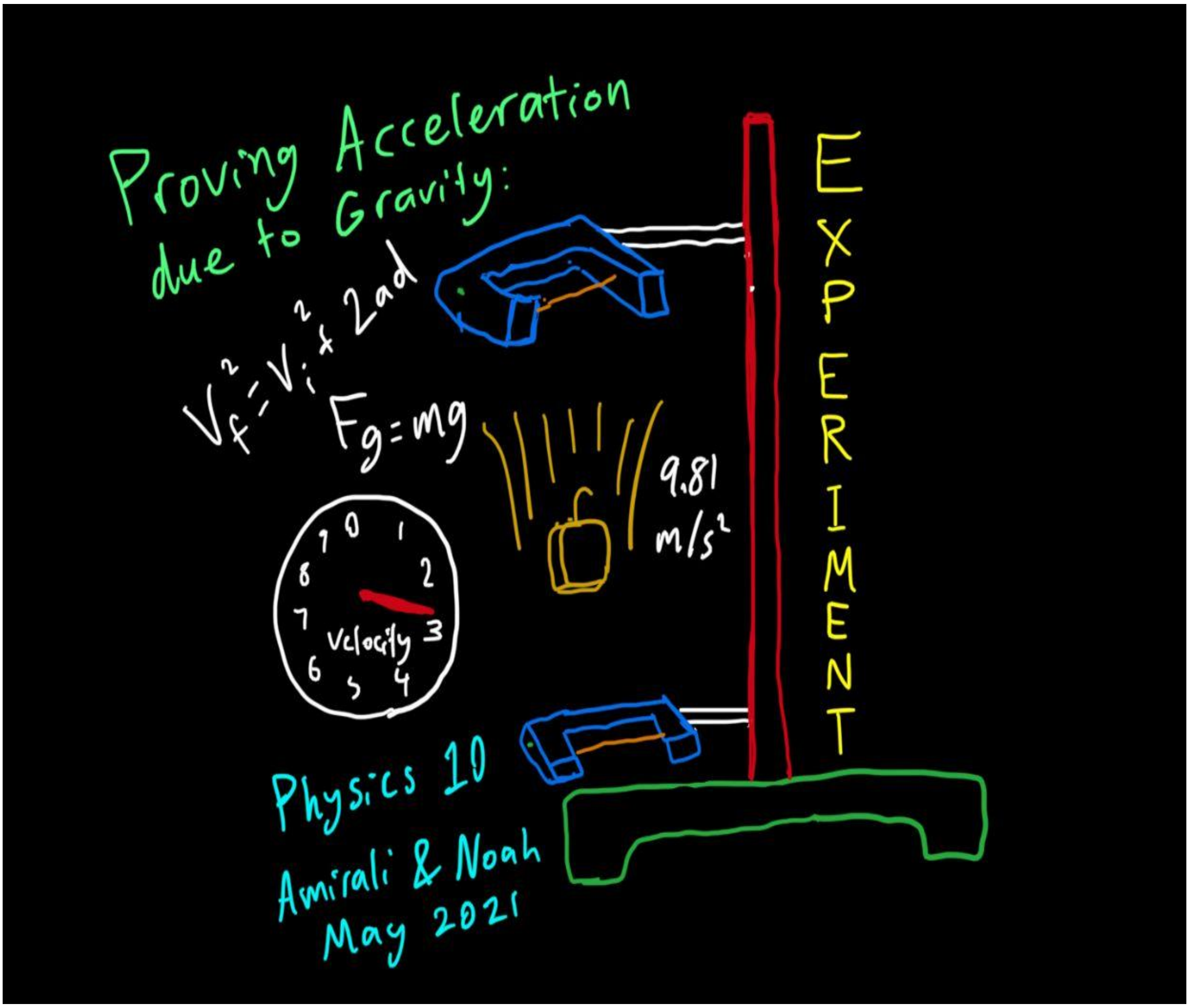
Proving Acceleration Due to Gravity on Earth



LABORATORY WORK

Purpose:

The purpose of this lab is to prove acceleration due to gravity on Earth by dropping objects of different masses through photocell timers and calculating their rate of acceleration using the measurements we obtain.

Variables:

Independent Variable: Mass (in kilograms)

Dependent Variables: Acceleration due to Gravity (9.81m/s^2 on Earth) and Force due to Gravity (in Newtons)

Controlled Variable: Distance between the two photocell lasers (in metres)

FORMULAS:

- $g = 9.8\ m/s^2$

$$F_g = mg$$

$$v_f^2 = v_i^2 + 2*a*d$$

Hypothesis

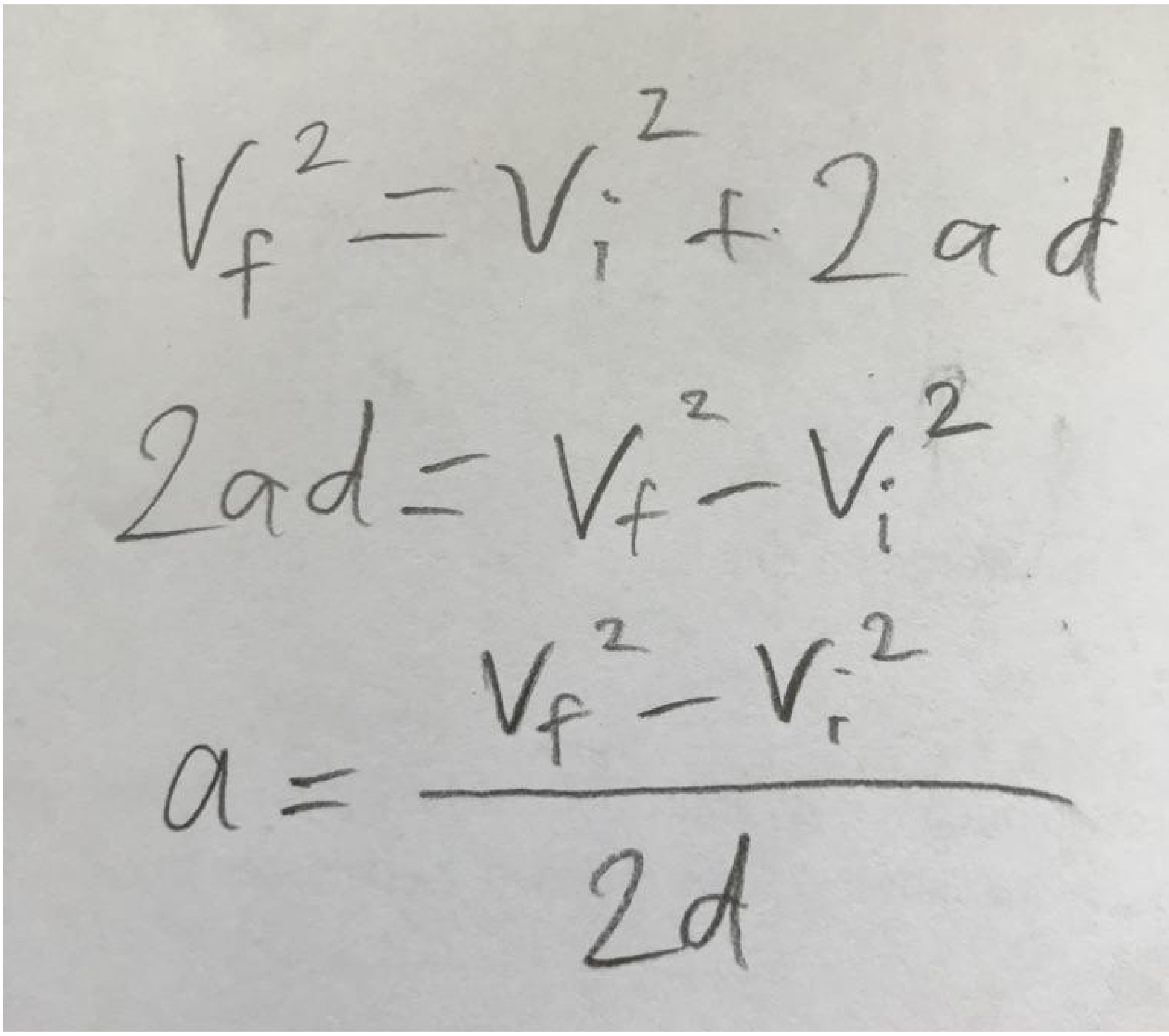
If you change the mass of an object and therefore the gravitational force at which the Earth pulls on the object, the acceleration due to gravity will always remain constant (9.81 m/s^2).

Introduction / Background Information

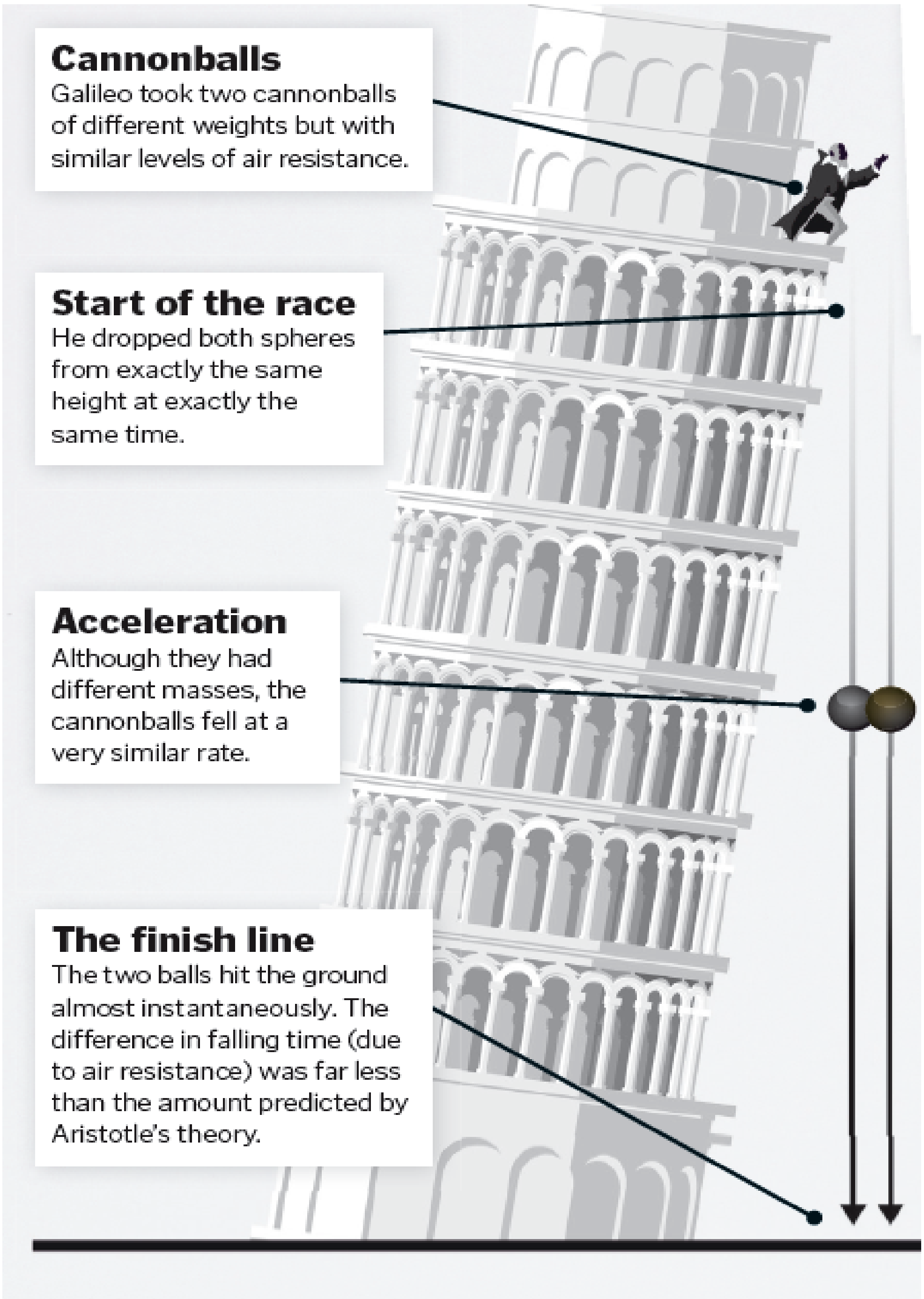
According to Sir Isaac Newton's 2nd Law of Physical Motion, the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object; increasing the amount of force applied to an object will increase its acceleration while increasing the object's mass will decrease its acceleration. Newton's 2nd Law can be represented by the equation: **F=ma (in other words, force is equal to mass times acceleration).** In the experiment that we will be conducting, the acceleration value is the constant: **acceleration due to gravity (9.81 m/s^2 on Earth → represented by a "g").** This, along with force due to gravity (a quantity measured in Newtons that's directly proportional to the mass of the object and the gravitational acceleration constant), will be the dependent variables of our experiment. Our independent variable will be the **masses (in kilograms)** of the objects that we will be dropping. Finally, our controlled variable is the **distance (in metres)** between the two photocell lasers. Altogether, these variables can be represented by the following elegant formula that forms the backbone of our experiment: **F=mg (in other words, the gravitational force is equal to mass times the gravitational acceleration constant).** Our goal with this experiment is to prove the acceleration due to gravity on Earth by dropping weights of different masses through photocells and calculating their gravitational acceleration using velocity measurements we have obtained based on data displayed on the Vernier Labquest and our control variable, distance. For our calculations, we must first use the following equation in Kinematics to determine acceleration using initial velocity, final velocity, and distance measurements:

$$v_f^2 = v_i^2 + 2*a*d$$

or in other words, the **final velocity squared** is equal to the **initial velocity squared** plus **two** times **acceleration** multiplied by **distance**. To prove acceleration due to gravity, we can rearrange the above equation to solve for "a":



Finally, to **confirm** the acceleration due to gravity on Earth and put the cherry on the icing, we will simply determine the gravitational force of each of the weights using an electronic spring scale. **After we have obtained the force value for each weight (also knowing their mass), we can use the formula explicated earlier in a rearranged manner to determine the acceleration due to gravity: g = F/m,** and prove the gravitational constant. In nature, Newton's 2nd Law of Motion explains why bowling balls fall faster than feathers (with the exception of vacuum environments), why an object with a particular mass falls to the ground faster on Earth than on Mars, why the weight of an object is greater on Earth than on the Moon, and ultimately, why the gravitational acceleration of an object is 9.81 m/s^2 on Earth, 3.72 m/s^2 on Mars, and 1.62 m/s^2 on the Moon. According to several scientific accounts, Galileo Galilei was once standing at the top of the Leaning Tower of Pisa to perform a physics experiment with gravity by simultaneously dropping two cannonballs of different masses from the top of the tower. From his famous experiment, he discovered that all objects fall at the same rate toward the Earth (9.81 m/s^2) regardless of their mass after realizing that the cannonballs he dropped encountered the ground at exactly the same time. We are going to perform a similar experiment to prove acceleration due to gravity.



Above: Galileo's famous experiment on falling bodies, Pisa, Italy, 16th Century

<u>Materials:</u>

- Photocells x 2
- Stand to attach the photocells to x 1
- Electronic Spring Scale x 1

- 50g weight x 1
- 200g weight x 1
- Vernier LabQuest x 1
- Computer to record experimental data x 1 or 2
- Placeholders x 2
- Textbooks to raise the elevation of the stand x 4

Scientific Procedure/Method for Conducting Experiment:

1. Grab all the materials described above.
2. Create an observations table on the document with your lab information showing the following information: 1st row → 50g weight; 2nd row → 200g weight, 1st column → Force due to gravity (in Newtons); 2nd column → Acceleration due to gravity (m/s^2); 3rd column → Initial Velocity (m/s); 4th column → Final Velocity (m/s).
3. Measure the distance between the two photocell lasers to determine the controlled variable measurement.
4. Place one photocell 5 cm below the top of the stand using the placeholder.
5. Place the second photocell 5 cm above the bottom of the stand using the other placeholder.
6. Now that you're all set, connect the two photocells to the Vernier LabQuest wirelessly.
7. Set the settings on the Vernier LabQuest to display "object velocity" using measurements from the photocells.
8. Release the 50g weight and let it fall vertically through the two photocells. Try to release it as close to the top photocell laser as possible.
9. After the weight has fallen through the two photocells, record the data displayed on the Vernier LabQuest showing the initial and final velocity of the weight in your observations table.
10. Repeat steps 8 and 9 two more times to obtain more accurate data (for a total of 3 trials).
11. After obtaining the measurements from the 3 trials, calculate the averages of the initial and final velocities and note them down in the 3rd and 4th columns of the observations table you created earlier. These averages from the three trials you conducted are the initial and final velocity values that will be used to calculate acceleration due to gravity in the next step.
12. Implement the distance, initial velocity, and final velocity measurements into the kinematics equation indicated in the background information of your lab

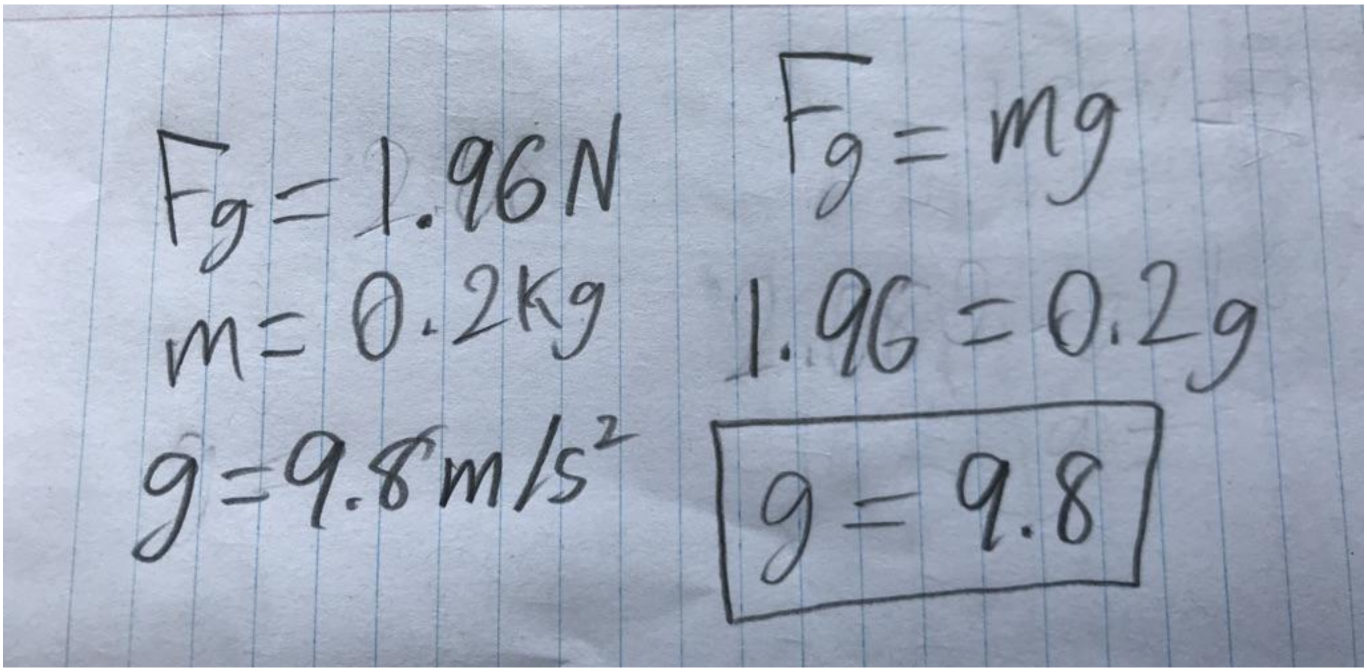
document to obtain the acceleration due to gravity value. Note this value down in the 2nd column of your observations table.
13. Repeat steps 8-12 but with a 200g weight this time.
14. Put the cherry on the icing: Measure the gravitational force (in Newtons) of both weights using the electronic spring scale. Using the force measurements and masses of the two objects, calculate acceleration due to gravity using the gravitational force formula (F=mg) to confirm the value of the gravitational constant. This should, in theory, give you a more precise measurement of the gravitational acceleration value on Earth → thereby allowing you to more confidently conclude that the gravitational constant is 9.81 m/s^2 on our planet. Note the gravitational force measurements for both weights in the 1st column of your observations table.
15. Summarize the results of your experiment using evidence-based explanations and present your experimental data using equations, graphs, and/or any other mathematical method you wish. For this experiment, it's best to make a scatter plot to graphically present the data you have obtained by doing the following steps: Calculate the gravitational acceleration of the 50g and 200g weights for each of the 6 trials you have performed (3 for 50g and 3 for 200g) using the kinematics equation described earlier. Then, calculate the average gravitational acceleration of the 3 trials for each of the two weights. After you have received these two values, create a table in a Google Sheets (preferred) or Microsoft Excel document with 1 column (depicting the average acceleration due to gravity of each of the weights) and 2 rows (one for each weight that is dropped in the experiment). Implement the results from your calculations showing the average gravitational acceleration values of each of the weights into the table. These will be the points of your scatter plot. From the table you created, insert a chart. The x-axis of your chart should be labelled as the masses of the weights (the independent variable), while the y-axis should be labelled as the acceleration due to gravity (the dependent variable). Set the scale of the y-axis of your chart as an interval between 0 and 11. Meanwhile, the x-axis will only have 2 values: 50g & 200g. In addition to the scatter plot and observations table, take and insert images of any mathematical calculations you have performed to obtain your data into your lab document.
16. Draw meaningful conclusions from the results of your experiment.

Results

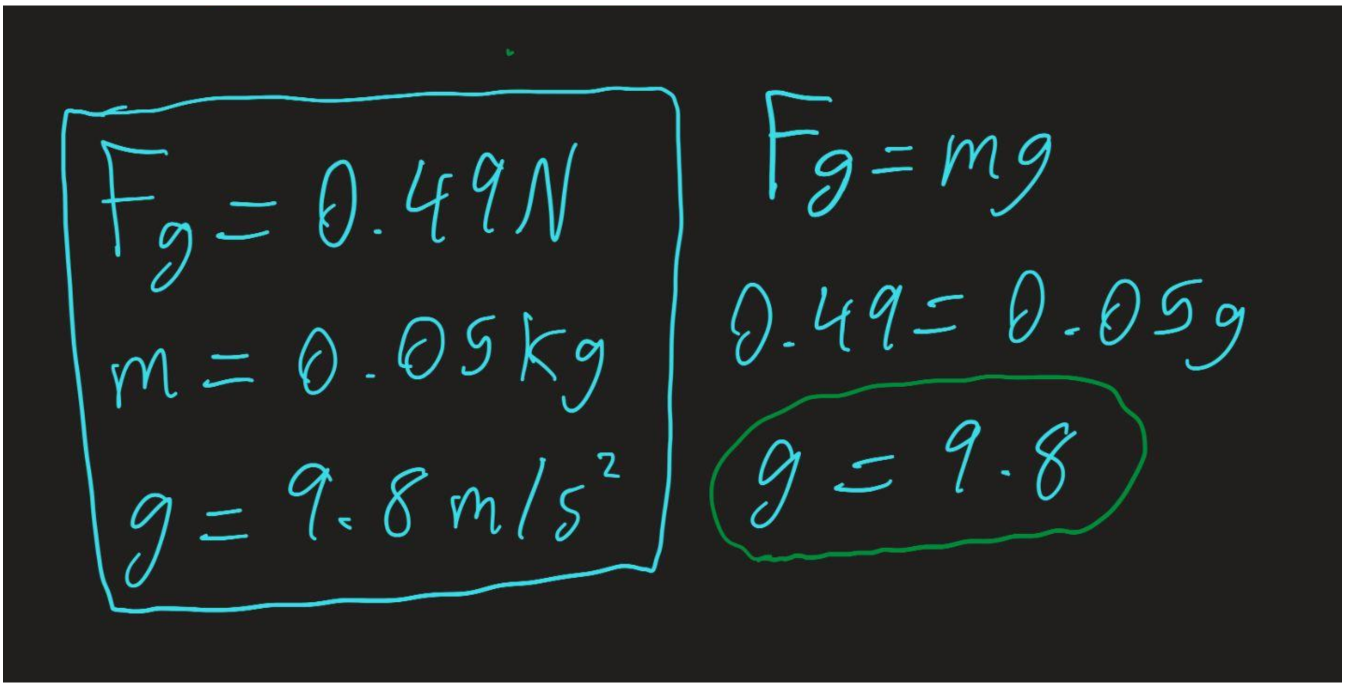
Mathematical Calculations:

<u>F=mg</u>

For 200g Weight:



For 50g Weight:



Kinematics Equation for obtaining Gravitational Acceleration:

50g

$$V_f^2 = V_i^2 + 2ad$$

$$2ad = V_f^2 - V_i^2$$

$$a = \frac{V_f^2 - V_i^2}{2d}$$

$$a = \frac{(2.942)^2 - (0.6)^2}{2 \times 0.42} = \frac{8.295364}{0.84} = 9.875\ m/s^2$$

Margin of Error: 0.66%

200g:

$$a = \frac{(2.935)^2 - (0.691)^2}{2 \times 0.42} = \frac{8.136744}{0.84} = 9.69\ m/s^2$$

Margin of Error: 1.2%

∴ ① 50g: $9.875\ m/s^2$
② 200g: $9.69\ m/s^2$

Acceleration due to Gravity on Earth: $9.81\ m/s^2$

Average of ① & ②: $9.7825\ m/s^2$

Calculations by Amirali & Noah
Science 10 Physics Experiment

Observations Table:

	Force due to gravity (N)	Acceleration due to gravity (m/s^2)	Initial Velocity (m/s)	Final Velocity (m/s)
50g Weight	0.49	9.875	0.6	2.942
200g Weight	1.96	9.69	0.691	2.935

Distance between the two lasers: 0.42 metres

Trials:

= Initial Velocity
= Final Velocity

200g Weight:

1st:
0.664 m/s
2.927 m/s

2nd:
0.741 m/s
2.930 m/s

3rd:
0.668 m/s
2.949 m/s

Average Velocities:
0.691 m/s
2.935 m/s

50g Weight:

1st:

0.667 m/s

2.946 m/s

2nd:

0.468 m/s

2.949 m/s

3rd:

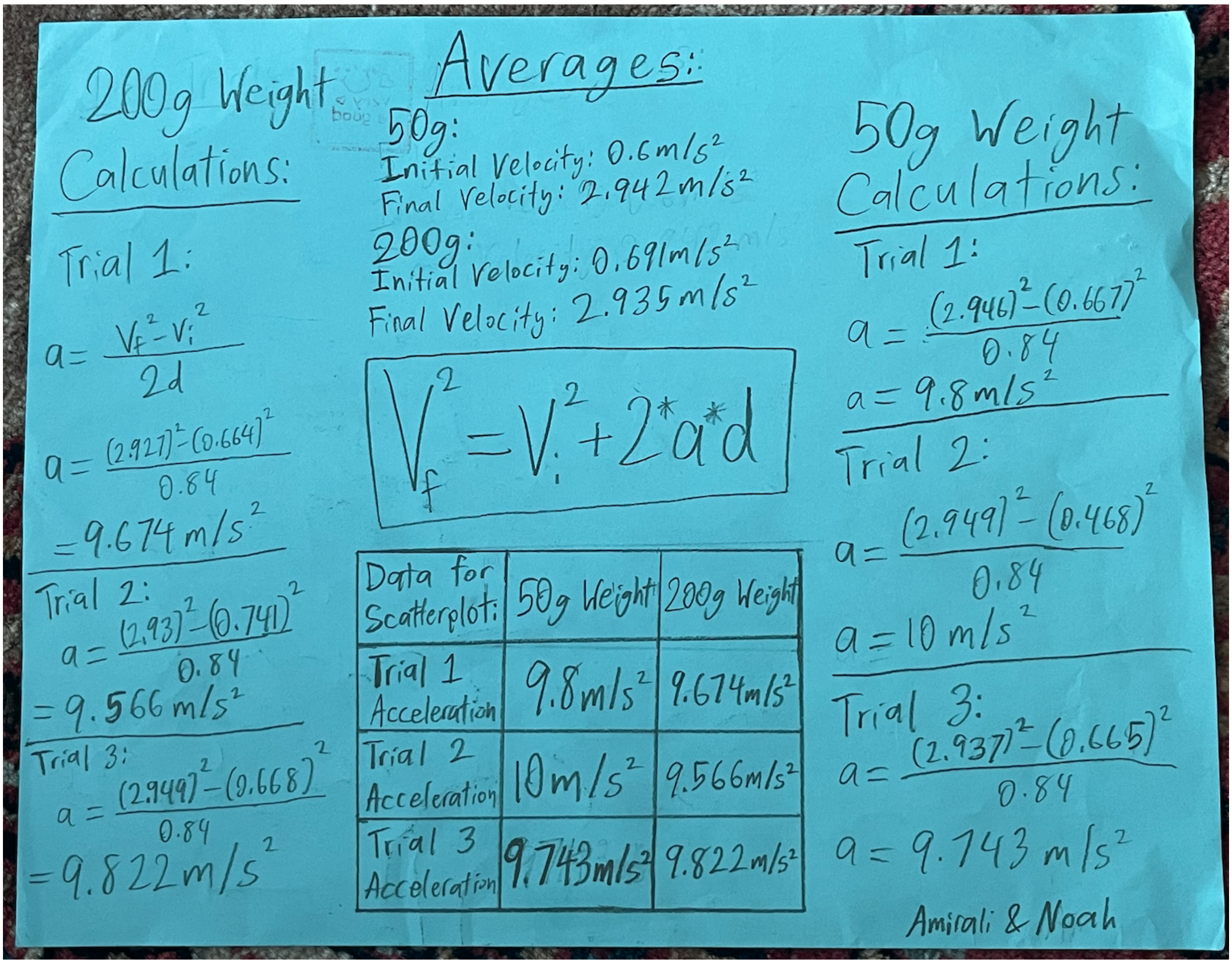
0.665 m/s

2.937 m/s

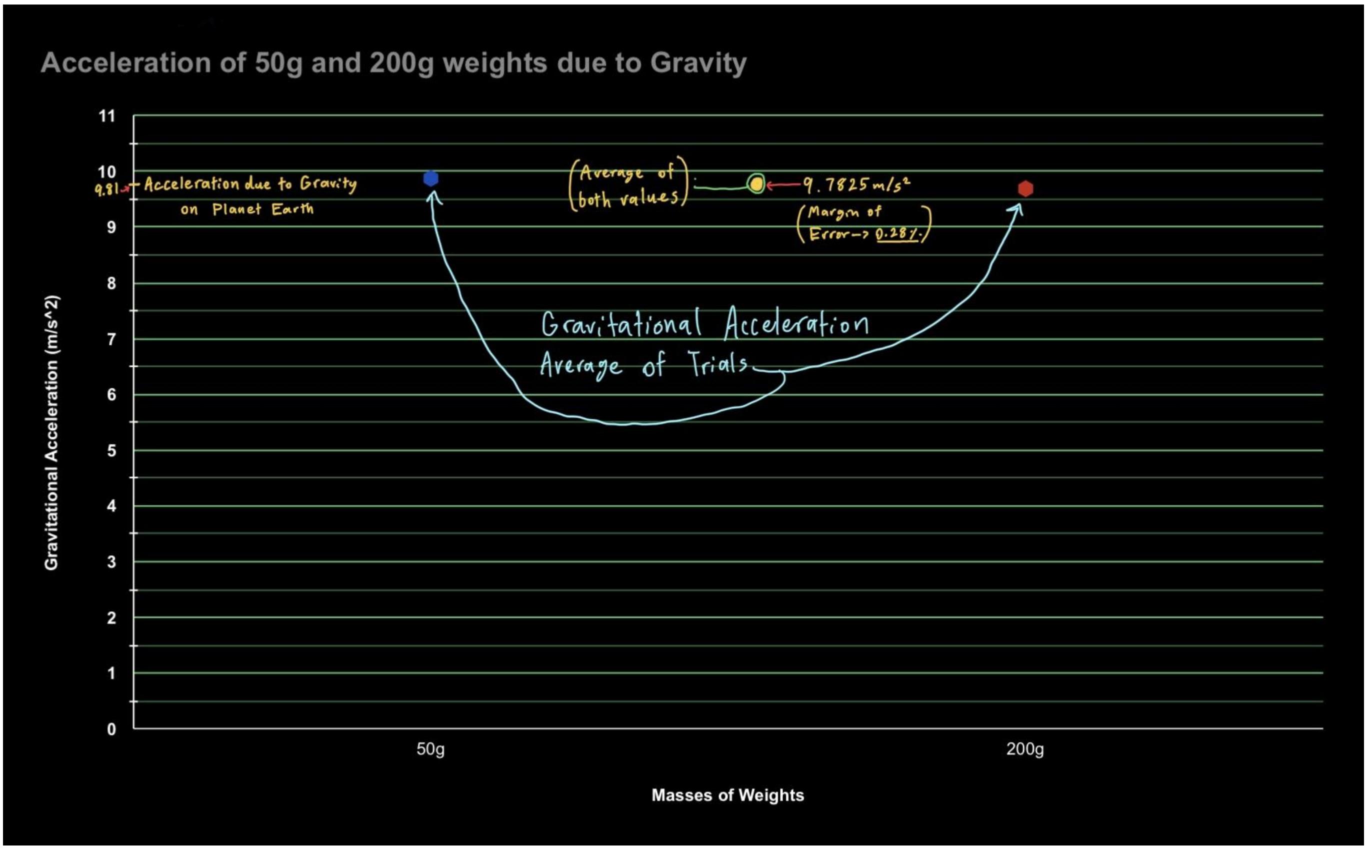
Average Velocities:

0.6 m/s

2.942 m/s



Scatterplot of our Experiment Results:



Conclusion

The purpose of our lab was to prove acceleration due to gravity on Earth and based on the results of our experiment, we can conclude that the value of gravitational acceleration on Earth is indeed valid. Although we didn't precisely obtain Earth's gravitational acceleration value of 9.81 m/s^2 from dropping the weights through the photocells, we did acquire very close results with a small margin of error. Of course, certain factors can cause this margin of error including where and at what height exactly we drop the weights from each time and how accurately the photocells can measure the initial and final velocity of the falling object, but these are factors that would inevitably alter the accuracy of our results regardless of what we do about them because after all, nothing in the world is perfect. Nevertheless, we confirmed the true value of gravitational acceleration on Earth using the gravitational acceleration equation, F=mg. We used the electronic spring scale to measure the force applied by the 50g and 200g weights and then used the force and mass measurements to determine the acceleration due to gravity. Amazingly, we obtained precisely 9.8 m/s^2 from this simple calculation, ultimately confirming acceleration due to gravity on Earth. One of Galileo Galilei's greatest contributions to Physics involved accurately measuring the effect of gravity on objects in free fall. Using his profound understanding of physical laws and theoretical physics, Galileo hypothesized that a falling object would gain equal quantities of velocity in equal quantities of time, meaning that its velocity increased at a constant rate as it fell. He tested his ingenious hypothesis with a famous experiment at the top of the Leaning Tower of Pisa where he dropped objects of different masses from the top and observed that every passing second, the velocity that each object was falling at increased by 9.81 metres. He also concluded from his experiment that the acceleration of a free-falling object due to gravity does not depend on the object's mass. This value of gravitational acceleration has had incredible implications in Earth Science, Astronomy, and even Biology → the effects of different "Gs" on the physiological processes of biological organisms (1G = 9.81 m/^2 → the gravitational acceleration value that we have evolved to adapt to; 5G = 49.05 m/s^2 → a gravitational force so strong that systemic circulation would be impossible, leading to death).

Lab Improvements & Future Experiments

1. Our experiment could have some improvements in planning, allowing us to have more time to experiment and thus draw more accurate conclusions. We have changed many procedures, materials, and formulas for calculations from the beginning of our physics lab until performing our final experiment. By spending a bit of time planning before going straight into working on our lab and perhaps doing some research on what physics formula(s) would be most suitable for our particular experiment, we can save a considerable amount of time for experimentation, drawing valid conclusions, and presenting data in various mathematical ways. Proper planning before experimenting can lead to more accurate results which can help us confirm with more confidence the acceleration due to gravity on Earth.

2. Another way we could improve our experiment is to make some sort of hook, place it on top of the stand, and attach a weight onto it whenever we want to drop one through the two photocells. By doing so, we can drop each weight from a precisely specified, constant height so that we can acquire measurements with higher accuracy. This could potentially eliminate the margin of error or reduce it to a small fraction of a percent, giving us more precise measurements which can help us prove more confidently the acceleration of gravity on Earth.

- If I had more time, I would investigate how the surface area may affect the gravitational acceleration of an object. While every object will fall at a rate of 9.81 m/s^2 towards Earth due to the force of gravity regardless of its mass, air resistance could affect the rate at which an object falls. Specifically, objects that have a greater surface area to mass ratio will fall at a slower rate toward Earth than objects with a lower surface area to mass ratio as they experience greater air resistance (drag). This is why, for example, a bowling ball falls to the ground much faster than a feather (in non-vacuum environments). With more time, Noah and I would love to experiment with objects that have varying surface areas to investigate the effects of this quantity on acceleration due to gravity and to what extent it actually affects the gravitational acceleration of an object.

Information Sources

What is Newton's second law? (article) | Khan Academy
NOVA - Official Website | Galileo's Experiments (pbs.org)
The Value of g (physicsclassroom.com)
Acceleration due to gravity - Energy Education
The Role of Mass in Free Fall (physicsclassroom.com)
Newton's Second Law of Motion (physicsclassroom.com)
12 experiments that changed the world – How It Works (howitworksdaily.com)

Experiment performed by Amirali Banani & Noah Dachner | May 2021