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Course & Section: PHYS101 - 004

Title:

Relation between an object's mass and the total time in the air.

Experiment Summary and Purpose:

The main purpose of this experiment is to study the relationship between an object's mass and its velocity with its total time in the air. In this experiment, three objects (a ping pong ball, a tennis ball, and a basketball) with different masses will be used to compare their velocity and the total time in the air. To achieve this, a stopwatch to calculate the total time in the air, and a tape measure to set a constant initial height for every object will be used. The experiment will be repeated at three different heights (0.5m, 1m, and 1.5m) for each three objects. Thus, the independent variable will be the mass of an object, whereas the dependent variable will be the total time in the air, and the controlled variable will be the constant height for all objects. Finally, the data gathered from the objects will be used to compute the gravitational acceleration to measure the error, and support the results of this experiment. If the computed gravitational acceleration gathered from the data is close to 9.8 (the gravitational acceleration), then the results of the experiment will be verified.

Theory

Newton's second law suggests that the product of an object's mass and its acceleration is equal to the net force being applied on the object (1).

$$(1)\, F = ma$$

Newton's law of universal gravitation shows that there is an attraction force between each particle in the universe. Such attraction forces depend proportionally on the object's mass, and are inversely proportional to the square of the distance between the center points of the objects (2).

$$(2)\, F = G\frac{m_1 m_2}{r^2}$$

Considering that Earth attracts every particle on the surface of the Earth, every particle has a gravitational force exerted on them. To calculate the force applied by Earth on an object, Newton's universal gravitation equation is used (3). In this equation, m_1 represents the mass of the object, m_2 (replaced by m_E) represents the mass of the Earth, and r^2 (replaced by r_E^2) represents the Earth's radius. Finally, G is used to indicate the gravitational constant.

$$(3)\ F_g = G\frac{m_1 m_E}{r_E^2}$$

Combining these equations (Newton's second law (1) and Newton's law of universal gravitation (2)), we get (4):

$$(4)\ F = m_1 a = m_1 \frac{Gm_E}{r_E^2}$$

Thus, the acceleration caused by the gravitational force of between an object and the Earth is equal to $\frac{Gm_E}{r_E^2}$, the gravitational acceleration (g). Thus, with this equation, it is shown that the mass of an object changes neither the acceleration nor the velocity of the free-falling motion. The gravitational acceleration (g) is only dependent on the Earth's radius, and its mass. However, this equation is only valid in environments that have no air resistance. Since there is air friction force caused by air resistance on the free-falling objects on Earth, such motion cannot be perfectly observed. Yet, the shorter the height of the free-falling object, air friction will have less effect since the duration of force exerted on the object will also be shorter. Therefore, not exact but highly close experimental acceleration values can be obtained with experiments on Earth where there is air friction.

In this experiment's setup, three objects with different masses will be dropped from the same fixed heights. To make sure that the heights are fixed, a tape measure will be used. To measure an object's total time in the air, a stopwatch will be used. Firstly, all three balls will be dropped from a fixed height of 0.5m, and the total time in the air will be measured for each object with the stopwatch. This step will be repeated three times in order to reduce the error rate. Then, the same procedure will be repeated by using different fixed heights of 1m and 1.5m. Finally, experimental acceleration of each height and each object will be calculated and compared with the gravitational acceleration. Using the experimental acceleration values and comparing them with the gravitational acceleratiion (g), error rate will also be calculated.

In this experiment, we will use the equations of motions for free-falling bodies. Since the independent variable is height (h), and the total time in the air (t) will be measured with a stopwatch, we can find the experimental acceleration (g) from the equation (5):

$$(5)\ h = h_0 + v_0 t - \frac{1}{2} g t^2$$

Rearranging this equation specifically for the free-falling motion, we get (6):

$$(6)\ h_0 = \frac{1}{2} g t^2$$

Finally, by rearranging the last equation to get the gravitational acceleration, we get (7):

$$(7)\ g = \frac{2h_0}{t^2}$$

In a nutshell, three objects with different masses will be dropped from three different fixed heights in this experiment. By using the measured values, experimental acceleration values will be calculated and compared to the gravitational acceleration.

Setup and the Experiment

Experiment consists of three different balls with different masses, a ruler to measure the height, and a stopwatch using a computer program. From the heights 0.5m, 1.0m, and 1.5m, a tennis ball (58g), a football (145g), and a basketball (265g) will be dropped. Total time in the air of these objects will be measured and experimental gravitational acceleration will be calculated. All of the balls are dropped three different times to get an average total time in the air to reduce the error rate.

Mass (m)	t_1	t_2	t_3	t_{avg}
58	**0.32**	**0.32**	**0.33**	**0.32**
145	**0.33**	**0.32**	**0.32**	**0.32**
265	**0.33**	**0.31**	**0.32**	**0.32**

Table 1. Mass and Time with the height of 0.5m

Mass (m)	t_1	t_2	t_3	t_{avg}
58	**0.45**	**0.46**	**0.45**	**0.45**
145	**0.45**	**0.44**	**0.44**	**0.44**
265	**0.44**	**0.45**	**0.45**	**0.45**

Table 2. Mass and Time with the height of 1m

Mass (m)	t_1	t_2	t_3	t_{avg}
58	**0.55**	**0.55**	**0.55**	**0.55**
145	**0.55**	**0.56**	**0.54**	**0.55**
265	**0.56**	**0.53**	**0.57**	**0.55**

Table 3. Mass and Time with the height of 1.5m

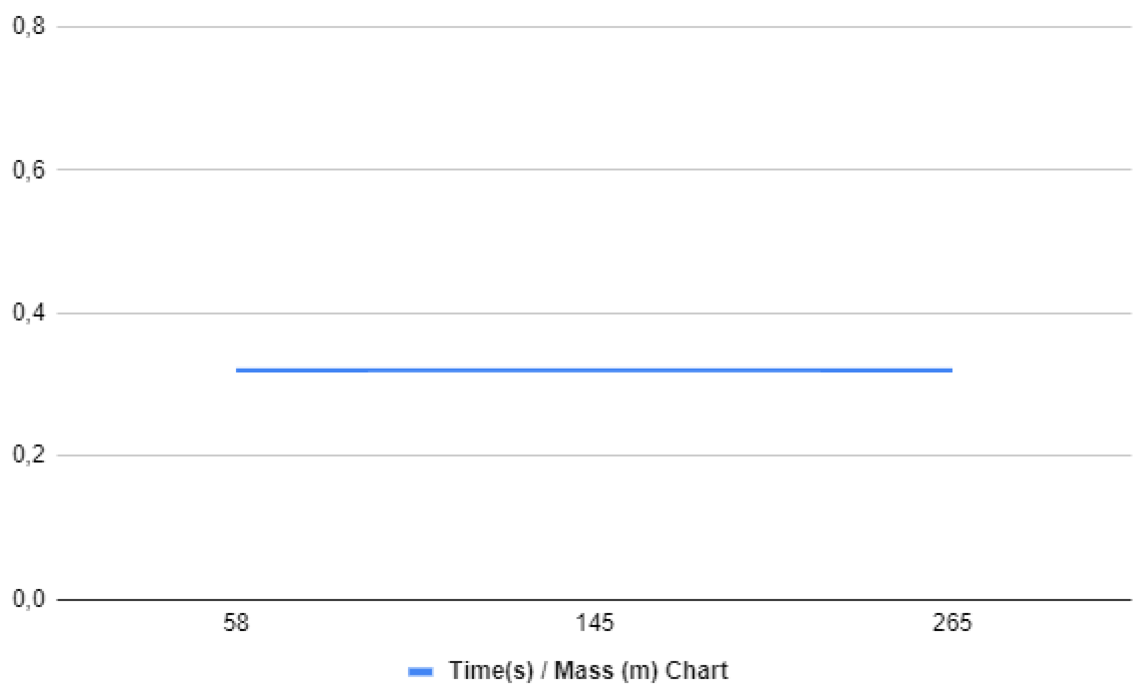
Calculations and Graphs

Expected gravitational acceleration value is 9.80 m/s^2 and thus, measured experimental gravitational value will be compared with this value to find the error rate.

Experiment with 0.5m Height

Mass (m)	$t_{avg}(s)$	$g_{exp}(\frac{m}{s^2})$	$Error$ (%)
58	**0.32**	**9.77**	**%0.31**
145	**0.32**	**9.77**	**%0.31**
265	**0.32**	**9.77**	**%0.31**

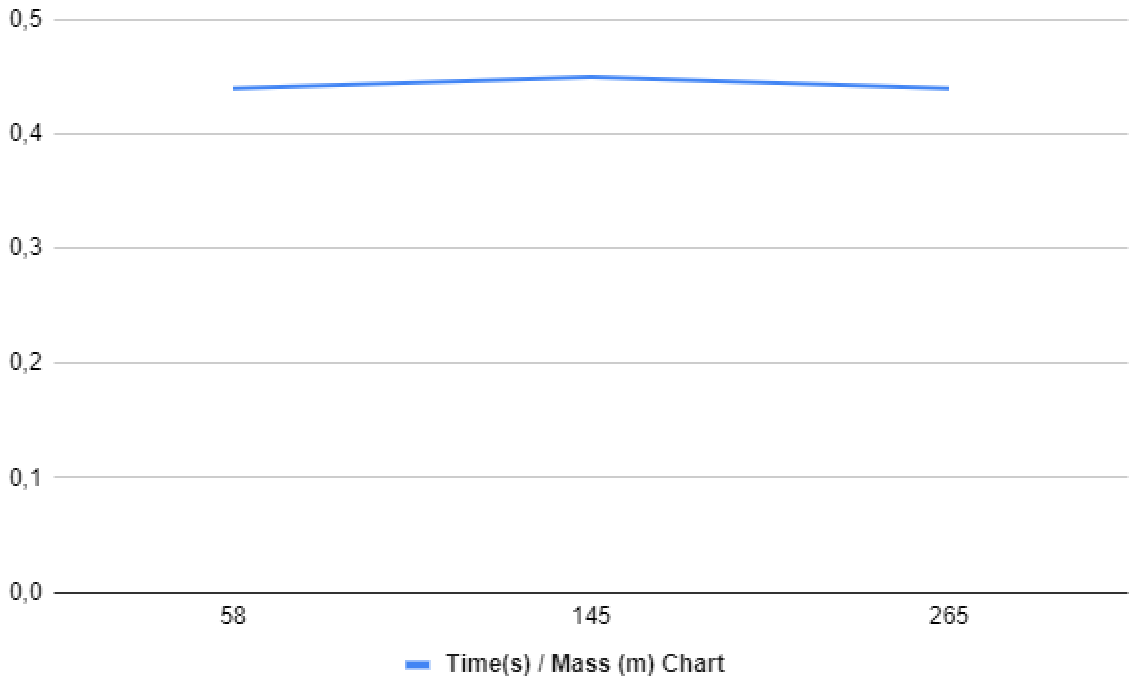
Table 4. Calculated gravitational acceleration values and error rates from 0.5m height



Experiment with 1.0m Height

Mass (m)	$t_{avg}(s)$	$g_{exp}(\frac{m}{s^2})$	$Error\ (\%)$
58	**0.45**	**9.88**	**%0.82**
145	**0.44**	**10.03**	**%2.35**
265	**0.45**	**9.88**	**%0.82**

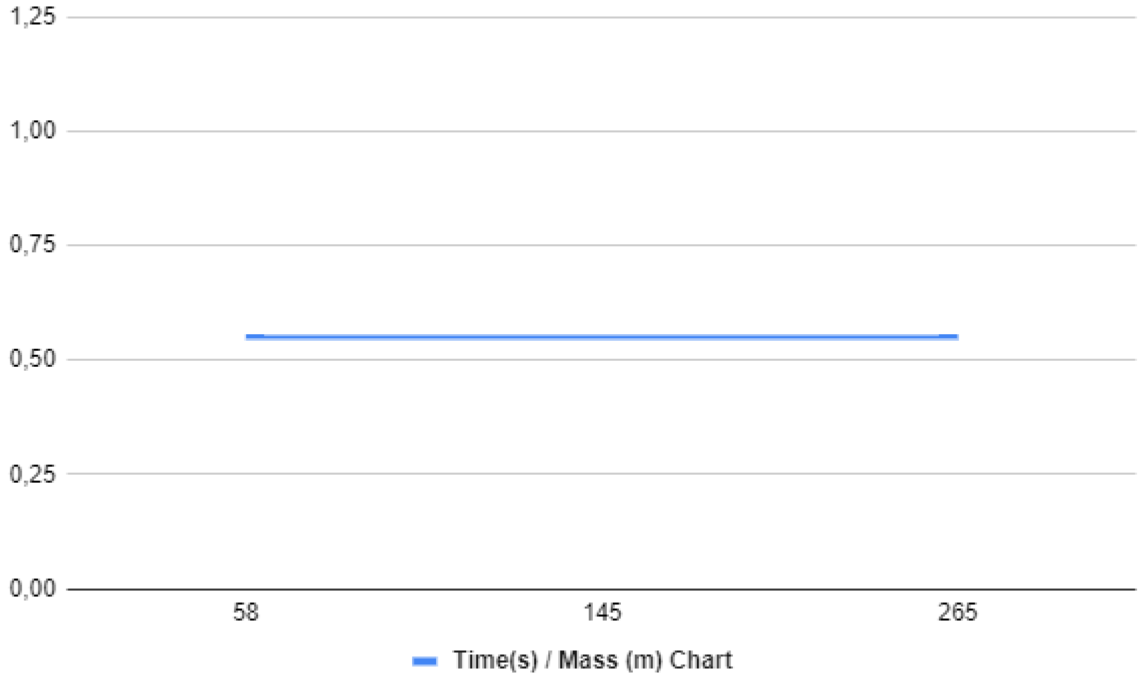
Table 5. Calculated gravitational acceleration values and error rates from 1.0m height



Experiment with 1.5m Height

Mass (m)	$t_{avg}(s)$	$g_{exp}(\frac{m}{s^2})$	$Error\ (\%)$
58	**0.55**	**9.92**	**%1.22**
145	**0.55**	**9.92**	**%1.22**
265	**0.55**	**9.92**	**%1.22**

Table 6. Calculated gravitational acceleration values and error rates from 1.5m height



Discussion and Analysis

When the balls were dropped from the 0.5m height, each ball had the same total time in the air which was 0.32s. Thus, as it can also be seen with the plot graph, average time stays the same, resulting in experimental gravitational acceleration also staying the same. Since gravitational acceleration stays the same throughout the projections in the same height for different masses, we can observe that an object's mass does not affect the gravitational acceleration. After repeating this motion for different heights, we can see that almost in every height, total time in the air is constant for each object dropped from the same height. While experimenting with 1.0m height, slightly different average time for the football is observed. This might be due to an error caused by the real world environment such as air friction. In addition, this error might also be caused by human related errors such as slight hand movements, changing the initial height when dropping the ball.

After calculating the experimental gravitational acceleration with the average total time in the air, the experimental gravitational acceleration is compared with the expected value. With comparing these values, error rate is calculated, and found to be in the range of %0.31 and %2.35. These error rates might be caused by the air friction, human-related errors or the insufficient accuracy of measuring tools.

Conclusion

With this experiment, showing that the mass of an object does not affect the total time in the air of the object during the free fall motion is aimed. Experiment suggests that an object's mass does not affect the total time in the air during free fall motion. With the results of this experiment, since the total time in the air does not change even when different balls with different masses are used, results proved the experiment’s state. Even though there were different calculated average times at the one meter height, this change in average time is a slight error which may have been caused because of the air friction or human related errors such as slight hand movement in the initial drop.

Youtube Link of the Experiment: https://youtu.be/kFh2wPzFOBk