Lab Report: Investigating how the falling distance affects the speed of an object

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1 Introduction

We have learned in physics that any falling object near earth has an acceleration of free fall g, whose value is about $9.8ms^{-2}$. This experiment is designed to testify that theory.

In this experiment, **falling distance** refers to the distance the object has travelled since it is released freely, provided no external force other than gravitational force. **Speed** is the rate of change of position, as is defined in physics.

Research question: **What is the relationship between the falling distance and the speed of an object that had been released freely and has fallen by that distance.**

2 Background Knowledge

People have not developed a systematic theory to explain the free fall until the 17th century. In ancient Greece, Aristotle proposed that the speed of a falling body would be proportional to its weight. That theory was widely accepted. Some objection was raised but it was not until Galileo dropped two objects of unequal mass from the Leaning Tower of Pisa that Aristotle's theory was completely proven wrong. It takes hundreds of years before people accept the new theory. Later, Newton discovered the Newton's Law of Motion, using mathematical way to fully explain the pheonomenon. In 1807, Thomas Young invented the concept of energy. That concept, although derived from Newton's Laws, provided a more simple explanation of the acceleration of free fall.

3 Hypothesis and Reasoning

If the release height is higher, the speed will be faster.

According to the conservation of energy, the gravitational potential energy released should be transfromed mainly into the kinetic energy of the object. That is to say,

$$mgh = \frac{1}{2}mv^2$$

From which we can easily get

$$v^2 = 2gh$$

indicating that v^2, the square of the falling speed should be directly proportional to h, the height. Since the density of the object is quite high, the effect of air resistance is considered negeligible.

4 Experiment design

4.1 Variables

- Independent Variable: Height $h(30cm, 50cm, 70cm, 90cm, 110cm.$ measured by a metre rule)
- Dependent Variable: The time needed for the object to pass the photogate.
- Controlled Variables: The size, mass, material of the object, the temperature and humidity of the environment, etc. They are listed in Table 1.

4.2 Materials

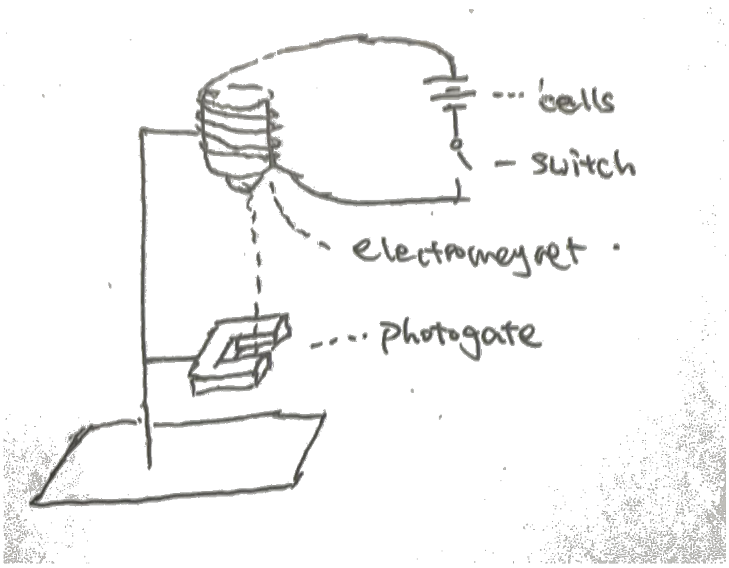
- 2 × iron stand
- 1 × plumb line (about 120 cm long)
- 1 × metal ball (diametre $d \approx 2cm$)
- 1 × photogate
- 1 × electromagnet
- 1 × meter rule

Table 1: Controlled Variables

Controlled Variable	Specific Control Variable Value	Reason to control	Method to control
Size and shape of the object	Sphere, diametre $= 1.82 \pm 0.005cm$	Might affect the time taken to completely pass through the photogate	Use the same object
Temperature	Local temperature. $31^oC \pm 1^oC$	Might affect the air resistance.	Complete the experiment during a short time period
Altitude	Local elevation. Less than $150m$	Might affect the gravitational acceleration.	Complete the experiment in one place

- 1 × soft cushion
- 1 × vernier caliper

4.3 Set up diagram



4.4 Method

1. Use the vernier caliper to obtain the diametre of the metal ball, d.
2. Attach the photogate to the lower iron stand.
3. Attach the electromagnet to the higher iron stand.
4. Adjust the iron stands to make the height difference to be $h = 30cm$.
5. Close the circuit of the electromagnet. Attach the metal ball to it.
6. Break the circuit and take down the reading t_1 on the photogate.
7. Repeat Step 6 twice to take down t_2 and t_3.
8. Repeat Steps 27 with $h = 50cm, 70cm, 90cm, 110cm$.

4.5 Risk Assessment

This experiment is relatively safe with little potential hazard. It is still needed to pay attention to his feet's position to avoid being hit by the ball, though.

5 Results

5.1 Raw data

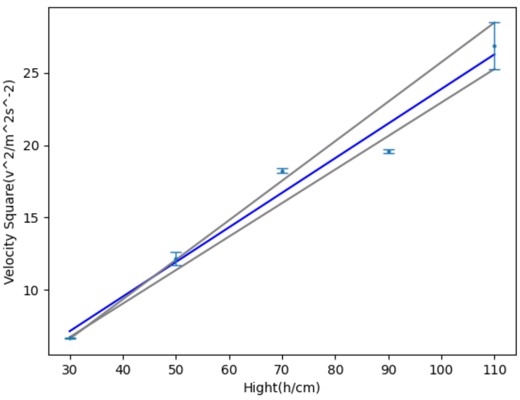
Table 2: Raw Data

Experiment	Height(h)/cm	Time to pass photo gate(t)/ms		
		Trial 1	Trial 2	Trial 3
1	30 ± 0.05	7.00	7.07	7.09
2	50 ± 0.05	5.28	5.38	5.00
3	70 ± 0.05	4.29	4.24	4.25
4	90 ± 0.05	4.10	4.10	4.13
5	110 ± 0.05	3.31	3.71	3.51

5.2 Processed data

Table 3: Processed Data

Experiment	Average Time $\bar{t}$ (ms)	Percentage Error	Speed	Percentage Error
1	7.05	1.28%	2.58	2.05%
2	5.22	7.28%	3.48	7.55%
3	4.26	1.17%	4.27	0.44%
4	4.11	0.73%	4.43	1.00%
5	3.51	11.4%	5.19	11.7%



5.3 Sample working

To calculate the average time taken to completely pass through the photogate ($\bar{t}$):

$$\bar{t} = \frac{t_1 + t_2 + t_3}{3} = \frac{7.00 + 7.07 + 7.09}{3} s \approx 7.05ms$$

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The speed passing the photogate (v)

$$v = \frac{d}{\bar{t}} = \frac{1.82cm}{7.05ms} \approx 2.58m/s$$

6 Discussion and conclusion

Our diagram suggests

- A slope of 0.240.
- A y-intercept of -0.0556.

From which we can derive $g = \frac{v^2}{2h} = \frac{2}{0.240} \approx 8.3ms^{-2}$. This is close to $9.8ms^{-2}$.

The y-intercept is expected to be zero, but -0.0556 is found.

Considering the small error, the results support our initial hypothesis. That is, higher the releasing height, faster the speed. The square of the speed should be proportional to the height.

7 Evaluation

Table 4: Evaluation

Limitation	Significancy	Improvement
It's difficult to make the height difference exactly the same as expected.	Might lead to inaccurate h and hence inaccurate t	Choose a better iron stand.
The metal ball may not fall exactly through the photogate as expected.	No reading, or a too small reading if the center of the object is a little away from the center of the photogate.	Use a glass tube too correct the falling route.
Might be affacted by air resistance.	Lenghthen the time needed to pass the photogate.	Use an object with a higher density.