COMPARATIVE METHODS OF MEASURING GRAVITATIONAL CONSTANT (G) USING SIMPLE PENDULUM AND BEAM BALANCE

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Abstract

Attempt was made to carry out a comparative approach in measuring gravitational constant (G). The G has been measured using simple pendulum and beam balance. Results from Experiment yields values of G with a relative error of approximately 0.05% and 0.03% respectively. In line with the results obtained, it is recommended that, when experimentally teaching students on how to determine the Newton's gravitational constant (G), it is recommended that the teacher should embrace the use of beam balance. Recommendation to varify other constant using different methods to ascertain the best way to go during teaching/learning has been proposed.

Introduction

Gravity is one of the most extensively studied phenomena in nature. At the macroscopic level, the observation of the interplay of the gravitational force and finite mass systems is commonplace. The trajectory of a falling object, orbits of celestial bodies, and motion of a pendulum all exhibit explicit dependencies on gravity. In lay terminology, gravity is generally described as a force by which systems with mass attracts one another. However, as elucidated by Einstein in his seminal works on general relativity, it is now known that gravity's influence extends to massless systems, such as light and even space itself Einstein (1909) as contained in (David N, 2018). Needless to say, a proper understanding of this ever-present phenomenon is vital for the development of a complete description of the observable universe and nature itself. Towards a quantitative description of gravity was the product of Sir Isaac Newton and Rob

The first documented effort Hooke in (1666) as contained in (Hendric H, 1985). Newton spurred on by the suggestion of Hooke that gravity was an attractive force whose magnitude depended on

the inverse square of the distance between interacting systems, began by investigating planetary motion through observations of bodies in the solar system, Newton developed and empirically confirmed a number of mathematical relations that ultimately served to validate the previously a-priori inverse square law (schaflichen, d, 2019).

One of the first experimental ventures into measuring the gravitational constant was performed by Henry Cavendish in (1798) as contained in (A.R kuhthan may 2000). Following after the work of geologist John Michel and Francis John Hyde Wollaston, Cavendish developed an apparatus to measure the nearly imperceptible gravitational attraction between a pair of small and large lead spheres. Cavendish's device consisted of a torsion balance - a wooden rod suspended by a thin wire, with two small lead spheres at the ends (Development of Gravitational Acceleration). A significantly larger spherical lead mass was then positioned near each small sphere. The attraction between each large and corresponding small sphere caused the balance to rotate, thereby precipitating the twisting of the thin wire. After twisting through a particular angle, the torque induced on the balance by the gravitational attraction was balanced by the oppositely-directed torsion torque. Measurement of this angle, along with the imparted torque, allowed for the calculation of G.

Methodology

This chapter deals with the method used for conducting this research work. Safety precautions were taken to ensure accurate result.

3.1 Determination of gravitational constant (G) using simple pendulum.

The apparatus used are as follows:

- simple pendulum
- Object of mass(M1)
- Meter rule
- Stop clock
- Retort stand
- Spring balance



Fig 1.0 spring balance



Fig 2.0 stop clock

Experimental Setup

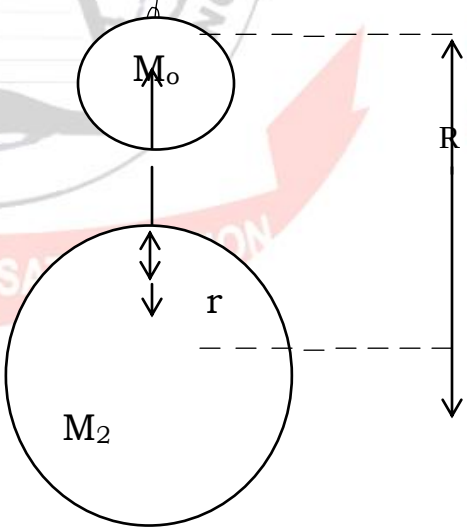

Fig 3.0

Where r is the radius of the earth and E is the distance between the earth and the center of the object. Thus R represents the total distance of the earth (M_2) and the center of the object (M_o).

3.2 Method and procedure (Using simple pendulum)

With the help of spring balance the mass of the (M_o) was obtained as

100g = 0.1kg as shown in the fig 4.0 below

With the help of stop clock, time (t) was obtained for 20 horizontal oscillations as shown in figure below. Fig 5.0

With help of meter rule, the distance was determined. Spring balance was used to determine the mass (M_o) of the object.

3.3 Determine gravitational constant (G) using simple pendulum

List of apparatus and their parameters used:

Extension E = 6cm = 0.06m

Mass of the object = 100g =0.1kg

Mass of the earth = 5.98×10^{24}kg

Time for 20 oscillation =10.0s

For any oscillating body, the period (T) is given as

$$T = 2\pi\sqrt{\frac{E}{g}} \text{ ----------(20)}$$

To obtain the value of acceleration due to gravity (g) from the above equation, we've

$$g = 4\pi^2\frac{E}{T^2} \text{ ----------(21)}$$

The time (t) for 20 oscillation was obtained to be t = 10s

$$\text{Period (T)} = \frac{time\ taken}{no\ of\ oscillation}\text{.....(22)}$$

From which, we have

$$T = \frac{10}{20}\text{.....(23)}$$

T = 0.5……(24)

$T^2 = 0.25s^2$……..(25)

Using equation (2) to obtain the acceleration due to gravity (g), We've

$g = 4\pi^2 \frac{E}{T^2}$……...(26)

E = 0.06m……(27)

$T^2 = 0.25s^2$……(28)

$\pi = 3.14$……(29)

Thus,

$g = \frac{4\times9.87\times0.006}{0.25}$……(30)

$g = \frac{2.368}{0.25}$……(31)

$g = 9.47ms^{-2}$……(32)

Since

$f = mg = \frac{Gmm1}{re^2} = \frac{Gm1me}{R^2}$……(33)

$\therefore \quad g = \frac{Gm}{R^2}$ ----------.(34)

$G = \frac{gR^2}{me}$ ----------.(35)

Where

g = 9.47m/s²……..(36)

$R = 5.98\times 10^6$m……(37)

$Me = 5.98\times 10^{24}$kg……(38)

Substituting into equation (4), we've

$G = \frac{gR^2}{me}$……..(39)

$G = \frac{9.47\times(6.38\times10^{6})^{2}}{5.98\times10^{24}}$……(40)

$G = (\frac{9.47\times40.7}{5.98}) \times 10^{-12}$……...(41)

$G = \frac{385.429}{5.98} \times 10^{-12}$……(42)

$G = 64.45\times 10^{-12}$……(43)

$G = 6.445\times 10^{-11}$ $m^3\ kg^{-1}\ s^{-2}$.....(44)

Thus the gravitational constant (G) obtained using simple pendulum experiment was given as:

$G = 6.445\times 10^{-11}$ $m^3\ kg^{-1}\ s^{-2}$.....(45)

3.4 Determine the gravitational constant (G) beam balance.

The apparatus used are as follows:

- Beam balance
- Mass as shown in figure below Fig 6.0



Fig 6.0

3.5 Method And Procedure

The beam balance was used to determine the mass (m1) of the object as shown in the figure below Fig 7.0

Fig 7.0

A formula for force between two bodies under gravitation in space was used.

Thus,

f = mg = $\frac{Gm1m2}{r^2}$……..(46)

Where

f = force of attraction between two bodies in space

g = acceleration due to gravity

m_1 = mass of the object

m_2 = mass of the earth

r = radius of the earth

G = gravitational constant

The mass of the body m_b = 100g = 0.01kg……..(47)

The mass of the earth = m_E = 5.98× 10^{24}kg……(48)

From the above statement, the total distance between the object and the radius of the earth was given as R = 5.98× 10^6m…….....(49)

Using the beam balance to measure the mass of the body, we've

M_b = 95g = 0.9kg……(50)

Where

g = 9.8m/s²……..(51)

R = 5.98× 10^6m……...(52)

M_E = 5.98× 10^{24}kg……(53)

From

f = mg = $\frac{Gm1m2}{r^2}$……(54)

$g = \frac{Gm}{R^2}$ ……(55)

$G = \frac{gR^2}{me}$……(56)

Substituting the value into equation (36), we've

$G = \frac{9.8\times(6.38\times10^{6})^{2}}{5.98\times10^{24}}$……..(57)

$G = (\frac{9.8\times40.7}{5.98}) \times 10^{-12}$ ……..(58)

$G = \frac{398.86}{5.98} \times 10^{-12}$……(59)

$G = 66.698\times 10^{-12}$……..(60)

$G = 6.6703\times 10^{-11}$ $m^3\ kg^{-1}\ s^{-2}$.....(61)

Thus, the gravitational constant (G) obtained with the help of beam balance experiment was given as

$G = 6.6703\times 10^{-11}$ $m^3\ kg^{-1}\ s^{-2}$…….(62

Result obtain using simple pendulum experiment

Extension E = 6cm = 0.06m……..(63)
Mass of the object =100g = 0.01kg……..,(64)
Mass of the earth = 5.98×10^{24}kg…….(65)
Time for 20 oscillation's = 10.0s……..(66)
Period for any oscillating body

$T = 2\pi\sqrt{\frac{E}{g}}$ ……(67)

Period (T) = $\frac{time\ taken}{no\ of\ oscillation}$……..(68)

$T = \frac{10}{20}$……(69)

T = 0.5…….(70)

$T^2 = 0.25s^2$……...(71)

$g = 4\pi^2 \frac{E}{T^2}$……(72)

Where

$E = 0.06m$……(73)

$T^2 = 0.25s^2$……(74)

$\pi = 3.14$……(75)

$g = \frac{4\times9.87\times0.006}{0.25}$……(76)

$g = \frac{2.368}{0.25}$……(77)

$g = 9.47ms^{-2}$……(78)

Since

$f = mg = \frac{Gmm1}{re^2} = \frac{Gm1me}{R^2}$……(79)

$\therefore \quad g = \frac{Gm}{R^2}$……(80)

$G = \frac{gR^2}{me}$……(81)

$G = \frac{9.47\times(6.38\times10^6)^2}{5.98\times10^{24}}$……(82)

$G = (\frac{9.47\times40.7}{5.98}) \times 10^{-12}$……(83)

$G = \frac{385.429}{5.98} \times 10^{-12}$……(84)

$G = 64.45\times 10^{-12}$……(85)

$G = 6.445\times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$ is the result obtain using simple pendulum.

Result obtained using Beam balance experiment

$R = 5.98\times 10^6 m$……(86)

$M_1 = 95g = 0.9kg$……(87)

Where

$g = 9.8 m/s^2$……...(88)

$R = 5.98\times 10^6 m$……(89)

$M_1 = 5.98\times 10^{24} kg$……(90)

From

$f = mg = \frac{Gm1m2}{r^2}$……(91)

$g = \frac{Gm}{R^2}$ ……(92)

$G = \frac{gR^2}{me}$ ……(93)

$G = \frac{gR^2}{me}$ ……(94)

$G = \frac{9.8\times(6.38\times10^6)^2}{5.98\times10^{24}}$……(95)

$G = (\frac{9.8\times40.7}{5.98}) \times 10^{-12}$……(96)

$G = \frac{398.86}{5.98} \times 10^{-12}$……..(97)

$G = 66.698\times 10^{-12}$……..(98)

$G = 6.6703\times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$……..(99)

Eqn (99) is the result obtained using beam balance.

Results Comparison

Calculated values of G from simple pendulum and beam balance can be compared with the value established by the committee on data for science and technology. The relative errors for the two results were also presented as follows:

Using simple pendulum experiment, we obtained: $G = 6.445\times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$ with a

$Error = \frac{actual\ value - experimental\ value}{actual\ value}$

$= \frac{6.674\times10^{-1} - 6.445\times10^{-11}}{6.674\times10^{-11}}$

$$= \frac{2.29 \times 10^{-12}}{6.674 \times 10^{-11}}$$

$$= 0.034$$

Relatively error of 0.034……(100)

Using beam balance experiment we obtained: G = 6.6703× 10^{-11} m^3 kg^{-1} s^{-2} with

$$\text{Error} = \frac{actual\ value - experimental\ value}{actual\ value}$$

$$= \frac{6.674 \times 10^{-1} - 6.6703 \times 10^{-11}}{6.674 \times 10^{-11}}$$

$$= \frac{3.52 \times 10^{-12}}{6.674 \times 10^{-11}}$$

$$= 0.053$$

Relatively error of 0.003……(101)

Comparing the errors from the two results obtained, shows that using beam balance is the best way to go when teaching students how to determine the Newton's universal gravitational constant 'G'.

Conclusion

The gravitational constant, G, has been measured using simple pendulum and beam balance. Results from Experiment yields values of G with a relative error of approximately 0.05% and 0.03% respectively.

Relevance Of The Study In The Field Of Education

According to Agan and Sneider (2004) as contained in (Nasser, M December 2007), today's method of teaching, the concept of gravity in classes is ineffective, not only because it ignores the physical aspect of the phenomenon by addressing only its mathematical aspect, but also because it does not take into account students' conceptions. The goal of the present study was to assess the most effective method of teaching gravity, Two methods of determining Newton's gravitational constant (G), were conducted and the data obtained would be used to enhance students' initial conceptions on the subject matter.

Ameh (1987) as contained in (Varda, B 1990), asserted that, science teacher who wanted students to understand that there is gravity in space and that weight has the Newtonian meaning of the force of gravity. The educational community is now faced with a new set of standards that

require students to think deeply about scientific issues, and to be able to apply learned concepts to new situations, and in many cases, to solve some challenging problems. That means it will no longer be sufficient for students to parrot back learned definitions, but to make it practical such as "weight is the force of gravity on an object." They must develop a conceptually deep understanding of the core ideas.

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