Experiment: Free Fall Experiment (steel ball)

Purpose

Use free fall motion to measure the value of gravitational acceleration. The method we adopt in this experiment is to measure the time and distance that a falling steel ball takes to pass photogates. Use the time and distance to calculate the corresponding value of gravitational acceleration

Theory

We can use direct and indirect measurements to measure gravitational acceleration.

In Kinematics,

$$V = V_0 + at \qquad (1)$$

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

$$V^2 = V_0^2 + 2aS \qquad (3)$$

From equation (1), if the initial speed is zero, we can obtain the value of g (suppose it is equal to a in the equation) from the following equation.

$$g = \frac{2S}{t^2} \qquad (4)$$

This is the equation of direct measurement.

We can obtain the equation of indirect measurement from the experiment.

$$S_0 = V_i t_0 + \frac{1}{2} g t_0^2 \qquad (5)$$

$$S_1 = V_i t_1 + \frac{1}{2} g t_1^2 \qquad (6)$$

After the calculation of equation (5) & (6), we can obtain

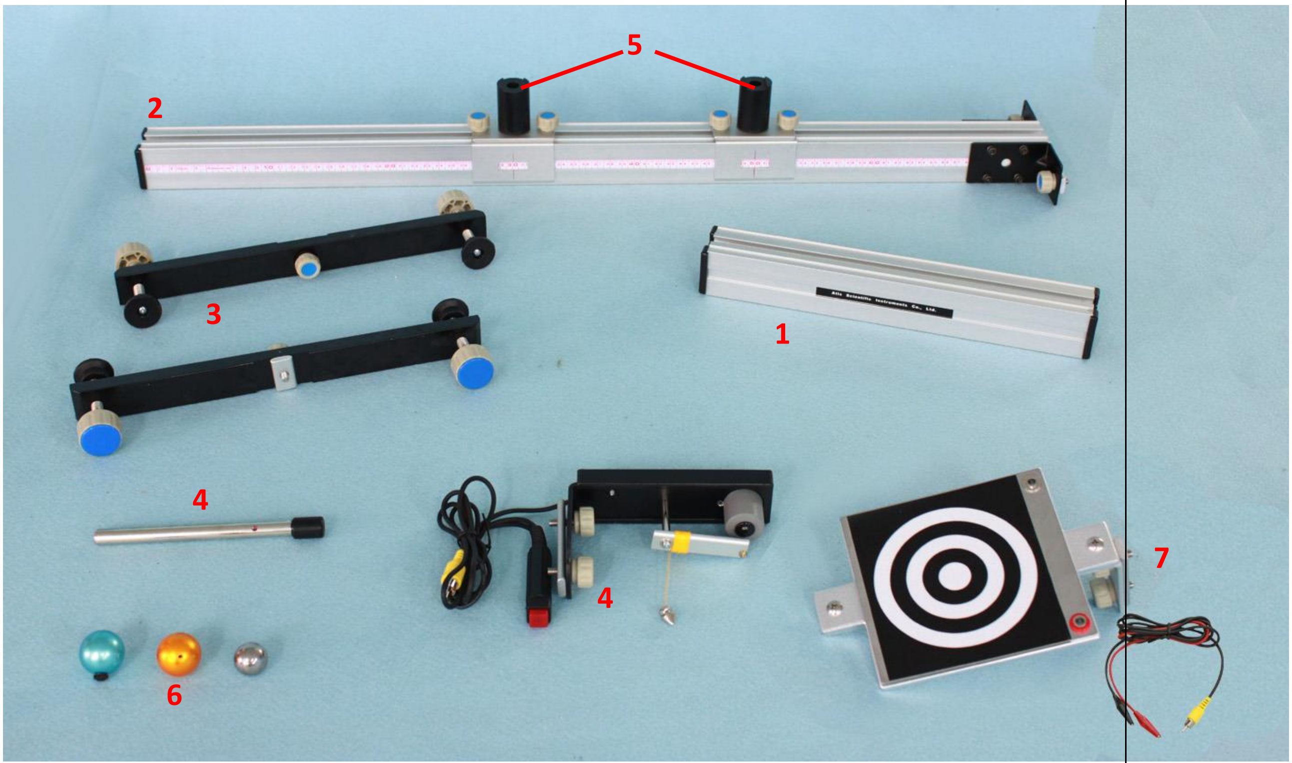
$$g = \frac{2(S_1 t_0 - S_0 t_1)}{t_0 t_1 (t_1 - t_0)} \qquad (7)$$

This is the equation we use to calculate the indirect measurement of g.

Instruments

Instrument list					
No.	**Accessory**	**Qty**	**No.**	**Accessory**	**Qty**
1.	Aluminum track	**1**	**2.**	Track support rod (Attachment: L-shaped movable feet ×2)	**1**
3.	Two-point adjustable feet	**2**	**4.**	Movable electromagnet (Attachment: Plumber regulator)	**1**
5.	Movable photogate indicator base	**2**	**6.**	Ball	**3**
7.	Electronic target (Attachment: Single-junction wire)	**1**	**8.**	Photogate (B)*2 (Attachment: Iron rod)	Additional purchase
9.	Digital photogate timing system (E01-111A-Y01) (Attachment: Power supply 12VDC)	Additional purchase			

Pictures of Instruments



Digital Photogate Timing System
(E01-111A-Y01)

Photogate (B)

Operation of Digital Photogate Timing System (E01-111A-Y01)

Magnet

Switch

Power：DC 12V

Photogate

Power	DC 12V
Start	Start timing or continue timing when we cut off electromagnet power.
Reset	Reset the timing to zero or re-energized the electromagnet
Stop	Stop timing.
Magnet	Generate the magnetic of electromagnet. Remove the wire when not using the electromagnet so the electromagnet will not be overheated. (When the electromagnet is energized, the temperature of it will be high so the device has a protection function. It will automatically cut of power for 60 seconds to protect the device and prevent people from burning.)
Left switch	When the switch is on, the circuit is a normal loop. When the ball hits the target, the spring on the target will interfere with the circuit and the circuit will become a short circuit. It will then trigger the “Start” function. The timer will start timing or continue timing.
Right switch:	When the switch is on, the circuit is a normal loop. When the ball hits the target, the spring on the target will interfere with the circuit and the circuit will become a short circuit. It will then trigger the “Stop” function and the timer will stop timing.
Left photogate	The photogate is switch on when it is connected to the power supply. When the ball passes the photogate, the ball interferes with the photogate and will then trigger the “Start” function. The timer will start timing or continue timing.
Right photogate	The photogate is switch on when it is connected to the power supply. When the ball passes the photogate, the ball interferes with the photogate and will then trigger the ” Stop” function. The timer will stop timing.

Procedure

1. The experimental setup is shown in **Figure 4-1**. Use the adjustable feet to adjust the level. The following is adjusted methods.

   a. Insert four screws to the base. Use screws to adjust the level of the base.

   b. Hang the plumb line (with mass) until it meets the horizontal correction rod. Adjust screws so the mass can meet the hollow point on the horizontal correction rod.

   c. Roll the plumb line and finish the level adjustment.

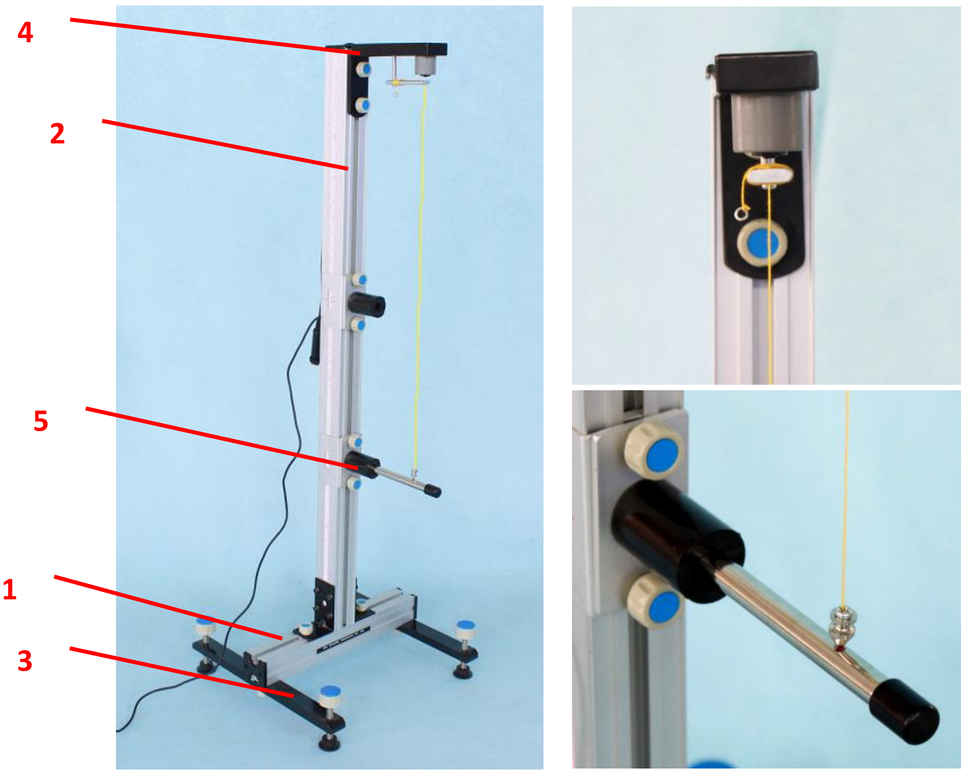


Figure 4-1

2. The setup of direct measurement is shown in **Figure 4-2** and **Figure 4-3**. Use experiment recording sheet 5-1 to record and calculate experimental results.

   a. Set up and record the distance S from the falling point to the photogate. Attract the ball with electromagnet and reset the digital photogate timing system to zero (press “Reset” button).

b. Press “Start” button on the digital photogate timing system. When the ball passes photogate A, the timing system will present the time that the ball takes from falling point to photogate A. The time we measured is t in the equation. Calculate the acceleration by substituting S and t into the equation. Compare the acceleration and gravitational acceleration.

When initial speed $V_0 = 0$, $g = \frac{2S}{t^2}$ 。

(S is the distance from falling point to photogate A. t is the time the ball takes from falling point to photogate A.)

Figure 4-2 Experimental setup

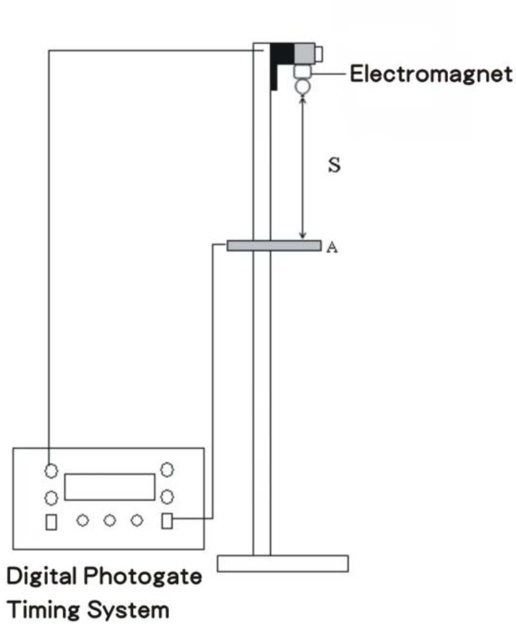


Figure 4-3

3. As shown in **Figure 4-5**, the setup of the experiment is much easeir for teacher to operate. The steel ball will hit the targer directly. Teachers can skip the level correction step. (S is the distance from falling point to target. t is the time that the ball takes from falling point to target.)

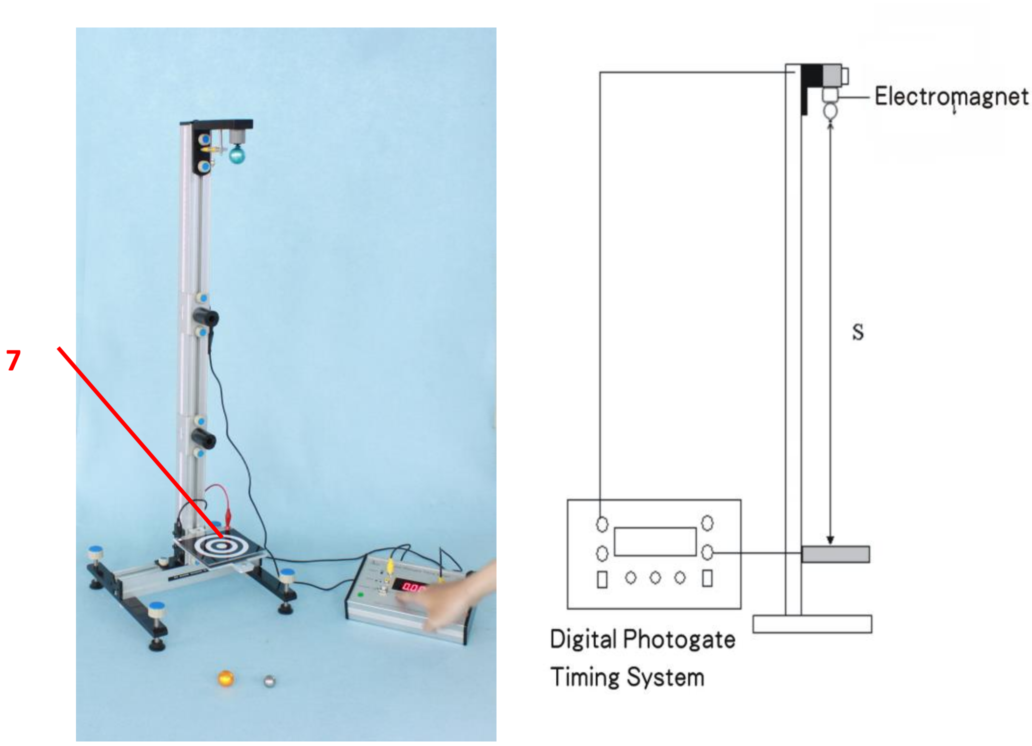


Figure 4-5 Experimental setup

4. The experimental setup of indirect measurement is shown in **Figure 4-6**. Use experiment recording sheet 5-2 to record and calculate experimental results.

The initial speed of an object is not zero ($V_0 \neq 0$).When the object falls and passes through point A to reach point B and B', distances from point A to point B and from point A to point B' are S_1 and S_2. The time from point A to point B and from point A to point B' are t_1 and t_2. Their relationship can be expressed as

$$S_1 = V_1 t_1 + \frac{1}{2} g t_1^2$$

$$S_2 = V_2 t_2 + \frac{1}{2} g t_2^2$$

From above equations, we can obtain

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

S_1 is the distance from the photogate A to photogate B.
S_2 is the distance from the photogate A to photogate B'
t_1 is the time from the photogate A to photogate B.
t_2 is the time from the photogate A to photogate B'.

a. Connect photogate A and photogate B respectively to the left and right photogates on the digital photogate timing system, as shown in **Figure 4-7**.

b. Set up and record the distance $\mathbf{S_1}$ from photogate A to photogate B. Attract the ball on the electromagnet and reset the digital photogate timing system to zero (press "Reset" button).

c. There is a button on the electromagnet, as shown in **Figure 4-6**. If the button is not pressed, the electromagnet can attract the falling ball. If the button is pressed, the electromagnet is not engerized so the ball falls down. When the timer is reset, press the button on the electromagnet. The timer will record the time that the ball takes to pass photogate AB. The time we measured is $\mathbf{t_1}$ in the equation.

d. As shown in **Figure 4-7**, photogate B' is the position after photogate B is moved. The distance of photogate AB' is $\mathbf{S_2}$. Repeat b and c on procedure 4. Record the time that the ball takes to pass photogate A and B'. The measured time is $\mathbf{t_2}$. Calculate the gravitational acceleration g.

Figure 4-6 Experimental setup

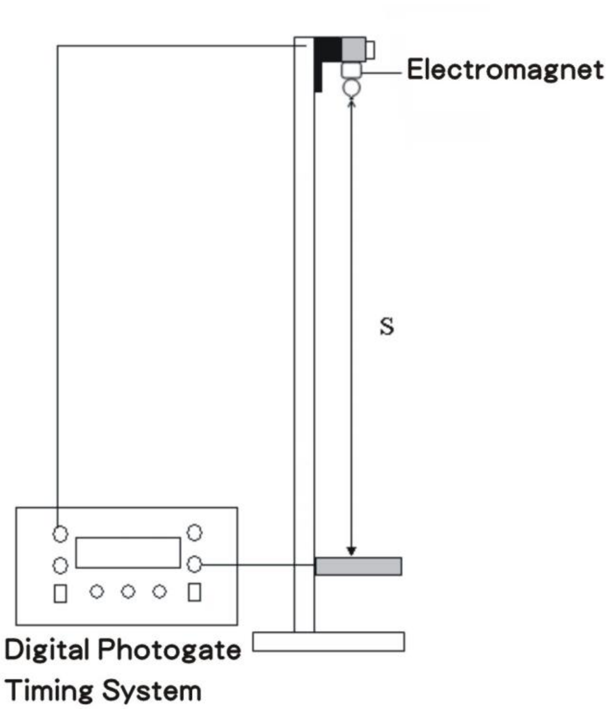
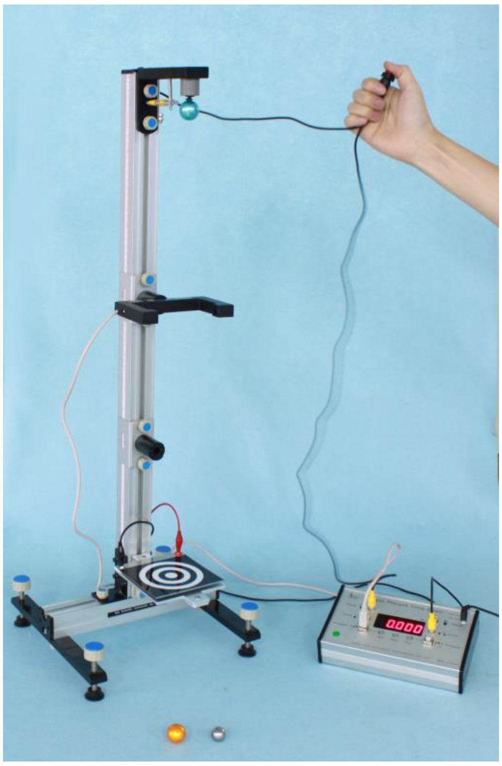


Figure 4-7

5. For teaching purpose, teachers can change photogate B into electronic target, as shown in **Figure 4-8**.



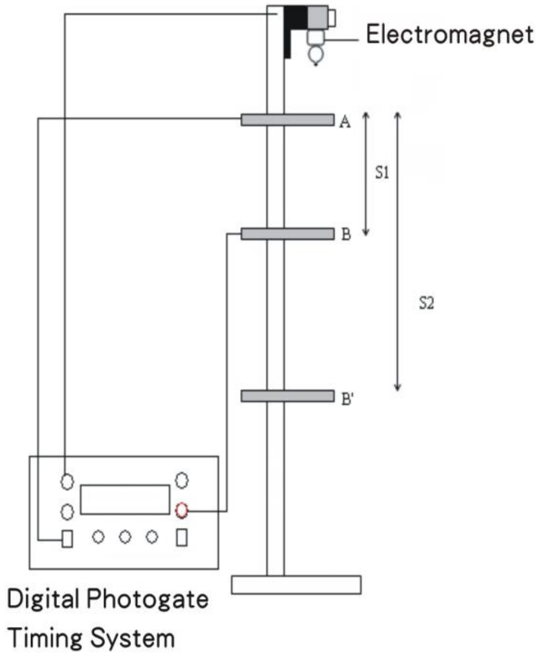


Figure 4-8

Experimental records

Experiment recording sheet 5-1			
Recorder：			Y ____ M ___ D ___
Metal ball	1st experiment	2nd experiment	3rd experiment
Reading t on photogate A (s)			
Distance S from falling point to photogate A (m)			
Calculated gravitational acceleration $g(m/s^2)$			
Theoretical gravitational acceleration $g(m/s^2)$			
Error in percentage (%)			

Heavy plastic ball	1st experiment	2nd experiment	3rd experiment
Reading t on photogate A (s)			
Distance S from falling point to photogate A (m)			
Calculated gravitational acceleration $g(m/s^2)$			
Theoretical gravitational acceleration $g(m/s^2)$			
Error in percentage (%)			

Light plastic ball	1^{st} experiment	2^{nd} experiment	3^{rd} experiment
Reading t on photogate A (s)			
Distance S between falling point to photogate A (m)			
Calculated gravitational acceleration g(m/s^2)			
Theoretical gravitational acceleration g(m/s^2)			
Error in percentage (%)			

Experiment recording sheet 5-2			
Recorder：			Y____M ___D___
Metal ball	1st experiment	2nd experiment	3rd experiment
Reading t1 of photogate A-B (s)			
Reading t2 of photogate A-B' (s)			
Distance S1 from photogate A to photogate B (m)			
Distance S2 from photogate A to photogate B' (m)			
Calculated gravitational acceleration g(m/s²)			
Theoretical gravitational acceleration g(m/s²)			
Error in percentage (%)			

Heavy plastic ball	1st experiment	2nd experiment	3rd experiment
Reading t1 of photogate A to photogate B (s)			
Reading t2 of photogate A to photogate B' (s)			
Distance S1 from photogate A to photogate B (m)			
Distance S2 from photogate A to photogate B' (m)			
Calculated gravitational acceleration $g(m/s^2)$			
Theoretical gravitational acceleration $g(m/s^2)$			
Error in percentage (%)			

Light plastic ball	1^{st} experiment	2^{nd} experiment	3^{rd} experiment
Reading t1 of photogate A to photogate B (s)			
Reading t2 of photogate A to photogate B' (s)			
Distance S1 from photogate A to photogate B (m)			
Distance S2 of photogate A to photogate B' (m)			
Calculated gravitational acceleration g(m/s^2)			
Theoretical gravitational acceleration g(m/s^2)			
Error in percentage (%)			

Questions and discussions

Q1: Discuss the difference between calculated and theoretical values. What are causes of theses errors?

Q2. If we change the mass of ball, will it influence gravitational acceleration g?

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