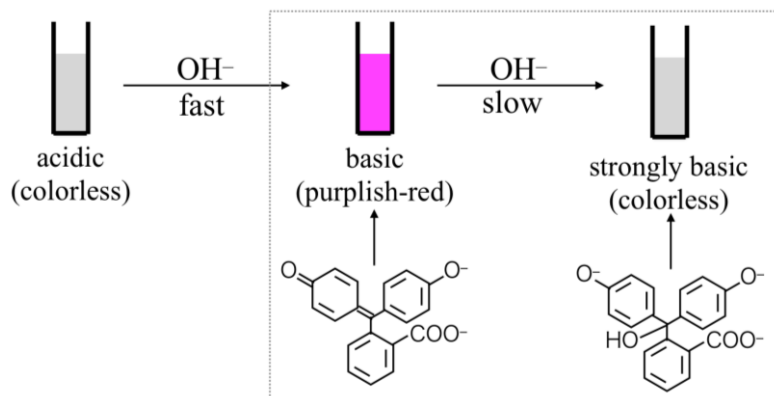Fig. 1 Classroom experiment for demonstration of reaction kinetics.

Fig. 2   Discoloration reaction of PP.

2. EXPERIMENTAL

PP used in this work was purchased from Wako, Japan. PP was dissolved in distilled water to make 0.0001 mol/L aqueous solution. Then the solution was basified by addition of sodium carbonate (Na_2CO_3) prior to the experiment. At this moment the solution was purplish-red. This solution was used to observe the discoloration.

A photograph of experimental setup is shown in Fig. 3. A portable colorimeter (Vernier COL-BTA) was connected to a interface (Vernier LabQuest2) [4, 5]. This interface records the data from colorimeter. The collected data were transferred to a computer and then represented on a graph. The graph can be projected on a screen equipped in the classroom, so that the students can share the data. This setup can be easily assembled on a classroom desk.
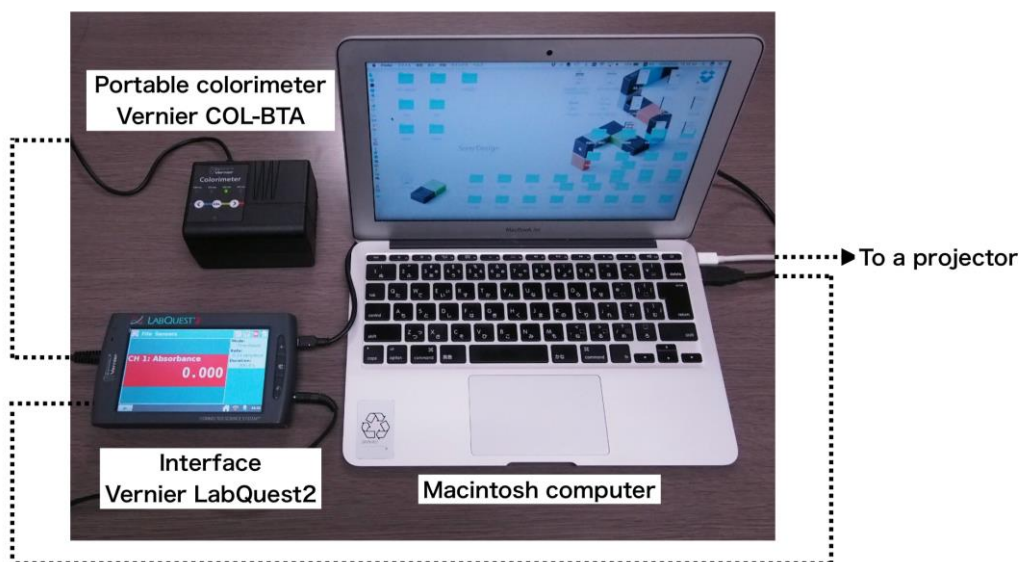

Fig. 3   Experimental setup.

The basified PP solution (1 mL) was mixed with 2 mL of 1 mol/L sodium hydroxide aqueous solution in a plastic cuvette. Then the absorbance measurement (wavelength: 565 nm) was immediately started. The overall procedure of the experiment is illustrated in Fig. 4.
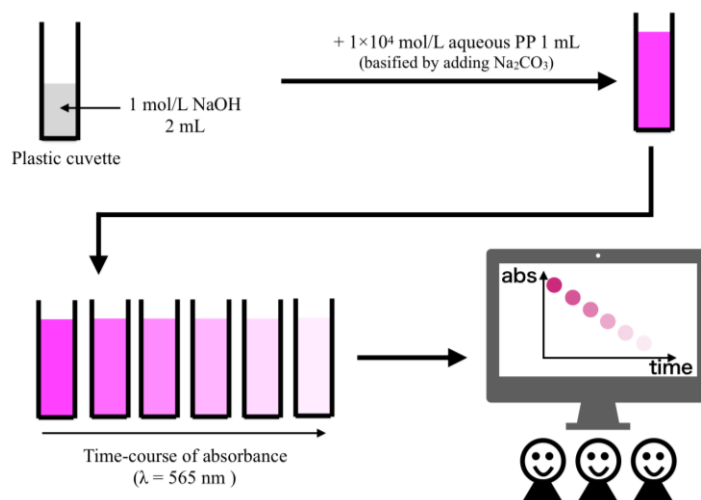
Fig. 4   Procedure of the classroom experiment.

3. OVERVIEW OF THE REACTION KINETICS

The reaction rate of the discoloration is expressed by the following pseudo-first-order equation

$$-d[PP]/dt = k[PP]$$

where [PP] is the concentration of PP, t is time, and k is rate constant. Integrating this equation, we obtain

$$\log\{[PP]/[PP]0\} = -kt$$

where $[PP]_0$ is the initial concentration of PP at t = 0. Based on the Lambert-Beer's law, relationship between the absorbance A of the solution and [PP] can be represented by the following equation

$$A = \varepsilon \bullet L \bullet [PP]$$

where ε is molar extinction coefficient of PP, and L is light path length of the cuvette used. Therefore, the concentration ratio $[PP]/[PP]_0$ can be replaced with the absorbance ratio A/A_0.

$$\log(A/A_0) = -kt$$

Here, A and A_0 are the absorbance measured for [PP] and $[PP]_0$, respectively. The pseudo-first-order kinetics of the discoloration can be easily confirmed by plotting $\log(A/A_0)$ against t and fitting the data to a linear function.

4. RESULTS AND DISCUSSION

Fig. 5 shows the screenshot of time-absorbance plot. In this case, fluctuation of the absorbance was observed in the early stage (0 – 15 sec). This is probably owing to inhomogeneous mixing of the reactants. After that, homogeneous dissolution of the reactants was achieved (this moment was defined as t = 0) and the concentration of purplish-red PP was exponentially decreased. The measurement was stopped at t = 60 sec.

Fig. 6 shows the time-$\ln(A/A_0)$ plot. Here, ln stands for natural logarithm (In Fig. 6, "ln" is represented with "Log"). The plot can be fitted well with a linear function. The rate constant k is obtained from the slope of the line. In this case, k was calculated to be 0.014 sec^{-1}. The students can use this value to solve the additional problems.

This experiment was performed in the introductory chemistry classes for the first-year students of Chitose Institute of Science and Technology (first semester, 2017). Fig. 7 shows the worksheet for calculations of half-life and concentration change during the given time. The students solved the problems using the obtained data to learn the numerical calculation on the reaction rate. The half-life $t_{1/2}$ can be obtained using k.

$$t_{1/2} = \ln2/k$$

For the concentration change calculation, reaction time was given as 150 sec. Based on the integrated kinetics equation, the concentration ratio at 150 sec is represented as follows.

$$A/A_0 = [PP]/[PP]_0 = \exp(-k \cdot 150)$$

In the worksheet, the ratio is represented in percent by multiplying by 100. These exercises would help understanding of the reaction kinetics.
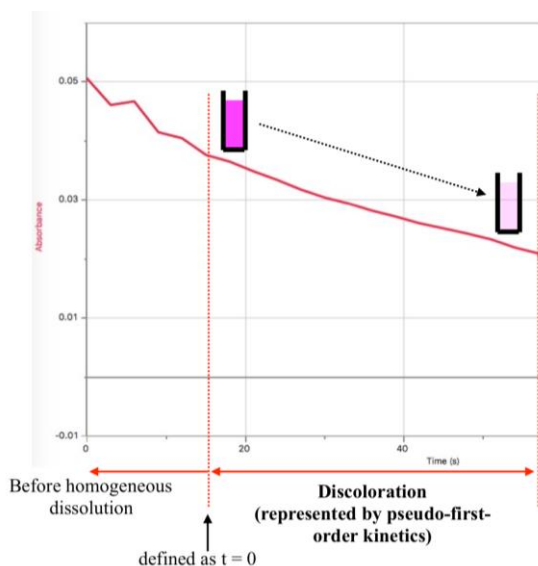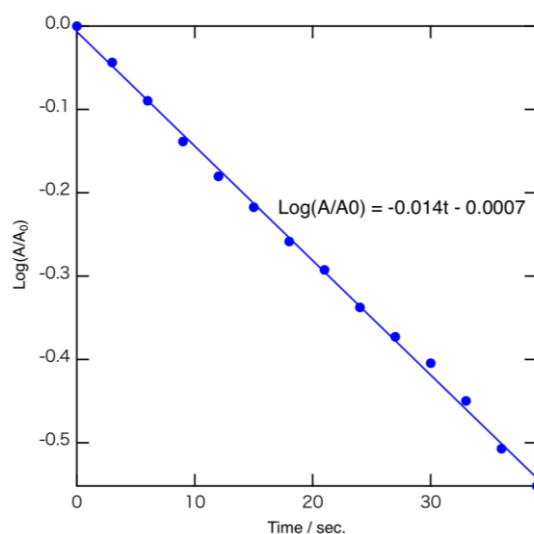

Fig. 5　An example of time-absorbance plot.

Fig. 6　Time-$\ln(A/A_0)$ plot obtained from the data shown in Fig. 5.

Fig. 7　A worksheet for calculation of half-life and concentration change during the given time (in this case t = 150 sec). The (1) means the rate constant obtained by the linear fitting of the data. The (2) and (3) are the half-life and the concentration change, respectively.

5. CONCLUDING REMARKS

An example of classroom experiment for demonstration of reaction kinetics was described here. The

author believes that classroom experiments significantly help understanding of abstract chemical concepts. Nowadays many portable sensors and interfaces such as the colorimeter used in this work are available, so that novel classroom experiments can be easily developed. To improve the educational environment of introductory chemistry, development of attractive classroom experiments will be remaining subject for future work.

References

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