



# A COMPARISON OF STANDARD DEVIATION OF GRAVITATIONAL ACCELERATION ( $g$ ) DUE TO GRAVITY MEASURED BY VARIOUS METHODS

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**Abstract:** This research aimed to compare the standard deviation of gravitational acceleration measured by various methods. The acceleration due to gravity ( $g$ ) was measured using four methods: free fall, simple pendulum, physical pendulum, and Atwood's machine. The experiments were designed for students to determine the accuracy of the results by comparing the standard deviation of experimental result to the acceleration due to gravity. The data was analyzed and the result was interpreted.

## I. INTRODUCTION

Acceleration due to the gravity of the Earth is denoted by the symbol  $g$  which is the acceleration of a body caused by the gravitational field acting on the body towards the center of the Earth, neglecting air resistance and mass. Gravitational acceleration ( $g$ ) was first determined by Galileo Galilei in 1604. The law of gravitational attraction was formulated by Sir Isaac Newton (1642-1727) and published in 1687. The magnitude of  $g$  varies over the surface of the Earth in which many measurements were undertaken at different locations on the earth [1]. JS Clark [2] and AH Cook [3] measured the absolute  $g$  constants by using a reversible pendulum and free motion experiments, respectively. Both the experiments of  $g$  values were very close to the mean of  $g$  absolute determination by using other methods. After that, the absolute  $g$  value was determined by Cook [4] using the British Fundamental Gravity Station in the N.P.L. getting 981181.75 mgal and the National Bureau of Standards near Gaithersburg, Maryland getting 980.1018  $\text{cm/s}^2$  [5] with a standard deviation of 0.0005  $\text{cm/s}^2$ . Recently, gravity was investigated to obtain the local acceleration due to gravity at the center of a test mass in the KRISS Watt balance system. The mean gravity value at the center of the test mass in the KRISS Watt balance was  $(979\ 832\ 568.9 \pm 5.0) \mu\text{Gal}$  at a reference height of  $(1.3893 \pm 0.001) \text{m}$  [6]. The numerical value of the acceleration of gravity is most accurately known as 9.8  $\text{m/s}^2$ . On the moon, the gravitational acceleration is one sixth of the earth equal to 1.63  $\text{m/s}^2$ .

Recently, many researchers have been provided gravitational acceleration computations by using innovative technologies for instance, the measurement of Earth's gravity field after the gravity field and steady-state ocean circulation explorer mission by the European Space Agency program [7], and they proposed a method to extract the gravitational acceleration from additional accelerations based on a simplified walking model [8].

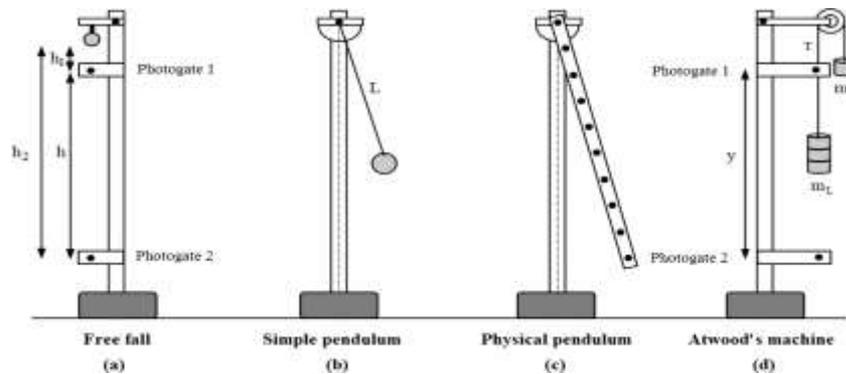
In teaching undergraduates in the Physics laboratory, that acceleration due to gravity can be measured by using free fall [9], simple pendulum, physical pendulum, projectile motion and Atwood's machine.

In this study, the methods used to investigate local gravitational acceleration at latitude of  $10^\circ 24' 0'' \text{N}$  and longitude of  $99^\circ 4' 0'' \text{E}$ , were by motion of free fall, simple pendulum, physical pendulum and Atwood's machine to provide valuable experience of measuring gravitational acceleration in the undergraduate experiments to allow students to study comparisons of acceleration due to gravity in a

Physics laboratory. Here the result of above four experiments [10] is used to find the standard deviation and analysis that.

## II. RESEARCH METHODOLOGY

### 1. Experimental Apparatus



**Figure 1.** Free body diagram of the experiments set up to measure gravitational acceleration.

#### 1.1. Free fall

In principle,  $g$  can be measured by using a smart timer to detect the time  $t$  for a metallic ball falling between photogate 1 and photogate 2 known as distance  $h$  as shown in figure 1(a), acceleration can be computed by applying the simple formula as equation (1).

$$\left[ 2(h_2 - h_1)^2 \right] \quad (1) \quad g = \frac{2(h_2 - h_1)^2}{t_{av}^2 (h_1 + h_2 + 2\sqrt{h_1 h_2})},$$

where  $h_1$  is the distance from the metal ball to photogate 1,  $h_2$  is the distance from the metal ball to photogate 2,  $t_{av}$  is the average time of the metal ball to fall between the two photogates.

#### 1.2. Simple pendulum

Using the simple pendulum to measure the acceleration due to gravity, the apparatus was constructed from string (length  $L$ ) connected to a metal ball and a snooker ball, which were attached to the aluminum bar as shown in figure 1(b). This experiment used an oscillation angle of less than  $10^\circ$ . In the simple pendulum experiment, digital timer was used to detect the time of the ball swing of 10 revolutions with five repetitions. The period of an oscillation is

$$T = 2\pi \sqrt{\frac{L}{g}} \quad (2)$$

The acceleration due to gravity can be calculated by equation (3) (3)

Where  $L$  is the length of the string, the *slope* can be calculated from the linear fitting curve as shown in figure 2.

#### 1.3. Physical pendulum

A physical pendulum consists of a rigid body that undergoes fixed axis rotation about a fixed point. In this experiment, we used 100 cm length metal ruler length with the holes for rotation points as shown in figure 1(c). The physical pendulum experiment was setup the same as the simple pendulum, digital timer was used to detect the time for the metal ruler to complete 10 revolutions, which estimated from five repetitions, in 5 cm phases, from 5 to 95 cm. This experiment also used an oscillation angle of less than  $10^\circ$  the same as the simple pendulum. The obtained  $g$  value was computed by using equation (4).

$$(4\pi^2/T^2) \cdot (x_1 + x_2) \quad (4)$$

#### 1.4. Physical pendulum

A physical pendulum consists of a rigid body that undergoes fixed axis rotation about a fixed point. In this experiment, we used 100 cm length metal ruler length with the holes for rotation points as shown in figure 1(c). The physical pendulum experiment was setup the same as the simple pendulum, digital timer was used to detect the time for the metal ruler to complete 10 revolutions, which estimated from five repetitions, in 5 cm phases, from 5 to 95 cm. This experiment also used an oscillation angle of less than  $10^\circ$  the same as the simple pendulum. The obtained  $g$  value was computed by using equation (4).

## 1.5. Atwood's machine

The Atwood's machine is a simple machine that consists of a pulley which has two suspended weights of unequal mass. The mass difference between the two hanging masses  $m_1$  and  $m_2$  determines the net force acting on the system of both masses. This net force accelerates both of the hanging masses; the heavier mass is accelerated downward and the lighter mass is accelerated upward. In the free body diagram of the Atwood's machine,  $T$  is the tension of the string,  $m_R$  is the lighter mass,  $m_L$  is the heavier mass. The time of the masses motion ( $t$ ) measured was the time taken to travel from photogate 1 to photogate 2 this is known as distance  $y$  in figure 1(d) and the  $g$  value can be obtained from equation (5a) or (5b).

$$g = M \times slope \quad (5a)$$

$$g = (m_L + m_R + m_P) \times slope, \quad (5b)$$

where  $M = m_L + m_R + m_P$  is the net masses of the system ( $g$ ),  $m_L$  is the left mass ( $g$ ),  $m_R$  is the right mass ( $g$ ) and  $m_P$  is pulley mass ( $g$ ).

### III. . RESULTS AND DISCUSSION

In the experiments, the acceleration due to gravity ( $g$ ) from free fall, simple pendulum, physical pendulum and Atwood's machine was determined.

**Table 1.** The gravitational acceleration values of 4 methods[11]

$g$  in  $ms^{-2}$

0	Free Fall	Simple pendulum	Physical Pendulum	Atwood's Machine
1	9.52	9.55	12.70	7.56
2	10.00	9.64	10.17	12.70
3	9.76	9.82	10.09	11.89
4	9.33	9.74	10.51	9.78
5	9.60	9.61	10.95	10.44
Mean	<b>9.77</b>	<b>9.67</b>	<b>10.88</b>	<b>10.47</b>

**Table.2** Standard Deviation

	Free Fall	Simple pendulum	Physical Pendulum	Atwood's Machine
STANDARD DEVIATION from standard value of $g=9.8 ms^{-2}$ due to gravity	0.276333	0.170353	1.524729	1.931558956

Conclusion: The result obtain from simple pendulum among all other method for acceleration due to gravity have least Standard Deviation and Atwood's machine method have largest from standard value of  $g=9.8 ms^{-2}$  due to gravity.

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