Isochronism of Simple Pendulum

Measurement of pendulum velocity

NaRiKa Corporation

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Galileo's discovery in 16th century

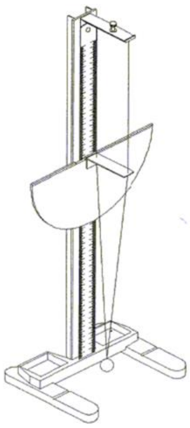
1. Historical Background

Galileo Galilei, later called "Father of science", was born in Tuscany, Italy over 400 years ago. Some anecdotes are told about him when he was a mathematics professor at the University of Pisa as follows.

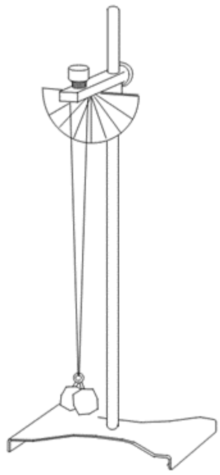
In the latter half of 16th century, Galileo discovered the crucial property that makes pendulums useful as timekeepers, called the isochronism of simple pendulum (pendulum), when watching the swings of the bronze chandelier in the cathedral of Pisa (photo on the right) using his pulse as a timer. The property is that period of pendulum swing is approximately independent of its amplitude or width of the swing. On another occasion, Galileo dropped balls (a bullet and a cannonball) of the same material, but different masses, from the Leaning Tower of Pisa, in the presence of professors from the University of Pisa, to demonstrate that their time of descent was the same and independent of their mass. Based on these two anecdotes, Galileo derived the two laws, by one of which freefall bodies of different masses have the same free-fall duration time and, by the other of which the distance traveled by a free fall body is proportional to the square of the elapsed time. This teachers' guide is intended to verify the Galileo's law of isochronism of pendulum by using Narika's equipment for pendulum experiments.

2. Equipment for pendulum experiments

Shown below is equipment for pendulum experiments manufactured and sold by Narika Corporation as it's representative product for school education in general. Equipment for teachers' demonstration is C15-4474. Equipment for experiments by group of students is C15-4475. Below are examples of experiments and data results using C15-4475.



C15-4474 Equipment for pendulum experiments FP



C15-4475 Pendulum

3. C15-4475 Pendulum set

Regarding demonstration of the law of isochronism of pendulum, it is required to verify the correlation among experimentally obtained values of "length of string", "weight of mass", "amplitude (swing width) of pendulum" and "cycle". To do this inevitably requires to repeat experiment many times to statistically derive the correlation despite time constraint of teachers who normally do not have enough time to collect sufficient data. Because of this background, a lot of teachers desired an apparatus for pendulum experiments with shorter setup time for assembling/adjustment/cleaning-up, as well as, user-friendliness and repeatability for their experiment.

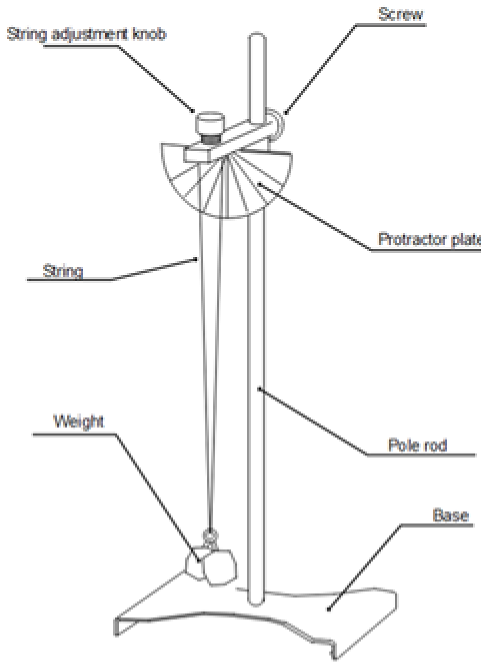
Essential product used in this teachers' guide is Narika's "Pendulum experiment set". It is equipped with the wind-up mechanism for string storage that enables easier adjustment of string's length, and prevention of non-linear swing of weight due to the V-shaped pendulum string. This product was designed in consideration of better space-saving storage and easier string replacement based on teachers' demands.

1. Specification and Contents

1) Pole rod

Material: Brass and nickel chrome plate

Size: ϕ12×440mm (ca)



2) Base

Material:	Steel
Size:	180×140×15mm
Weight:	ca. 480g

3) Protractor plate

Material:	Plastics
Shape:	Semi-circular (10 degrees steps max.120)
Size	ϕ100mm

4) String adjustment knob (system):

String reeling knob

5) Screw:

Screw fitting with rod, M4×8mm

6) Thread

Length:	max. 1m, to be suspended in V-shape

7) Weights

Weight:	10g×10 pieces
Material:	Plastics

2. Preparation for the experiment

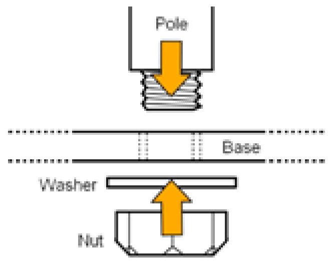
1) Assembling Stand

① Remove the nut and washer from the pole at once.

② Install the pole into the hole in the base.

③ Tighten the pole by the washer and the nut using tools.

④ Before experiment, check that the screw is tightened enough.



2) How to set up Pendulum

① Loose its screw and turn the protractor plate of the pendulum unit to be mounted orthogonally on its rod (see step1).

② Tighten the screw on the rod at the orthogonal position of the protractor plate and the rod (see step2).

③ Protractor plate should be fixed by the screw (see step3).

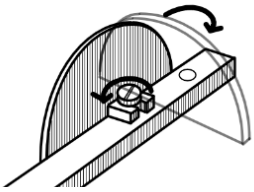
④ Loose the screw at the end of the rod and insert the top of pole (see step4).

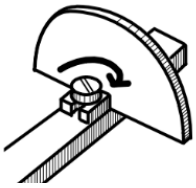
⑤ Tighten the screw at a suitable position (height) for the pendulum experiment (see step5).

⑥ Pull out a string while turning the string adjustment knob anticlockwise by your fingers (see step6).

⑦ 7. Hook a weight on the string.

⑧ 8. Adjust the string to suitable length for the experiment by turning the string adjustment knob clockwise or anticlockwise (see step7).


Step 1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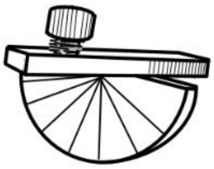
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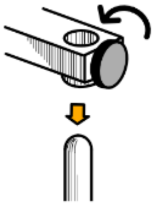
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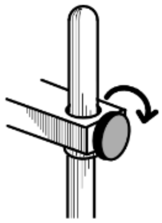
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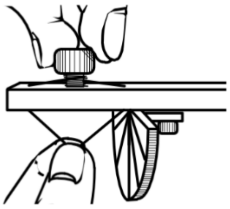
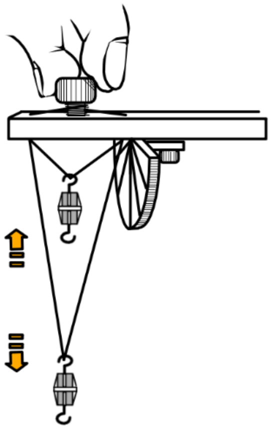
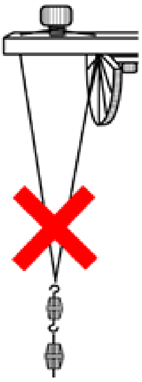

Step 6

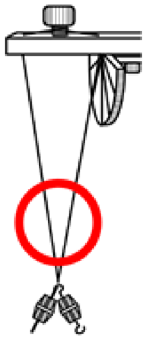

Step 7

3) Caution on Pendulum Apparatus during the experiment

① Position of weights

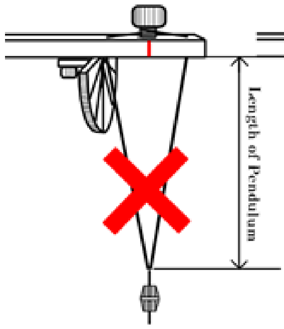
If the weights are hooked as shown in Fig.1, they may cause errors in the experiment. When using several weights in the experiment, hook them as shown in Fig.2 in order to align the center of weights (see Fig.1 & 2).


[Fig.1]

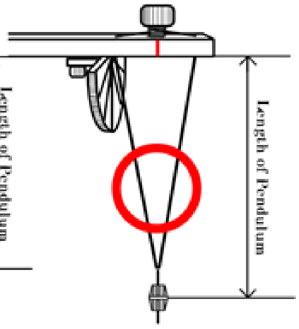

[Fig.2]

② Length of Pendulum (thread length)

Common mistake in measuring the length of pendulum is measuring the distance between the bottom vertex of a triangle, where weight is hooked (V shape), and the bottom surface of the rod (see Fig.3). The correct length of pendulum is from the center of weight to the bottom surface of the rod – red line (see Fig.4). You should use the vertical line distance shown in Fig.4 as the correct length of pendulum.



[Fig.3]



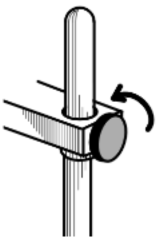
[Fig.4]

4) Storing Pendulum Apparatus

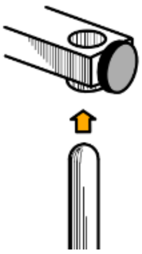
The pendulum apparatus (unit) has storage mode.

① Pull the pendulum unit out from the pole rod (see step 1, 2, 3).

② Turn the Protractor plate by 90 degrees (see step 4, 5).



Step 1



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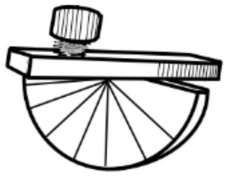

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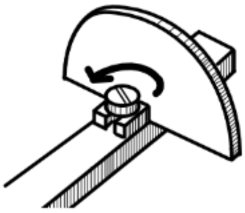

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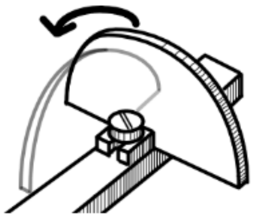


Step 5

5) Maintenance of Pendulum

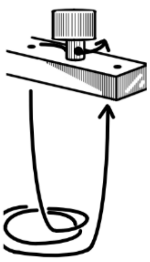
When replacing a thread of pendulum to a new one, follow steps below.

① Remove existing string from the pendulum unit.

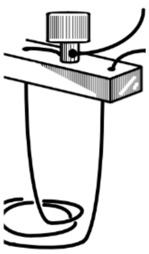
② Insert a new string into 2 holes, one edge on the top of the pendulum unit and the other edge on the string adjustment knob (see step 1 and step 2).

③ Tie both ends of the string (see step 3).

④ Move the tied knot into the hole of the string adjustment knob (see step 4).



Step 1



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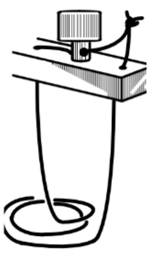
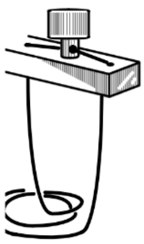


Step 3



Step 4

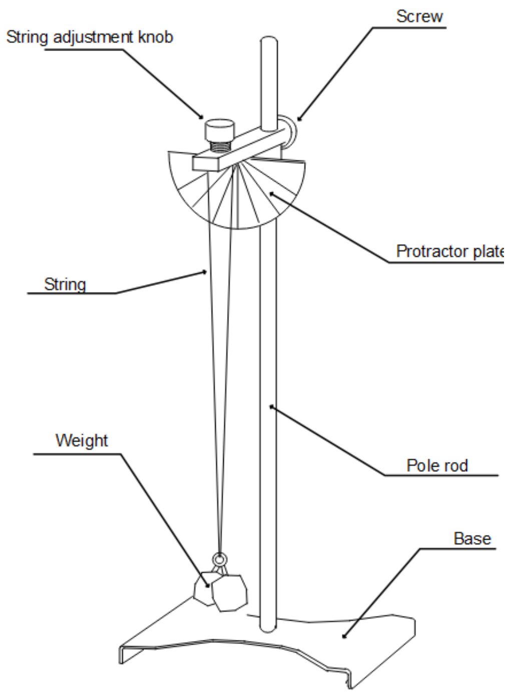
4. Measurement of pendulum velocity

As shown in the preceding experiment, cycle of a pendulum is theoretically determined by the length of the (string of) pendulum almost regardless of mass of the weight and amplitude if less than 30 degrees (If amplitude is more than 30 degrees, amplitude determines the cycle). Then, this can also lead to a hypothesis that velocity of a pendulum is not affected by the mass of the weight. To verify this hypothesis, the correlation between the velocity of weight at the lowest point of the pendulum and the essential values of "[1] pendulum length", "[2] mass of the weight (of the pendulum)" and "[3] amplitude of the pendulum" have to be experimentally examined as shown below.

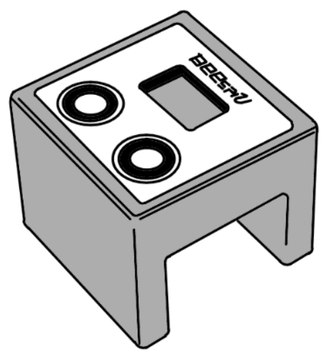
1. Necessary equipment

C15-4475 Pendulum set: 1 (weight and stand included)

S77-1321 BeeSpi v (Portable speed measurement device): 1



Pendulum experiment set

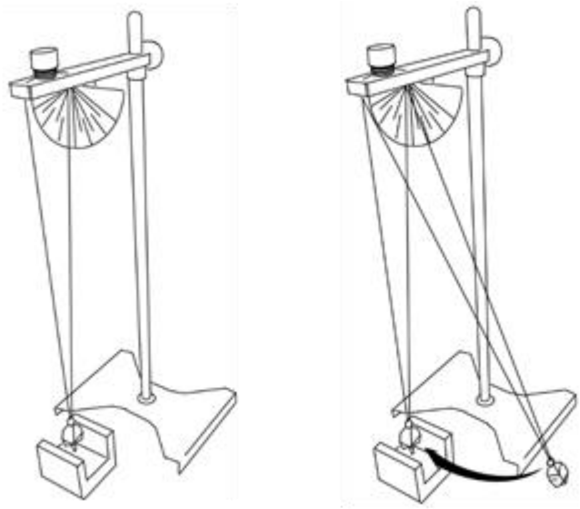


BeeSpi v

2. How to make experiment

Portable speed measurement device, BeeSpi v, is recommended product by Narika Corporation for measuring the velocity of weight at the lowest point of the pendulum. While the combination of photogates and PC has been commonly and traditionally used for speed measurement experiments in schools, BeeSpi v equipped with built-in photosensors and microcomputer can be used for the same purpose without PC. Therefore, the BeeSpi v is perfect product for students' experiments because of the teachers' simple and easy explanation to students.

As shown in the figures on the right hand, start experiment by putting a BeeSpi v upside-down on a table after setting it into the measurement mode to measure the velocity of a weight running through the photogates of the BeeSpi v. Be sure not to trigger measurement of BeeSpi v by putting your finger between the photogates during measurement mode, especially at the moment of measurement.



3. Setup of BeeSpi v

1) Insert two AAA batteries in BeeSpi v after sliding off the battery cover.

2) Check if four numeric characters, "0" (zero), appears on the LCD display. In case of using BeeSpi v with batteries already inserted, you may find nothing appears on the LCD display, which means it is off. If so, turn the power on by pressing "START" or "SELECT" button.

3) Measurement unit appears at the right edge of the LCD display. Unit of "m/s" is selected for every experiment covered in this teachers' guide. To select the measurement unit, press "SELECT" button for more than two seconds to change the unit in order of "m/s" → "m/h" → "cm/s".

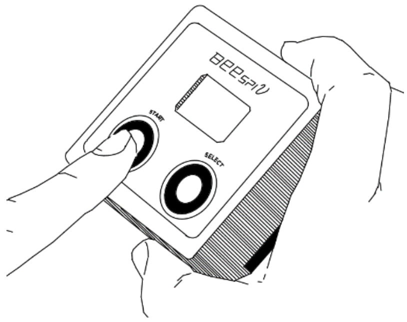
4) Press "START" button to set BeeSpi v into measurement mode after confirming "m/s" unit is appearing on the LCD display.

5) In the measurement mode, BeeSpi v is activated if the selected unit "m/s" is flashing. In this state, speed measurement starts when the first photogate is shielded and ends when the second photogate is shielded by the moving object running through the BeeSpi v.

6) BeeSpi v retains up to five latest measurement results that can be brought up with data number (1~5) at the upper-left of the LCD display by repeatedly pressing "SELECT" button.

SELECT Button:

To activate measurement mode



START Button:

To select unit and retrieve measurement results

4. What factors determine the velocity of pendulum?

Measurement results are shown in Table 1.

Table 1. Result of measurements with different length of strings, mass and amplitudes

Length of string (cm)		50		25		12.5	
Weight (g)		10	20	10	20	10	20
Amplitudes	5°	0.37	0.33	-	-	-	-
	10°	0.57	0.56	0.30	0.31	-	-
	15°	0.77	0.73	0.46	0.44	0.31	0.35
	20°	0.97	0.91	0.59	0.60	0.43	0.39
	25°	1.15	1.06	0.73	0.72	0.57	0.51
	30°	1.29	1.27	0.88	0.89	0.61	0.67
	35°	1.53	1.58	0.99	1.00	0.74	0.75
	40°	1.74	1.79	1.11	1.12	0.86	0.84
	50°	2.04	2.01	1.34	1.42	1.11	1.07
	60°	2.46	2.45	1.60	1.61	1.21	1.19

Unit: m/s

According to Table 1, correlation between velocity of the pendulum and other factors can be summarized as follows.

(1) Velocity of the pendulum gets faster as length of the string gets longer.

(2) Velocity of the pendulum is not affected by mass of the weight.

(3) Velocity of the pendulum gets faster as amplitude of the pendulum gets bigger.

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