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Energy Conservation Experiments in Classroom

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Abstract : *We discuss energy conservation experiments for students in teacher-training course of University. Most of Students will be teacher of elementary and/or junior high school in Japan.By performing experiments of simple pendulum and rolling ball on inclined rail, with heavy and light ball, students successfully found that the rolling ball experiment is not appropriate as an experiment of energy conservation law with sufficient accuracy, becauseof the rotationaleffect.This practice will be helpful for futurescience teachers to design their classes for their future students.*

Keywords-*Classical Mechanics, Energy Conservation Law, Physics Education, Classroom Experiment*

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I. Introduction

As classroom experiments to showstudents the conservation law of mechanical energy, rolling object on inclined plane [1-4], and simple pendulum [5-8] have been studied so far. For the experiment of rolling object, rotational kinetic energy which possessessome part of the initial energymust be taken into account. Howeverin some cases students have not learned rotational motion before the experiment. Therefore students cannot estimate the rotational effect in this case. In order to overcome the curricular problem, Newton's Cradle experiment has been suggested [9] as an experiment of two-dimensional motion. In general, experiments of pendulum are simple and cheap as classroom experiment.

On the other hand, it is known that students have difficulties for rotational and rolling motion [10].In Ref. [10], it is reported that considerable number of students in general introductory (GI) class do not understand kinetic energyof rotation. They consider that sliding cube without rotation and rollingsphere without slipping with the same center-of-mass speed has the equal kinetic energy.This implies that it might bedifficult for general students to find that the center-of-mass speed of the rolling sphere is smaller than that of the sliding cube whentheir total mechanical energy is the same.

In this paper, wediscuss classroom experiment for students in teacher-training course of University. Most of students will be elementary and/or junior high school teacher in Japan.In order to make students think how to design experiments for their future students, Iasked them to find the most appropriate experiment among arranged experiments to confirm the conservation law of mechanical energy. I prepared the following four experiments: rolling ball on inclined rail and simple pendulum, with heavy and light balls. Students release a ball at the starting point with height h and measure the center-of-mass speed $v$at the lowest point. For simple pendulum experiments, students will measure the predictable value of the speed $v = \sqrt{2gh}$because all of the initial potential energy of the ball is converted to the kinetic energy of the translational motion. However for rolling experiments on inclined rail, they will find that measured speed is smaller than the prediction because some fraction of the initial potential energy will be converted to the rotational kinetic energy.The purpose of this classroom experiment is to make studentsi) to find the best experiments for their future students and ii) to think the reason and find other appropriate experiments.

We find that students were able to find the best experiment, the simple pendulum, with sufficient accuracy and find other appropriate experiments such as free fall, in which the rotational effect can be negligible. This practice will be helpful for students in teacher-training course of University and their future students.

In the next section, theory and experimental setup of the experiments are given. In Section III, wediscussthe results and educational benefits of our practice. Finally Section IVis devoted to the conclusions.

II. Theory And Experimental Set Up

In this section we give a brief review of energy conservation in our experiments: simple pendulum and inclined rail shown in Figure 1. In both cases, ball of mass m and radius a starts to move due to gravity from point P of height h, and students measure its speed v byBeeSpiV[11], a digital speed measuring device,at point Q of zero height. The gravitational acceleration is g and we neglect any effects of friction and air resistance. We define the initial mechanical energy $E_{\mathrm{P}}$and the final kinetic energy of the translational motion K_{Q}as

$$E_{\rm P} = mgh, \qquad K_{\rm Q} = \frac{1}{2}mv^2. \tag{2.1}$$

Theenergy conservation law for simple pendulum isgiven by

$$E_{\rm P} = K_{\rm Q}, \tag{2.2}$$

which means that all of the initial energy converts to the kinetic energy of translational motion.

On the other hand for the case of rolling ball on inclined rail, the ball rotates when it moves.If the ball rotates without slipping during its motion, the ball has the kinetic energy of rotation defined by

$$R_{\rm Q} = \frac{1}{2}I\omega^2, \tag{2.3}$$

where$I = (2/5)ma^2$ is the moment of inertia, andω is the angular velocity.In this case, the energy conservation law is given by

$$E_{\rm P} = K_{\rm Q} + R_{\rm Q}. \tag{2.4}$$

In our experiments, although we directly measure not the angular velocitybut the speed of the translational motion of the ball at point Q, we can estimate $R_{\rm Q}$. When the ball moves along the rail, it rotates as if its radius is b, as shown in Figure 2 [2]. Therefore,

$$v = b\omega, \tag{2.5}$$

is satisfied. Substituting Eq. (2.5) into Eq. (2.3), we obtain

$$R_{\rm Q} = \frac{2a^2}{5b^2}\cdot\frac{1}{2}mv^2. \tag{2.6}$$

In the simple pendulum experiment, the initial energy will convert into the kinetic energy. However in the inclined rail experiment, we will find that some of the initial energy *seems* to be lost at point Q because it convertsto the rotational kinetic energy$R_{\rm Q}$. Here we define the "loss" of the initial energy as

$$\varepsilon = \frac{E_{\rm P} - K_{\rm Q}}{E_{\rm P}}. \tag{2.7}$$

Theoretical value of the energy loss is calculated by making use of Eq. (2.6), and given by

$$\varepsilon_{\rm th} = \begin{cases} 0 \text{ (pendulum)} \\ \dfrac{2a^2}{2a^2 + 5b^2} \text{ (rail)} \end{cases}. \tag{2.8}$$

Since width of the rail is constant in our experiments, smaller radius gives larger ε. Students will estimate the factor ε for each experiment to find what is the best experiment to confirm the energy conservation law.

Here we describe details of the classroom experiments. This practice was performed as a 90-minute class on 23 January 2018 to students in the first grade of teacher-training course of University.The number of the students are 28, and they made nine groups for the experiments. I just instructed students,before the experiments, to find the most appropriate experiment to confirm the energy conservation law by calculating the energy loss ε from Eq. (2.7). Since the students will be elementary and/or junior high school teacher, I added a condition "to make your future studentsto perform the experiment". Idid not explain about conversion of the initial potential energy to the rotational kinetic energy in order to make the students think about the reason of non-zero ε and find other appropriate experiments.

In each experiment, we used two balls:i) steel ball of $m = 67.5$g,$a = 2.5$cm, and $b = 1.0$cm, ii)plastic ball of$m = 5.2$g,$a = 1.9$cm, and $b = 0.63$cm. We name four experiments as listed in Table1, and show the energy loss $\varepsilon_{\rm th}$calculated from Eq. (2.8). The height h of the starting point P is arbitrary chosen in each group (10cm-25cm). Students measured velocity at point Q three times, and took their average to calculate ε.

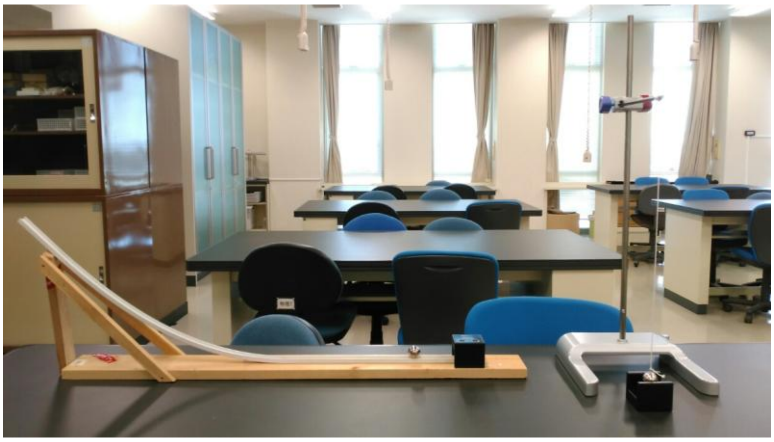

Figure1:Set up of the experiments (left: inclined rail, right:pendulum).

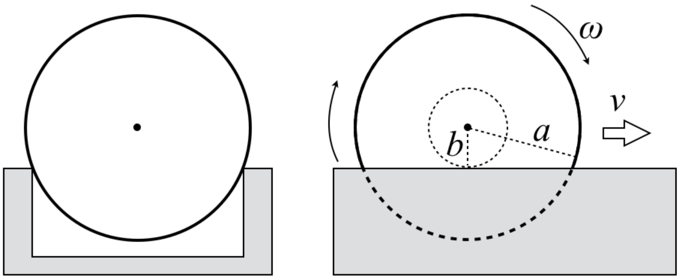

Figure2: The ball rotating on the rail.

	Steel ball	Plastic ball
Inclined rail	A(38.5%)	B(47.7%)
Pendulum	C(0%)	D(0%)

Table1: Four experiments and their energy loss $\varepsilon_{th}$from Eq. (2.8)

III. Results and Discussions

Here we describe results of the classroom experiment.The purpose of this classroom experiment is tomake students i)to find the best experiments for their future students and ii)to think the reason and find other appropriate experiments.

Figure 3 shows the result of the energy loss ε with 3σ error bars for each experiment from data of nine groups. Horizontal redlines indicate theoretical value ε_{th}shown in Table 1.One can see that each experimental value of energy loss is within 3σ deviation from its theoretical value except for Experiment B, which is4.0σ above its theoretical value.In the data of the energy loss of nine groups, none is smaller than its theoretical value. This is becausemore of the initial mechanical energy was lost by other reasons such as air resistance, false of slippless assumption,mistakes of experiment, and so on.

In nine groups,sevengroups choseExperiment C and two chose D as the best experiment. No groupchose Experiment A and B, as expected.In the seven groups who chose Experiment C, the largest experimental value of $\varepsilon$for Experiment C is 5.7% (theoretically it must be 0%). Even in the two groups who chose Experiment D, their results for energy loss of Experiment C is at most 7.0%. Therefore, as an experiment for their future students in junior high school, we can say that they chose correct experiment with sufficient accuracy.

As for Experiment A and B, 14 students considered that the reason of the energy loss is friction and/or air resistance. After giving the explanation of rotational effective to students, they suggestedthe followingexperiments as alternatives (in multiple-answer question. The numbers of students are also given):

- free fall:25,
- frictionless objects without rotations such as mechanical cart, ice, and so on:15,
- pendulum in vacuum:3,
- nearly massless and volumeless object:1.

No students described how to realize the third experiment (pendulum in vacuum), and what object it is for the forth experiment (nearly massless and volumeless object). Although the forth experiment is suggested in order to avoid the effect of rotation, the student did not consider how to calculate the potential energy of a massless object.Despite such problems, students understood that teachers must prepare appropriate experiments of which the effect of rotation can be negligible.

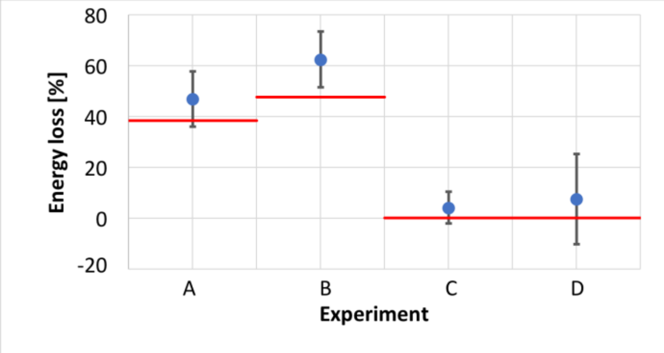

Figure3: Energy loss ε of Eq. (2.7) for each experiment with 3σ error bars.
Horizontal red lines are theoretical valuesε_{th} shown in Table 1.

IV. Conclusions

In this paper, we reportedthe practice of classroom experiments about conservation law of mechanical energyfor students in teacher-training course of University. Since students will give classes of natural science including Physics in near future, it is important to make the students to be able to design experiments, such as energy conservation law.In four experiments, students found the best experiment to confirm the energy conservation lawwith sufficient accuracy. Although many students thought the reason that the inclined rail experiment is not appropriate was friction, not kinetic energy of rotation, after understanding its effect, they suggested and designedalternative experiments to show their future students such as free fall. This practicewill be helpful for future science teachers to design their classes for their future students.

References

[1]. E. Hobart Collins, American Journalof Physics, 12, 44(1994).
[2]. Jaime R. Taylor, Arthur W. Carpenter, and Patrick H. Bunton,The Physics Teacher, 35, 146 (1997).
[3]. M. Bastia, M. Di Gennaro, and V. Picciarelli, Physics Education, 34, 371 (1999).
[4]. Matthew Mears, American Journalof Physics, 83,817 (2015).
[5]. James Wiss and Bernard D. Zak, American Journal of Physics, 41, 1100 (1973).
[6]. Leung Chinn, The Physics Teacher, 17, 385 (1979).
[7]. David G. Willey,The Physics Teacher, 29, 567 (1991).
[8]. Herbert T. Wood, The Physics Teacher, 32, 422 (1994).
[9]. Michael Paesler, The Physics Teacher, 50, 109 (2012).
[10]. Lorenzo G. Rimoldini and Chandralekha Singh, Physical Review Special Topics-Physics Education Research 1, 010102 (2005).
[11]. NaRiKa: http://global.narika.jp/product/others/beespi-v

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