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A teaching tool for molecular kinetics

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Abstract
Kinetic models of a gas can be hard for students to understand. Typical tools do not display events at the microscopic level, yet computer simulations of the molecules lack a hands-on aspect. Here a new tool is described that combines the squeezing of a syringe with a computer simulation, and it is shown that this has worked well in class for both teachers and students.

Introduction

In Japan, students learn about the compressibility of air and the phase change of water in elementary school and begin to use kinetic models of a gas in junior high school. When they are in the first or second year of senior high school, they learn more about molecular kinetics in chemistry classes, as shown in figure 1 [1]. Although they learn that gas molecules are constantly in motion, it is not easy for them to accept such an abstract idea without any direct observation. As a result, there are quite a few students who cannot explain the difference between the gas and liquid phases from a microscopic viewpoint based on the difference in molecular behaviour. Since they do understand the difference between these two phases based on the difference in densities, they can answer practice exercises regarding Boyle's and Charles's laws and/or the equation of state. However, it is difficult for them to understand the physical meaning of these laws from a microscopic viewpoint, and they could encounter similar difficulties when they study other topics such as 'vapor pressure', 'atmospheric pressure' and 'vapor pressure depression'. This means they learn these phenomena by heart and do formal calculations.

Although students could gain a greater understanding of molecular kinetics if more time were available for this subject, it is difficult to provide extra time under the present curriculum in Japan. This means that a more effective and efficient tool is needed in this subject, especially for those who have not studied it enough in junior high school.

A typical tool to illustrate molecular behaviour in the gas phase consists of small steel balls and a vibrating base plate in a cylindrical or rectangular cell as shown in figure 2, which is called a kinetic vibrator. The movement of the small balls can be displayed directly to students or via an overhead projector or a TV camera. Since students can touch the top plate of the kinetic vibrator, they can somehow experience the relation between pressure and volume by pressing it downward and releasing it. However, it is not very easy for them to correlate this vibrator to a syringe containing air.

Computer simulations are believed to be effective for explaining abstract or invisible phenomena in science, and a variety of simulation software has been developed regarding the molecular kinetics of gases for educational purposes. However, a simulation is not part of a student's feeling (they cannot touch or feel anything in simulations), and therefore it is too optimistic to conclude that students would understand molecular kinetics without difficulty if

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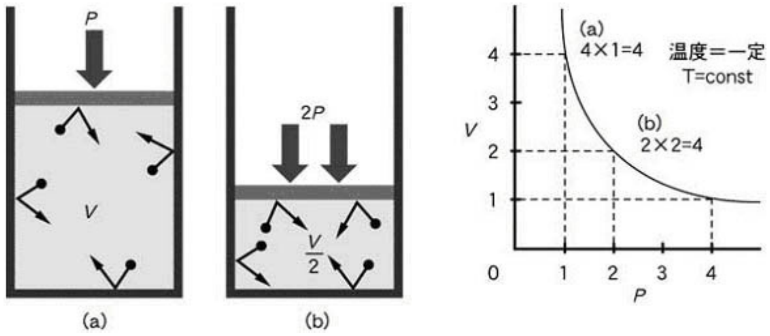

Figure 1. Extract from a chemistry textbook.

Figure 2. Kinetic vibrator.

only they could observe simulated images of some phenomena.

Our new teaching tool

Based on the concerns described above, we have developed a new teaching tool (TTMK: Teaching Tool for Molecular Kinetics) with two human interfaces as shown in figure 3. One is a display to show a visualized image of molecular behaviours and the other is a plastic syringe with a built-in pressure sensor and temperature sensor. These two interfaces have nothing individually special about them because the visualized image is quite similar to those used in ordinary simulation software, and these sensors are often used to demonstrate Boyle's and Charles's laws using microcomputer measurements. The point of this work is the combination of these two interfaces, which means that students can feel the relation between P, V and T by manipulating the syringe with their hands, and simultaneously can see the molecular behaviour of the gas on the monitor.

The external appearance of the syringe with sensors and analogue-to-digital convertor is presented in figure 4 and the image on the monitor screen is presented in figure 5. The temperature sensor and the pressure sensor used in this work are a Seiko S-8100B and a Fujikura FPM-15PAR, respectively. The measuring range of the former is from −40 to 100 °C and that of the latter is from −500 to +500 mm Hg with an accuracy of 0.75 mm Hg. When the piston in the syringe (50 ml) is pushed in to compress the air in it, the image of the piston on the monitor screen also simultaneously moves according to the volume change of the gas, which is derived from the measured temperature and pressure using the equation of state: $PV = nRT$. Since the mean square velocity of the molecular particles is expressed as $v^2 = 3RT/M$, the velocity of each particle on the screen was made to be proportional to $T^{1/2}$.

Every time gas molecules hit the wall of the piston, a short beep sounds. This means that students can confirm the pressure change physically by hand, visually through the computer graphics and audibly by these beep sounds.

Practical research in chemistry class

Practical research using TTMK was carried out for the third-year students from a six-year secondary school, when they learn the relationship between the pressure and volume of a gas. The students

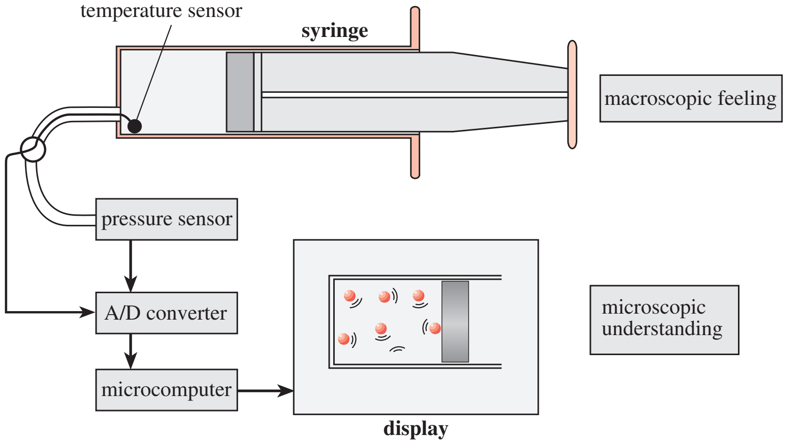

Figure 3. Principle of TTMK (teaching tool for molecular kinetics).

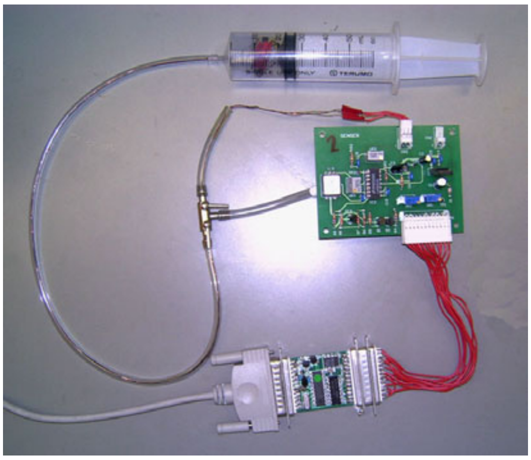

Figure 4. Syringe with pressure and temperature sensors and analogue-to-digital convertor.

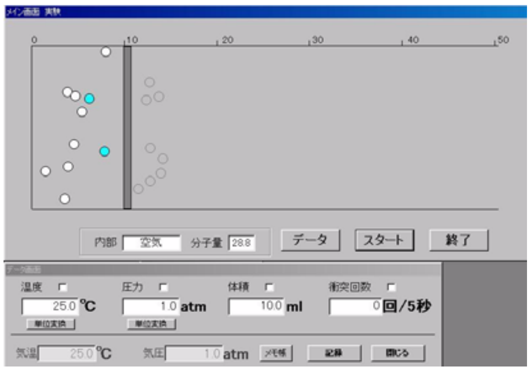

Figure 5. Image on monitor screen.

were divided into two groups, A and B; the former consisted of 44 students and the latter 47. In group A, we used the TTMK with an LCD projector to show the computer graphics and an overhead camera with a TV display to show the syringe so that all students could see from their seats how it was manipulated and the results. Although it would be ideal to let each student operate the tool by themselves, only one unit was available during the practical application. Thus, the experiment had to be conducted by a teacher and the students simply observed it. On the other hand, group B did not use this tool and both groups were asked to answer the same question (cf figure 6) regarding the relation between P and V.

The students in group A noted the number of particle collisions in unit time and they concluded that the number of collisions between the particles and the piston wall increases as the distance between the particles becomes shorter. Some students mentioned that the sound of the particles hitting the wall made it easy to understand the relation between pressure and the impact frequency.

On the other hand, most of the students in group B understood the volume change as a density change. For example, they answered that the gas density in the syringe was greater than that in air. This tendency is coincident with that of Yamaguchi's work [2], in which first-year students in junior high school were investigated.

Comments from science teachers

There was an in-service training course at Kitazato University for 28 science teachers from junior

The outlet of the syringe in figure A is plugged up and 20 mL of air is enclosed in it. Suppose there exists no friction between its piston and the inner wall of the cylinder so that the piston can move smoothly.

In figure B, air in the syringe is illustrated with kinetic models, where nitrogen and oxygen in air are shown with the same symbol ● .

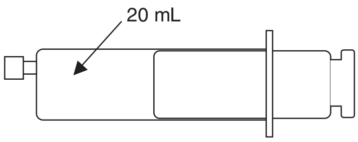

Figure A. Syringe with air packed in.

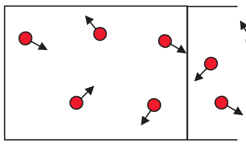

Figure B. Kinetic model of air.

Suppose the piston of the syringe is pressed in and the volume of air is changed from 20 mL into 10 mL. Please explain what is changed using figure B.

Figure 6. Question used in practical research.

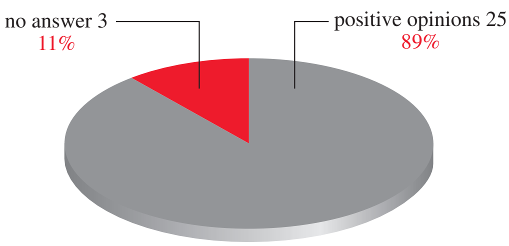

Figure 7. Teachers' impressions of TTMK.

and/or senior high schools in August 2001. We presented our new TTMK tool at this meeting and let all the participants operate it. After our presentation, we investigated how they liked the TTMK using a questionnaire as shown below.

Q1: Please write down your impression and opinion of our TTMK.

Q2: Which subject in which school is TTMK suitable for?

1. physics and chemistry in junior high school
2. chemistry in senior high school
3. physics in senior high school
4. other subject
5. useless (Reason:)

Q3: Who is TTMK suitable for?

1. junior high school students
2. senior high school students
3. both junior and senior high school students
4. others

Q4: How do you want to use the TTMK in your class?

1. as a demonstration experiment
2. as a student experiment
3. other

In their answers to Q1, nearly 90% of them expressed positive opinions and no one expressed

Box 1. Teachers' impressions of TTMK.

- It must be exciting for students to see their operations being displayed on the monitor screen in real time.
- I believe students can enjoy studying.
- This would be a good help for students.
- This tool would attract students more than blackboards.
- Since students tend to visually understand the phenomenon, this tool is interesting.
- This tool is effective for helping students understand invisible gas molecular kinetics.
- It helps students to get a clear image of gas molecular kinetics.

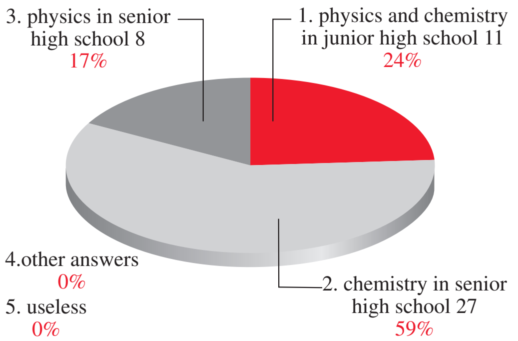

Figure 8. Which subject is TTMK suitable for?

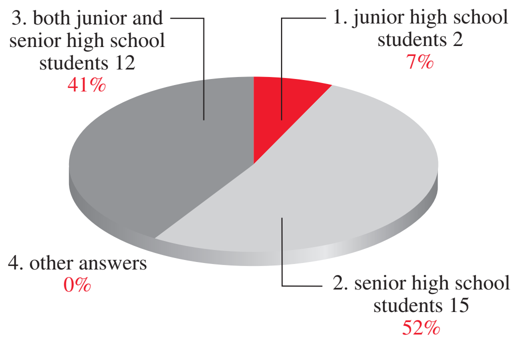

Figure 9. Who is TTMK suitable for?

a negative one (figure 7). Some of their typical opinions are presented in box 1.

The answers for Q2 and Q3 are presented in figures 8 and 9[1]. The former result indicates that nearly 75% of the teachers judged that this tool is suited to senior high school students and 25% for junior high school students. The latter results also indicated a similar tendency.

The answers for Q4 are presented in figure 10. Although we have developed this tool for student experiments, nearly half of the teachers answered that this tool is also useful as a demonstration experiment by a teacher.

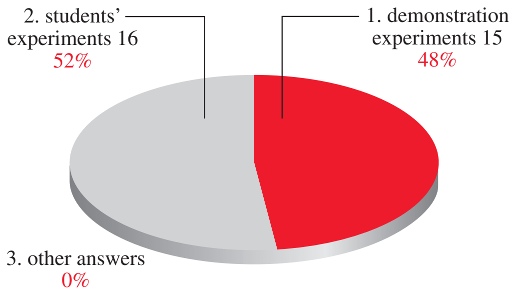

Figure 10. How should TTMK be used?

Conclusion

We have developed a new type of a teaching tool, called TTMK, with which students can relate their physical experience to the conceptual understanding of molecular kinetics. The educational effect of this tool has been partly confirmed in practical research, and many teachers have recognized the validity of this tool especially for senior high school students.

Note. Readers wishing to obtain further technical information should contact the author directly by e-mail at masahirok@nifty.ne.jp.

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[1] The total numbers of responses for each question differ because the answer for each question was not necessarily one regarding figures 8, 9 and 10.