Experiment: Dynamic Demonstration Kit

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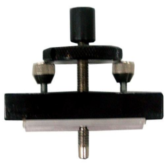
II. Instrument

NO	Accessory	Quantity
1	Track	1
2	Cart	1
3	L-type Mass Hanger	1
4	Mass (10 g)	3
5	Pulley	1
6	Photogate Flag (5 cm)	1
7	Light Plastic Ball (approximately 9 g)	1
8	Heavy Plastic Ball (approximately 12 g)	1
9	End Stop	1
10	Pivot Clamp	4
11	Photogate Bracket	2
12	Bracket for Incline	2
13	Bumper Set	1
14	Bumper with Holder	1
15	Electromagnet and Freefall Adapter	1
16	Steel Ball	1
17	DC Power Supply	1
18	Photogate	2
19	Pedestal	1

20	Adjustable Feet (short)	1
21	Adjustable Feet (long)	2
22	Photogate Bracket on Pedestal	2
23	Support Rod (10 cm)	2
24	Support Rod (3 cm)	2
25	Timer Holder	1
26	Timer	1
27	Storage Case	2
28	Leveling Rod	1
29	Angle Indicator	1
30	Support prop	1
31	One-stand Support Base	1

				
1	**2**	**3**	**4**	**5**
				
6	**7**	**8**	**9**	**10**
				
11	**12**	**13**	**14**	**15**
				
16	**17**	**18**	**19**	**20**

				
21	**22**	**23**	**24**	**25**
				
26	**27**	**28**	**29**	**30**
				
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Experiment 1, Newton's First Law

I. Instrument

NO	Accessory	Quantity
1	Track	1
2	Cart	1
9	End Stop	1
16	Steel Ball	1

II. Purpose

An object maintains the original condition without being influenced by force, which is called the inertia of an object. In real life, when a person jumps up in a moving bus, why does he fall at the original position? As a car begins to move forward, we spontaneously lean backwards, and vise versa; all of these are caused by inertia. In this experiment, a Steel Ball and a moving Cart are used to prove the law.

III. Procedure

1. Release the screw on the Cart, and put the Steel Ball on the Track. See **Figure 1**.

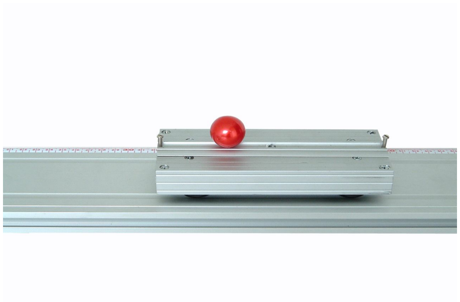

Figure 1

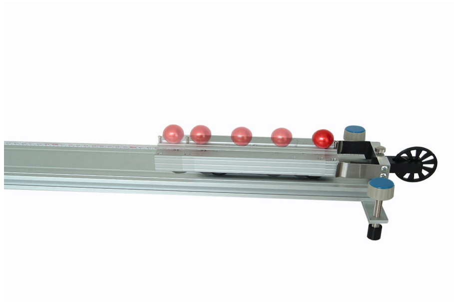

Figure 2

2. Push the Cart by hand. When the Cart starts to move, the Steel Ball and Cart will move to opposite directions; actually the Steel Ball will stop at the original position because of the law of inertia, so does the Cart. The Cart stops after reaching the End Stop, but the Steel Ball still keeps moving due to the law of inertia, which is "an object at rest stays at rest, and an object in motion stays in motion." Please see **Figure 2**.

IV. Discussion

1. In daily life, what phenomenon belongs to Newton's First Law (law of inertia)?

Experiment 2, Newton's Second Law

I. Instrument

NO	Name	Amount
1	Track	1
2	Cart	1
3	L-type Mass Hanger	1
4	Mass (10 g)	3
5	Pulley	1
6	Photogate Flag (5 cm)	1
9	End Stop	1
10	Pivot Clamp	4
11	Photogate Bracket	2
17	DC Power Supply	1
18	Photogate	2
20	Adjustable Feet (short)	1
23	Support Rod (10 cm)	2
26	Timer	1
31	One-stand Support Base	1

II. Theory

The Newton's Second Law indicates that with ignoring friction and air resistance, the acceleration is directly proportional to the net force and inversely proportional to the mass, which can be expressed in equation as follows:

$$F=Ma \qquad (1)$$

In Eq (1), F means net force, M stands for mass of an object, and a is the abbreviation of acceleration of an object.

In this experiment, the Newton's Second Law is validated by performing two kinds of approaches below:

1. The mass of the object is unvaried, change the net force, and observe the relationship between the acceleration and net force.
2. The net force is unaltered, vary the mass of the object, and observe the relationship between the acceleration and the mass of the object.

This experiment can be shown as **Figure 3**. If the gravity of m_2 accelerates the mass of $m_1 + m_2$, the theoretical value of the acceleration will be:

$$a_{th} = \frac{m_2}{m_1 + m_2} g \qquad (2)$$

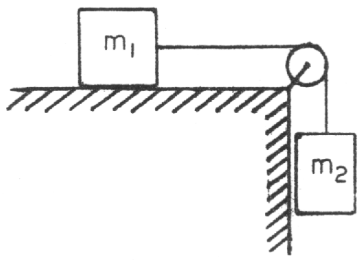

Figure 3

By operating this instrument, the Newton's Second Law is validated with the concept – free fall. If an object is in a linear motion, the acceleration is regular, and then the acceleration must be constant, which is called uniformly acceleration motion as well. This motion is the result of an object being influenced by net force; few tiny different results occur if performing this experiment at the diverse locations on the earth. Under the uniformly acceleration motion, a, the relationship among distance, velocity, and time can be expressed in equation as follows:

$$V_t = V_0 + at \qquad (3)$$

It indicates the relationship between velocity V_t vs time t, this is a linear equation, and the slope of this straight-line is a. As a result of the uniformly acceleration, the average of the velocity within time t can be expressed as $\overline{V} = \frac{(V_t + V_0)}{2}$.

In terms of $\overline{V} = \frac{S}{t}$, we get $S = \overline{V}t = \frac{V_0 + V_t}{2} t \qquad (4)$

From Eqs (3) and (4), we obtain $S = V_0 t + \frac{1}{2} a t^2 \qquad (5)$

Eq (5) is a curved equation, and the slope of the tangent at every point of this curve is the velocity.

$$\Theta\, V_0 = 0$$

$$\therefore S = \frac{1}{2}at^2 \qquad (6)$$

$$\therefore a = \frac{2S}{t^2} \qquad (7)$$

a: the acceleration after calculation

S: the distance between two Photogates

t: the time which the Cart passes through two Photogates

III. Procedure

1. Fasten the Adjustable Feet under the Track, and maintain the level of it; fix the End Stop at the end of the Track, and fasten the Pulley on the stationary base. These are presented in **Figure 4 and 5**.

Figure 4

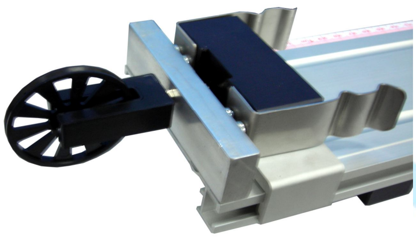

Figure 5

2. In **Figure 6**, mount two Photogates on the Photogate Bracket, and fasten the Pivot Clamp on the side of the Track.

Figure 6

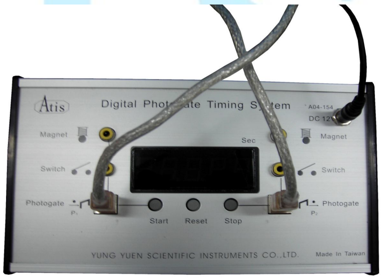

Figure 7

3. Connect the Photogates to the Timer in compliance with the Cart passing the Photogate, and connect the Timer to the DC Power Supply, which is expressed as **Figure 7**.
4. As shown in **Figure 8,** tie one of the extremities of the thin rope on the Cart and the other on the mass hanger, and install the Photogate Flag on the Cart. As mounting the Photogate Flag, maintain the direction of the Photogate Flag and the direction where the Cart is heading.

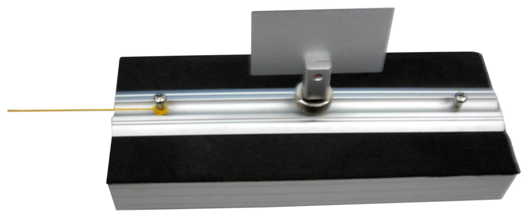

Figure 8

5. The entire instrument after setting up is indicated as **Figure 9**.

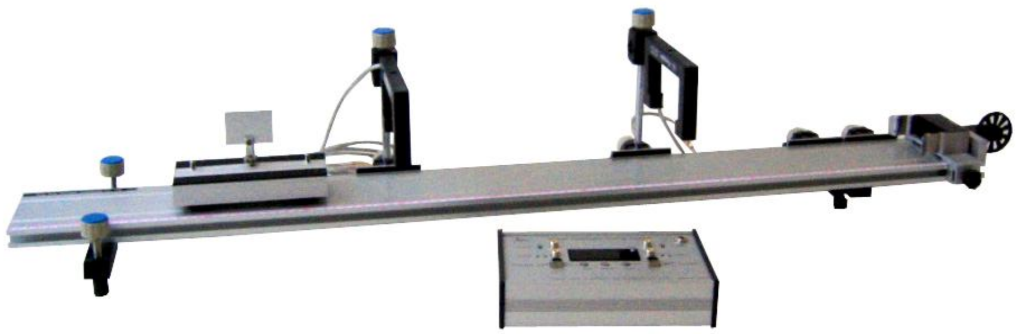

Figure 9

6. Measure the Mass of the Cart and the additional object with a scale.
7. Turn on the Timer. In order to reduce the error of experiment, make the Cart approach as close as possible to the first Photogate before starting to be in motion, and make the Cart glide in acceleration by the falling weight. Note the time displayed on the Timer and the distance between both of the Photogates, calculate the acceleration of the Cart, and repeat this step three times.
8. Add Mass on the mass hanger and repeat step 7.

IV. Discussion

$$a = \frac{2S}{t^2}$$

Mass of Cart M	Additional weight m'	Distance between both of Photogates *S*	Time which the Cart passes through both of Photogates *t*	Theoretical acceleration a (cm/s^2)	Actual acceleration a' (cm/s^2)

a: the acceleration after calculation.

S: the distance between two Photogates.

t: the time which the Cart passes through two Photogates.

1. What will the error be if the Photogate Flag on the Cart is not as close as to the first Photogate?

2. What influences the error in this experiment except question 1?
3. If performing this experiment on the moon, would the result differ from the one on the earth?

Experiment 3, Acceleration down an Inclined

I. Instrument

NO	Accessory	Quantity
1	Track	1
2	Cart	1
4	Mass (10 g)	3
6	Photogate Flag (5 cm)	1
9	End Stop	1
10	Pivot Clamp	4
11	Photogate Bracket	2
12	Bracket for Incline	2
17	DC Power Supply	1
18	Photogate	2
20	Adjustable Feet (short)	1
23	Support Rod (10 cm)	2
26	Timer	1
29	Angle Indicator	1
31	One-stand Support Base	1

II. Theory

The theory of this experiment is quite easy. Assume mass m of an object on an incline without friction, and the inclined angle is θ, which can be displayed in **Figure 10**. The motion of this object depends on the factor F of the gravitational acceleration mg along the incline. The amount of F is:

$$F = m\ g\ sin \qquad (1)$$

$$a = g \times sin\theta \qquad (2)$$

$$sin\theta = \frac{h}{s} \qquad (3)$$

The *h* and *s* indicate the height and length of the incline.

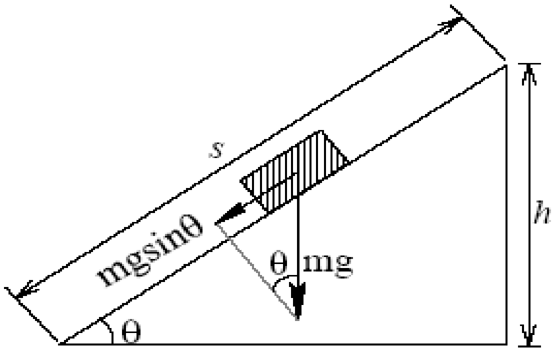

Figure 10

III. Procedure

1. The approach to install this instrument is approximately similar to the one for the Newton's Second Law. The difference between them is that two extra components, the Bracket for Incline and Angle Indicator need to be mounted, which is presented in **Figure 11 and 12**.

Figure 11

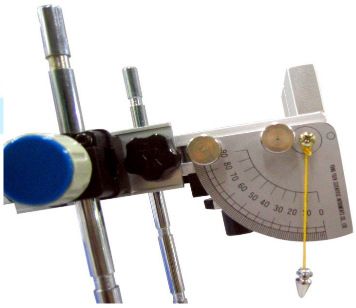

Figure 12

2. The entire instrument after setting up is displayed as **Figure 13**.

Figure 13

3. Adjust the position of the Track which is fastened on incline and note the angle. The θ in Eq (2) is the angle. However, when installing the Angle Indicator, it is necessary to confirm that the upper edge of the Angle Indicator must be parallel to the track, and then tighten the screws. That way, the angle after measuring will be accurate. If more inclined angle needs to be performed, just move the Bracket for Incline to the middle or lock the Pivot Clamp in the higher latch on the Bracket for Incline.
4. Turn on the Timer. In order to reduce the error of experiment, make the cart be as close as possible

to the first Photogate before starting to be in motion. Note the time displayed on the Timer and the distance between both of the Photogates, calculate the acceleration of the Cart, and repeat this step three times.

IV. Discussion

$$a = g \times sin\theta$$

$$\therefore a' = \frac{2S}{t^2}$$

Inclined angle θ	Distance between both of Photogates S	Time which the Cart passes through both of Photogates ***t***	Theoretical acceleration a (cm/s^2)	Actual acceleration a' (cm/s^2)

a: Theoretical acceleration
a': Actual acceleration
S: Distance between both of Photogates
t: Time which the cart passes through both of Photogates

1. Try to increase the mass of the Cart and observe whether or not it is related to this experiment.

Experiment 4, Free Fall Motion

I. Instrument

NO	Name	Amount
7	Light Plastic Ball (approximately 9 g)	1
8	Heavy Plastic Ball (approximately 12 g)	1
15	Electromagnet and Freefall Adapter	1
16	Steel Ball	1
17	DC Power Supply	1
18	Photogate	2
19	Pedestal	1
21	Adjustable Feet (long)	2
22	Photogate Bracket on Pedestal	2
24	Support Rod (3 cm)	2
25	Timer Holder	1
26	Timer	1
27	Storage Case	2

28	Leveling Rod	1
30	One-stand Support Base	1

II. Principle

The average velocity of an object in motion can be defined the ratio of the distance *S* which it moves to and the time *t* which it takes.

$$\overline{V} = \frac{S}{t} \qquad (1)$$

This is the average velocity during this period of time. The instantaneous velocity is the ratio when the time is approaching the limit of zero, or it can be expressed with a limit symbol as follows:

$$V = \lim_{\Delta t \to 0} \frac{\Delta S}{\Delta t} \qquad (2)$$

ΔS is the increasing amount of distance of an object within the time Δt. The curve in **Figure 14** indicates the relationship between the distance and time of Free Fall; apparently the instantaneous velocity *t* is the slope of the tangent at that moment of this curve (Eq (2) is the definition of the slope). If an object is in motion at the same velocity, the slope must be constant, and this line must be a straight line. For Free Fall, evidently the connection between distance and time is not a straight-line because velocity always accelerates with increasing time. When velocity of an object changes, it is called an acceleration motion, and we define this acceleration as a variation of velocity within time *t*, which is as follows:

$$\overline{a} = \frac{V_t - V_0}{t} \qquad (3)$$

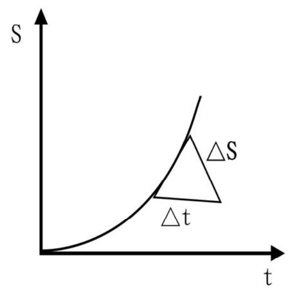

Figure 14

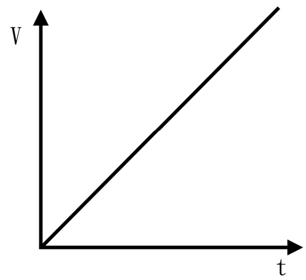

Figure 15

Within the time *t*, apparently a is the average acceleration from V_0 to V_t. The unit of acceleration is velocity divided by time, so in CGS system the unit of acceleration is centimeter per square second.

If an object is in a linear motion, the alteration of velocity is regular, then the acceleration must be constant, and this motion is called uniformly acceleration motion as well. This motion is the outcome of an object being influenced by force, and Free Fall is the most common example. The acceleration g is called gravitational acceleration, which is approximately 980 centimeters per square second, and there are tiny differences at diverse locations on the earth. Under equivalent acceleration g, the relationship among distance, velocity and time from the definition of Eq (3), the equation can be written as:

$$V_t = V_0 + gt \qquad (4)$$

It points out the relationship between velocity V_t and time *t* – a linear equation, which means that the slope of this straight-line is g. Due to the equivalent acceleration, the average velocity within the time *t* can be expressed as $V = \frac{(V_t + V_0)}{2}$. From Eq (1), we get:

$$S = \overline{V}t = \frac{V_1 + V_2}{2}t \qquad (5)$$

Substituting Eqs (4) into (5), the equation becomes:

$$S = V_0 t + \frac{1}{2}gt^2 \qquad (6)$$

Eq (6) is a curved equation, and the slope of the tangent at every point of this curve is the velocity. When the beginning velocity is $V_0 = 0$, it is Free Fall. **Figure 15** is a relationship of Free Fall between velocity and time. It can be expressed below:

$$S = \frac{1}{2}gt^2 \qquad (7)$$

$$\therefore g = \frac{2S}{t^2} \qquad (8)$$

S is the distance between the ball and the Photogate A; *t* is during the time from the ball falling off to pass through the Photogate A.

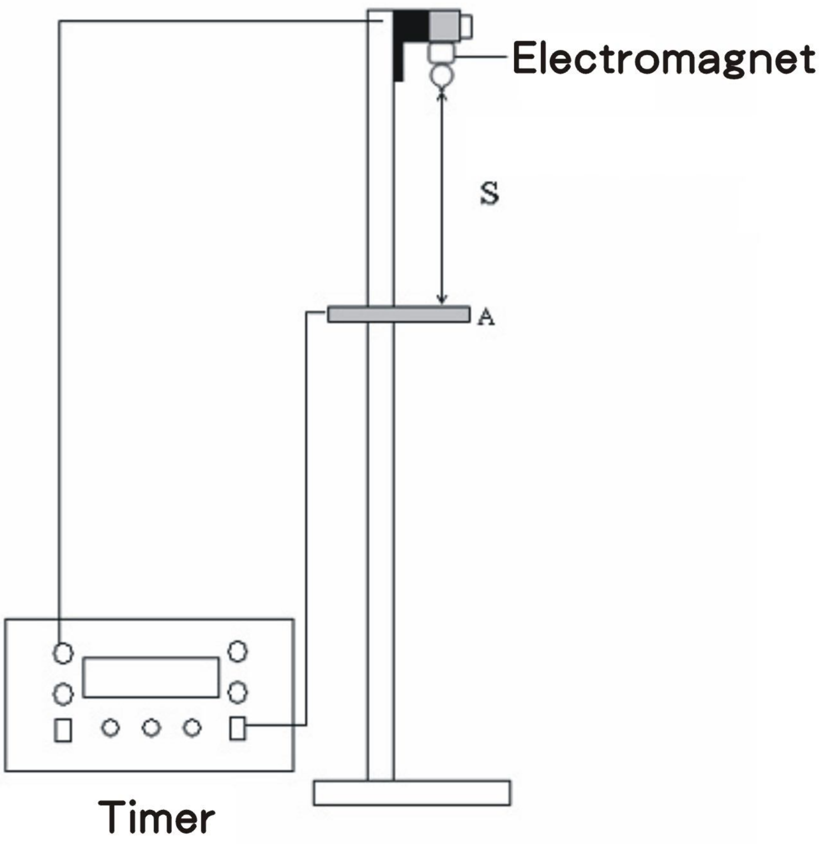

Figure16

When the beginning velocity $V_0 \neq 0$, an object falls off, passes through point A and reaches B and B'. The distance between A and B is S_1, and the time which the object takes is t_1; the distance between and A and B' is S_2, and the time which the object takes is t_2, so

$$S_1 = V_1 t_1 + \frac{1}{2} g t_1^2 \qquad (9)$$

$$S_2 = V_2 t_2 + \frac{1}{2} g t_2^2 \qquad (10)$$

From Eqs (9) and (10), we obtain

$$g = \frac{2(S_2 t_1 - S_1 t_2)}{t_1 t_2 (t_2 - t_1)} \qquad (11)$$

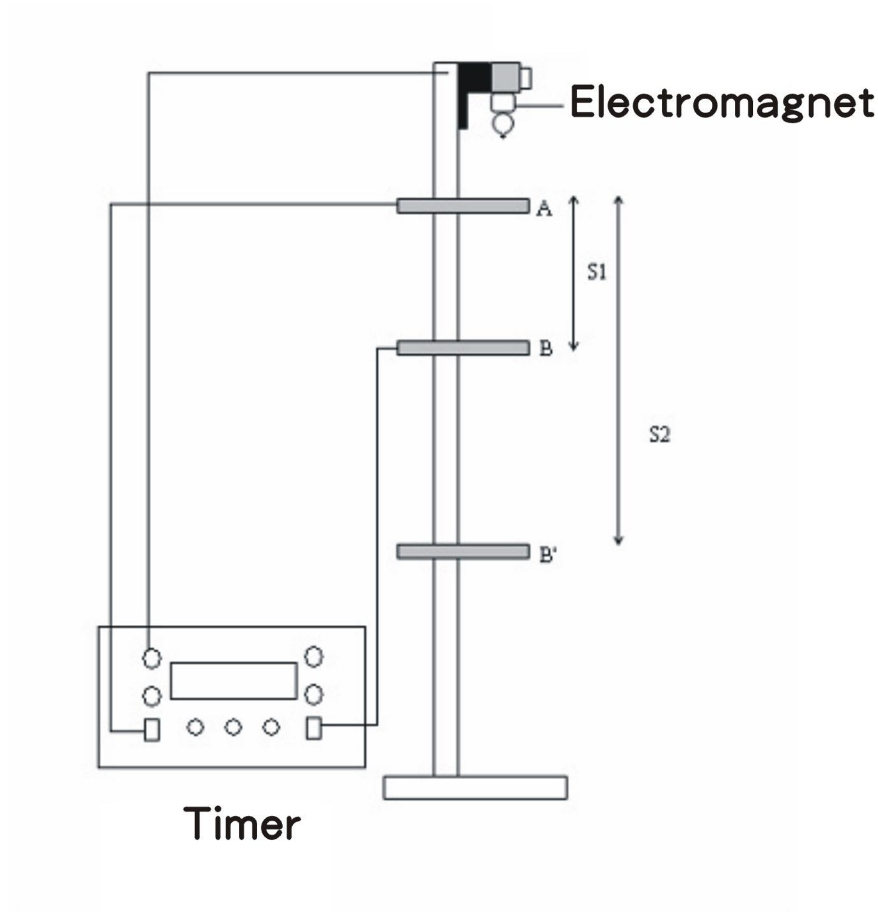

Figure 17

S_1 is the distance from the Photogate A to B.

S_2 is the distance from the Photogate A to B'

t_1 is the time from the Photogate A to B.

t_2 is the time from the Photogate A to B'.

III. Procedure

Figure 18

1. The experiment kit is displayed as **Figure 18**.
2. Use the Leveling Rod and the plumb line which is attached to magnet to observe whether or not the ball is able to pass through all of the Photogates precisely. If not, adjust the Adjustable Feet to the horizontal.
3. If the beginning velocity in this experiment is zero, the approach to connect the Photogate and Timer is expressed as **Figure 16 and 19**.
4. The magnet is magnetized without pressing the switch, and it is capable of attracting the ball; if once pressing the switch, the magnet will be demagnetized, and the ball falls off right away.
5. Firstly set the distance from the Steel Ball to the Photogate and note it down. Have the Steel ball attracted on the Magnet and reset the Timer (press the Reset button). After reset, press the Start button on the Timer, the Steel Ball falls off and passes through the Photogate, and the Timer will display the time which the Steel ball takes from starting to fall off to pass through the Photogate A, which can be shown as **Figure 20**. The time is the t in Eqs (7) and (8). Substitute S and t into *the* equation, and we are able to obtain the acceleration and gravitational acceleration g and compare them.

Figure 19

Figure 20

Figure 21

Figure 22

6. If the beginning velocity in this experiment is not zero, the approach to connect the Photogate and Timer is displayed as **Figure 17 and 21**. The Photogate B' is the position after the Photogate B is moved, and plug the Photogate A and B into the plug P1 and P2 on the Timer which is demonstrated in **Figure 21**. Have the Steel Ball attracted on the magnet and reset the Timer (press the Reset button). Press Start and the Steel Ball falls off. At the first time note down the time which the Steel Ball takes to fall off from the Photogate A to Photogate B as **Figure 22**. After that, move the Photogate B to B', and measure the time again which the Steel Ball takes to fall off from the Photogate A to Photogate B'. Put S_1, S_2, t_1, t_2 in Eq (11) and calculate the gravitational acceleration g.
7. It is available to change the distance between photogates and repeat the procedure of the experiment to prove the gravitational acceleration g.

IV. Discussion

The beginning velocity is not zero.

$$g = \frac{2(S_2 t_1 - S_1 t_2)}{t_1 t_2 (t_2 - t_1)}$$

Light plastic ball

	1st experiment	2nd experiment	3rd experiment
Reading t_1 from Photogate A to B (s)			
Reading t_2 from Photogate A to B' (s)			
Distance S_1 from Photogate A to B (m)			
Distance S_2 from Photogate A to B' (m)			
Gravitational acceleration g (m/s^2)			
Theoretical gravitational acceleration g (m/s^2)	9.78		
Percentage of error (%)			

Heavy plastic ball

	1st experiment	2nd experiment	3rd experiment
Reading t_1 from Photogate A to B (s)			
Reading t_2 from Photogate A to B' (s)			
Distance S_1 from Photogate A to B (m)			
Distance S_2 from Photogate A to B' (m)			

Gravitational acceleration g (m/s^2)			
Theoretical gravitational acceleration g (m/s^2)	9.78		
Percentage of error (%)			

Metal ball

	1st experiment	2nd experiment	3rd experiment
Reading t_1 from Photogate A to B (s)			
Reading t_2 from Photogate A to B' (s)			
Distance S_1 from Photogate A to B (m)			
Distance S_2 from Photogate A to B' (m)			
Gravitational acceleration g (m/s^2)			
Theoretical gravitational acceleration g (m/s^2)	9.78		
Percentage of error (%)			

S_1 is the distance from the Photogate A to B.

S_2 is the distance from the Photogate A to B'

t_1 is the time from the Photogate A to B.

t_2 is the time from the Photogate A to B'.

The beginning velocity is zero.

$$g = \frac{2S}{t^2}$$

Light plastic ball

	1st experiment	2nd experiment	3rd experiment
Reading t of Photogate A (s)			
Distance S from Steel Ball to Photogate A (m)			
Gravitational acceleration g (m/s^2)			
Theoretical gravitational acceleration g (m/s^2)	9.78		
Percentage of error (%)			

Heavy plastic ball

	1st experiment	2nd experiment	3rd experiment
Reading t of the Photogate A (s)			
Distance S from Steel Ball and Photogate A (m)			
Gravitational acceleration g (m/s^2)			
Theoretical gravitational acceleration g (m/s^2)	9.78		
Percentage of error (%)			

Metal ball

	1st experiment	2nd experiment	3rd experiment

Reading *t* of the Photogate A (s)			
Distance S from Steel ball and Photogate A (m)			
Gravitational acceleration g (m/s^2)			
Theoretical gravitational acceleration g (m/s^2)	9.78		
Percentage of error (%)			

V. Questions and Discussions

1. Do different weights of balls influence the gravitational acceleration g?