Newton's Second Law Experiment

Physics

Objectives

- Study the relationship between force, mass and acceleration as described by Newton's second law.
- Use different masses to observe and analyze variations in acceleration.

Modules and Sensors

- PC + NeuLog application
- USB-200 USB module (or BLT-202 Bluetooth module)
- NUL-213 Motion logger sensor

Equipment and Accessories

▪ 1m track	1
▪ Track leg	2
▪ Track rider	1
▪ Cart with hook	1
▪ Reflector plate	1
▪ Utility stand	2
▪ Right-angle clamp	3
▪ 20" rod	1

▪ Extension clamp	1
▪ Rod with pulley	1
▪ 50g slotted mass	3
▪ 100g slotted mass	2
▪ Slotted mass for challenge	-
▪ Slotted mass holder rod	1
▪ Slotted mass hanger	1
▪ 150cm Thread	1

- The items above are included in the NeuLog Mechanics kit, MEC-KIT.

Introduction

Newton's second law of motion defines the precise relationship between force, mass and acceleration. The law states that the acceleration of an object is directly proportional to the net force applied and inversely proportional to its mass:

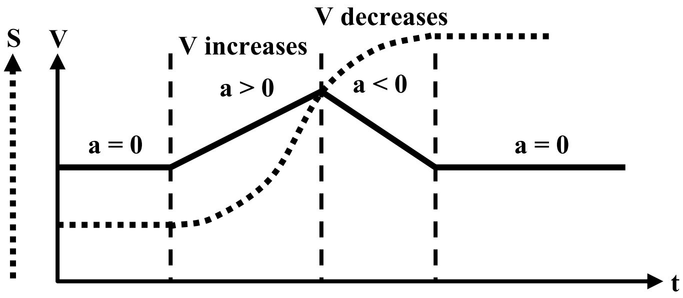
$$\mathbf{F = m \cdot a}$$

In this experiment, different slotted masses (300g, 250g, and 200g) will be placed on a cart. A 50g mass connected to the cart via a thread will be dropped, pulling the cart along the track. Understanding this relationship is crucial in physics and engineering, as it explains the fundamental mechanics behind motion and force interactions.

You will measure the cart's position and velocity using a motion sensor and calculate its acceleration in the different stages.

Mathematical Representation

The following graph illustrates the velocity of a cart moving along a track..



The velocity and distance of the cart can be described using the following equations:

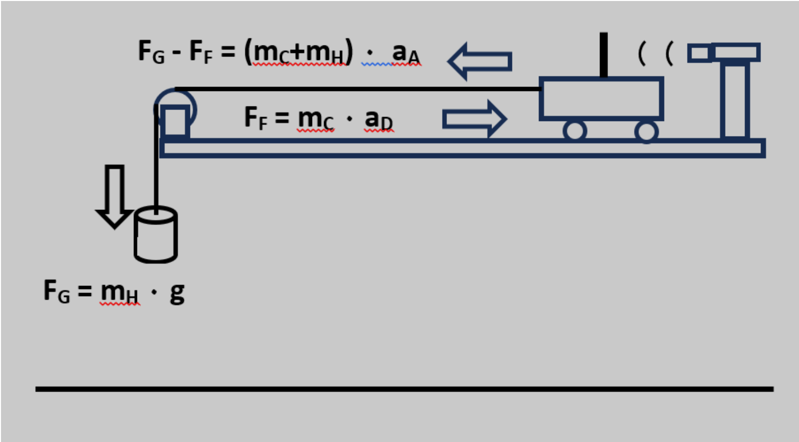
$$\mathbf{V = at + V_0}$$
$$\mathbf{S = \frac{a}{2}t^2 + V_0 t + S_0}$$

Where:

- V_0 is the initial velocity.
- S_0 is the initial distance.
- a is the acceleration.

Forces Acting on the Cart

The following picture illustrates the forces acting on the cart.



1. **Gravitational Force (F_G)**: The force pulling the cart is the weight of the hanger and its attached masses. We denote it as $\mathbf{m_H}$.

   $\mathbf{F_G = m_H \cdot g}$

2. **Friction Force (F_F)**: The frictional force acts against the cart's movement, slowing it down.

   We define the cart's deceleration as $\mathbf{a_D}$ and its mass as $\mathbf{m_C}$.

   $\mathbf{F_F = m_C \cdot a_D}$

3. **Total Net Force (F)**: The force acting on the cart is the gravitational force minus the friction force:

   $\mathbf{F = F_G - F_F}$

Newton's Second Law Applied to the System:

When the force **F** pulls the cart, it experiences a positive acceleration, resulting in an increase in velocity.

We define the cart's acceleration as $\mathbf{a_A}$.

$\mathbf{m_H \cdot g - m_C \cdot a_D = (m_H + m_C) \cdot a_A}$

When the hanger mass lands. the cart is no longer pulled forward and friction becomes the dominant force, causing deceleration.

To verify experimental results, we calculate the acceleration due to gravity using:

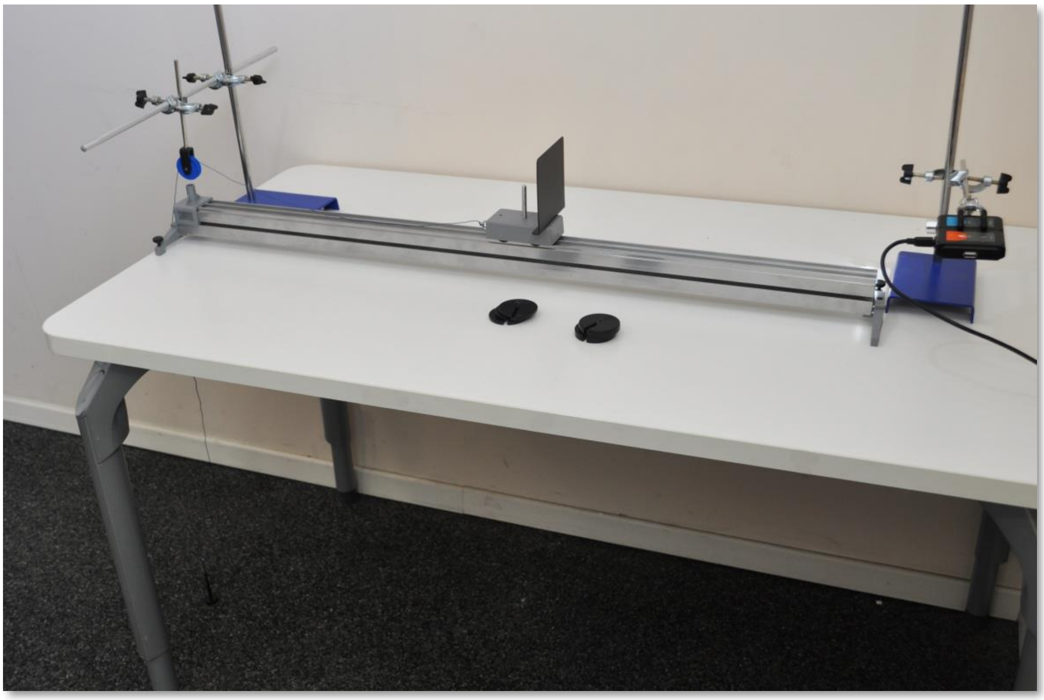
$$g = \frac{(m_H + m_C)a_A + m_C a_D}{m_H}$$

$\mathbf{g = ((m_H + m_C) \cdot a_A + m_C \cdot a_D)/m_H}$

Procedure

Experiment setup

1. Set up the experiment as shown in the picture below.



2. Assemble a 1 m track with two legs and a track rider.

3. Position a utility stand at each side of the track.

4. Attach the cart with a slotted mass holder rod and a reflector plate.

5. Ensure one end of the track is near the table's edge. Install the rod with pulley on the utility stand using two right-angle clamps and a 20" rod.

6. Tie a 150cm thread to the cart's hook.

7. Pass the other end of the thread through the pulley and attach it to the slotted mass hanger.

8. Ensure that when the slotted mass hanger reaches the floor, the cart has 30-40 cm left to move on the track.

9. Attach the motion sensor to the USB-200 module, securing it to the utility stand.

10. Direct the motion sensor toward the cart reflector plate, ensuring alignment along the track.

    The reflector plate's size should be at least 10 x 10cm.

<u>Sensor setup</u>

11. Connect the USB-200 module to the PC.

12. Verify the motion sensor is connected to the USB-200 module.

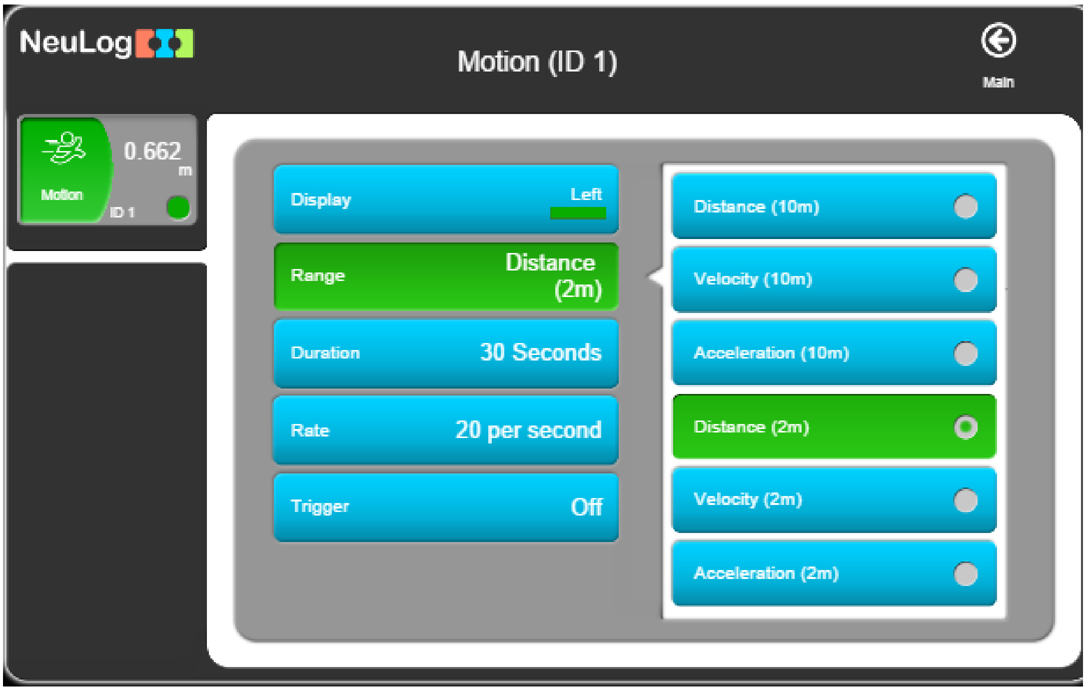
> **<u>Note:</u>**
>
> The following application functions are explained in short. It is recommended to practice the NeuLog application functions (as described in the user manual) beforehand.

13. Run the NeuLog application and check that the motion sensor is identified.

<u>Settings</u>

14. Click on the **Sensor's Module** box and select the **Range** button.

15. Set the mode to Distance (2m) to measure position.



16. Click on the icon to go back to the graph.

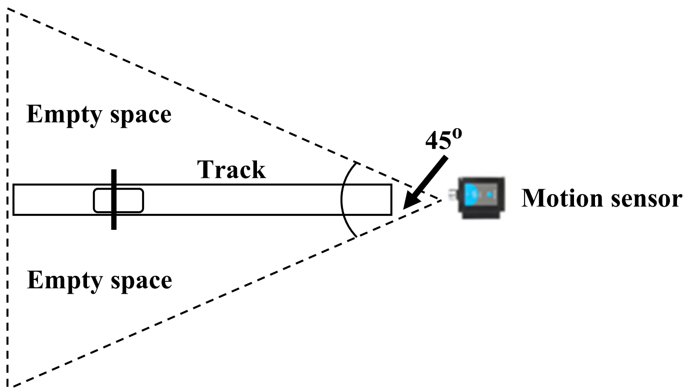
Testing and measurements

Note:

The sensor measures the distance from an object by emitting an ultrasonic pulse, which is inaudible to humans, and calculating the time it takes the echo to return.

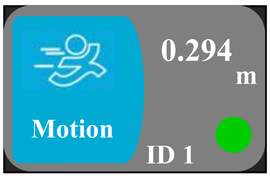
The sound beam angle is approximately 45°, the sensor records the time of the first received echo.

Ensure that no objects are present within the beam range to prevent interference and inaccurate readings.



17. Before starting the experiment, ensure that the motion sensor is well aligned with the cart's path.

    Observe that the position (distance from sensor) values appear in the sensor's module box.



18. Move the cart from the starting position (30 cm from the motion sensor) to the edge of the track, ensuring the sensor tracks the cart's distance accurately.

19. Place two 100g slotted masses and two 50g slotted masses (total 300g) on the cart's slotted mass holder rod.

20. Attach a 50g mass to the slotted mass hanger.

21. Click on the **Run Experiment** icon  and configure:

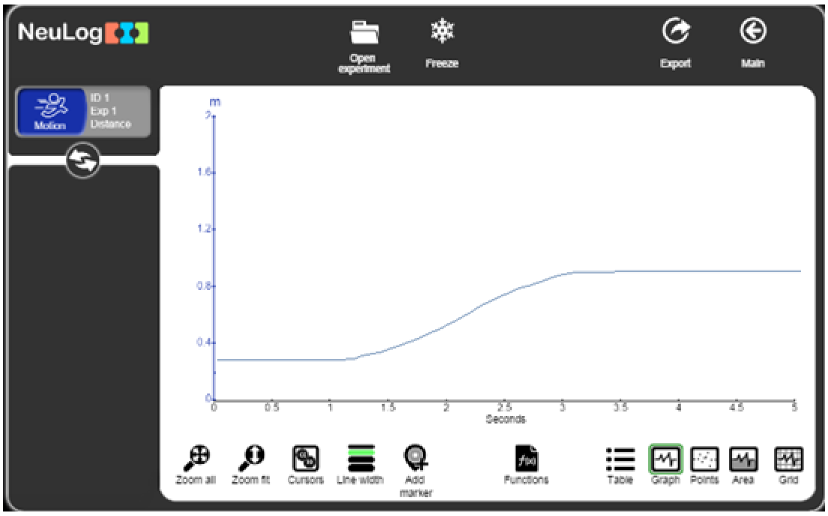
- Experiment duration: **5 seconds**
- Sampling rate: **50 per second**

Executing the Measurement

22. Place the cart at the starting position and click on the **Record** icon  to start the measurement.

23. Drop the slotted mass hanger, release the cart, and observe its movement.

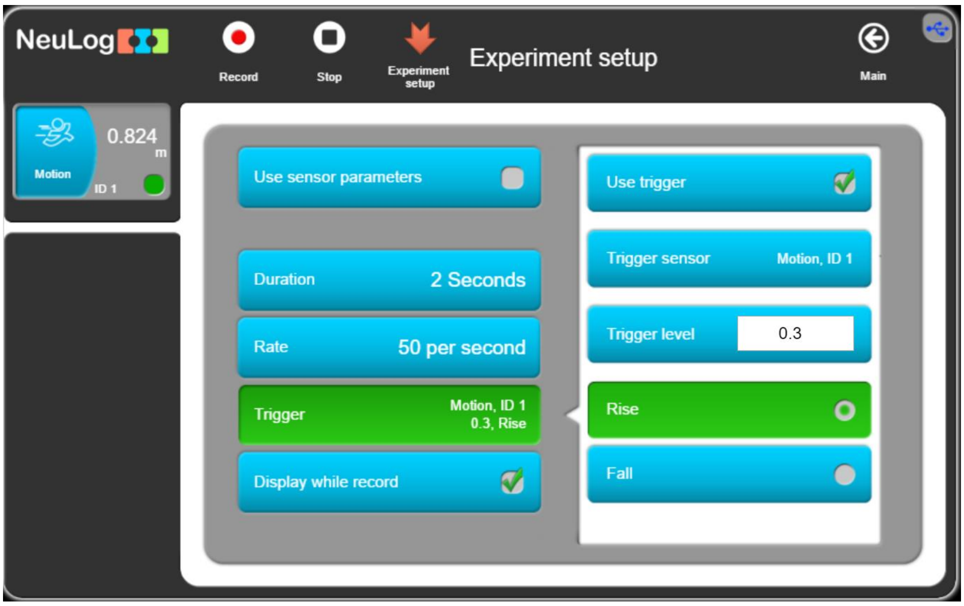
24. Your graph should resemble the expected velocity-time curve (use the **Zoom fit** icon  if needed):



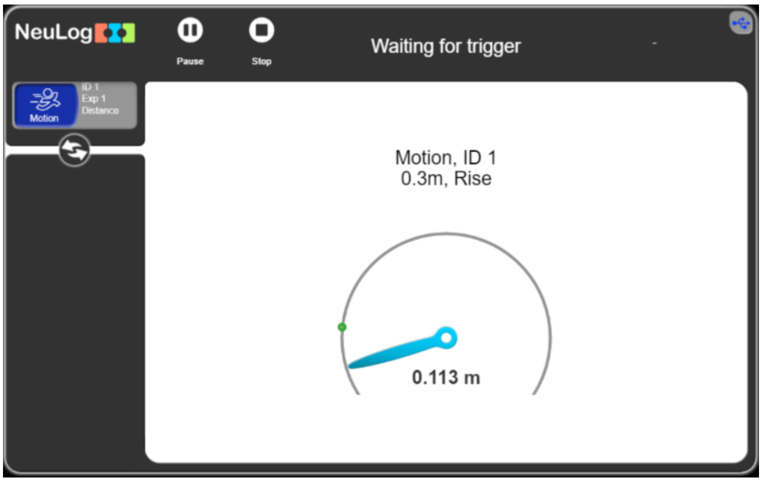
25. If your graph does not match expectations, verify that:
    - The cart moves continuously toward the motion sensor,
    - No objects interfere with the sensor's echo readings.

26. Identify the distance where the weight reaches the floor and the thread remains stretched. This is the slowing down distance.

27. Click on the **Run experiment** button and set up a 30cm trigger.



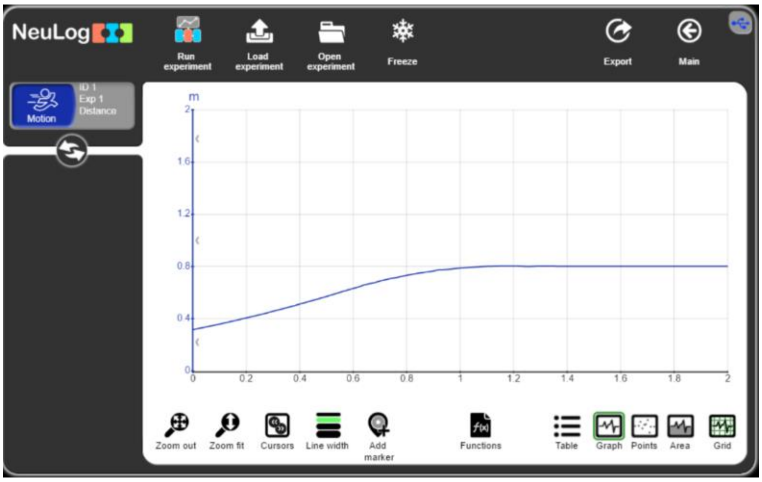
28. Bring the cart to a distance less than 30cm from the sensor and click on the **Record** button.



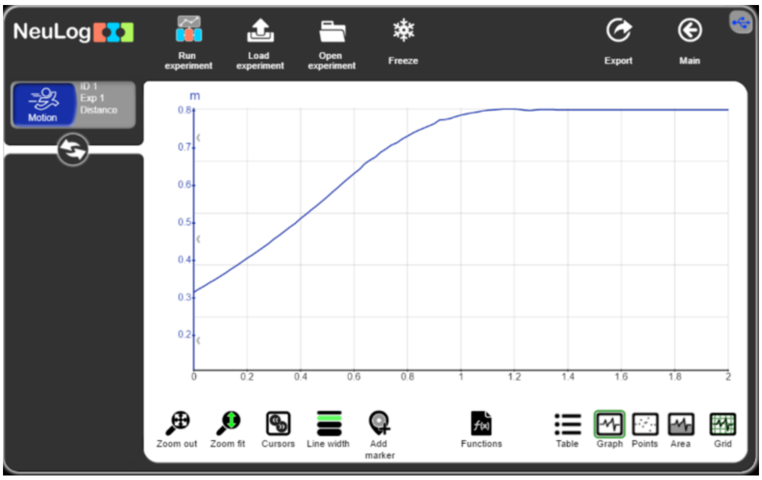
The system will wait for the trigger before recording data.

Analyzing the Data

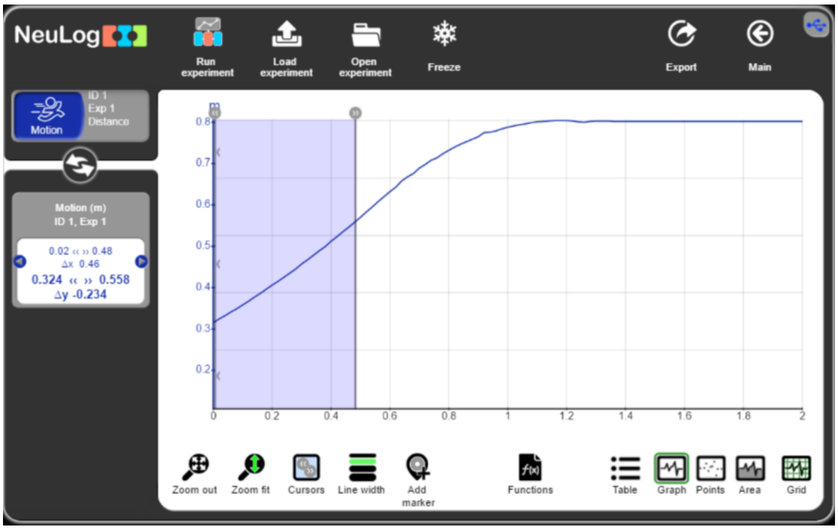
29. Leave the cart and observe the results displayed on the screen.



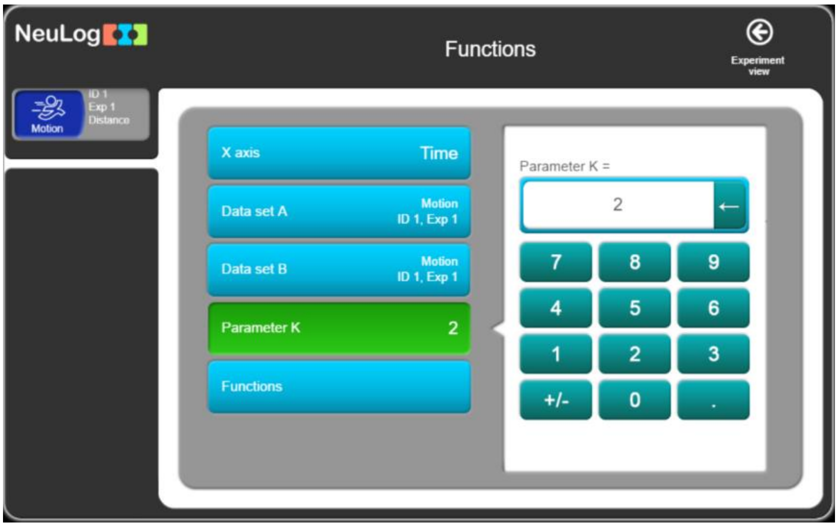
30. Click on the **Zoom fit** to view the full dataset.



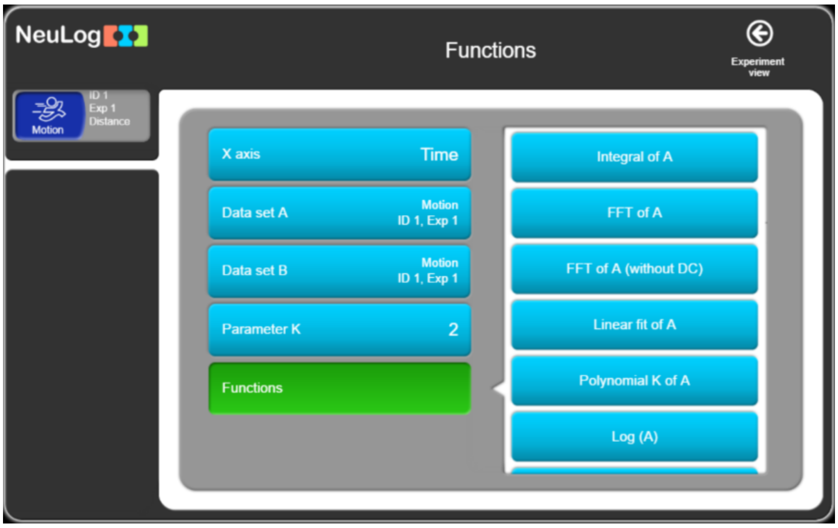
31. Click **Cursors** and position them at the start of the graph to just before the slowing down distance.



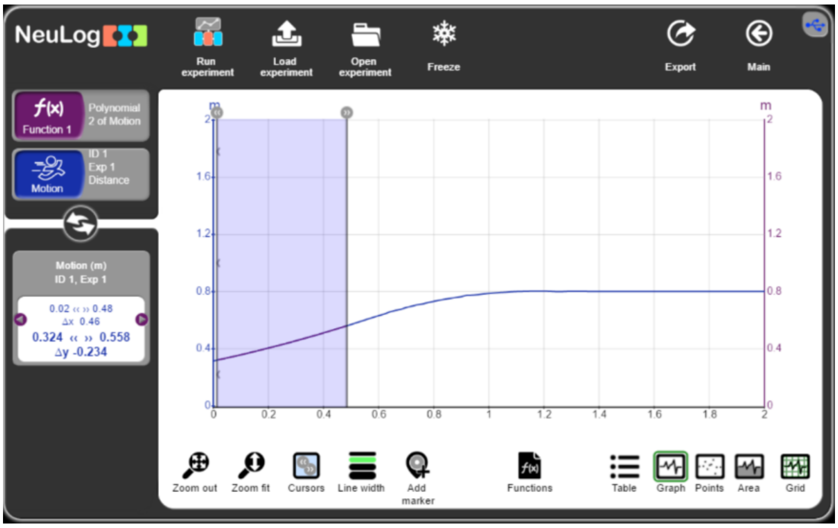
32. Click **Functions**, set K to 2.



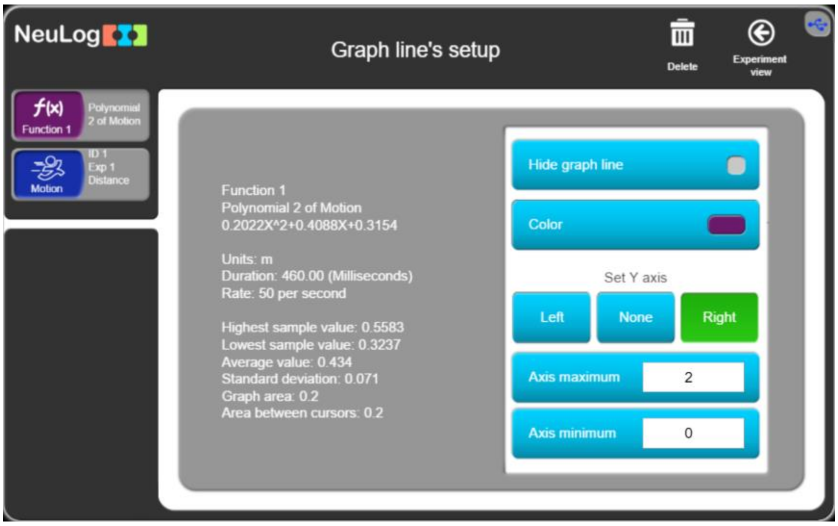
33. Click on **Functions** and click on the **Polynomial K of A** button.



34. A new icon for the polynomial curve will appear on the left.



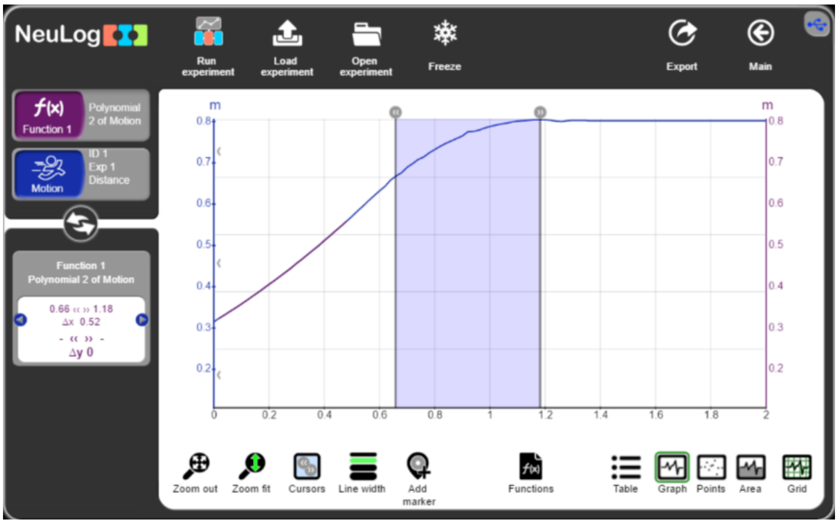
35. Click on this icon to view the data and the formula on the screen.

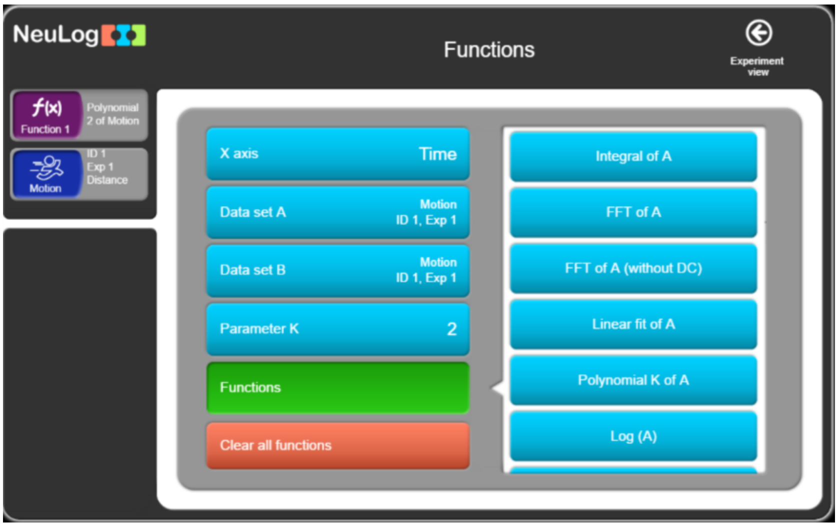


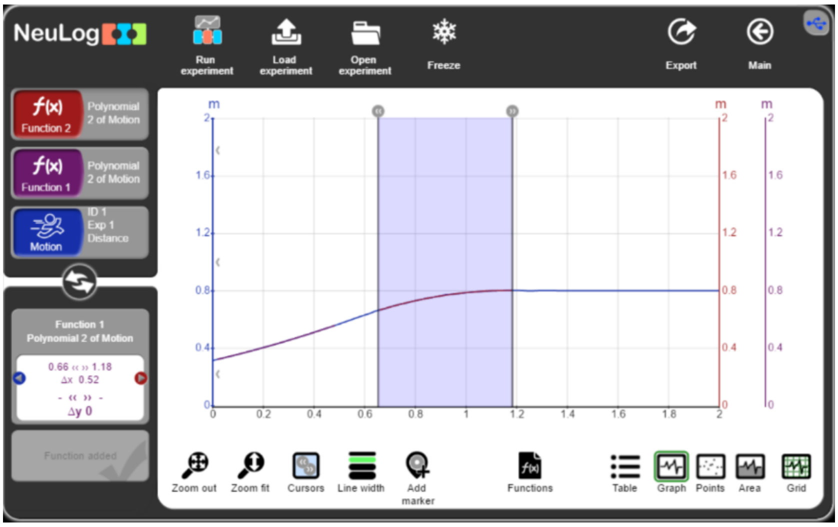
36. The coefficient of $X^2 = 0.20$, meaning:

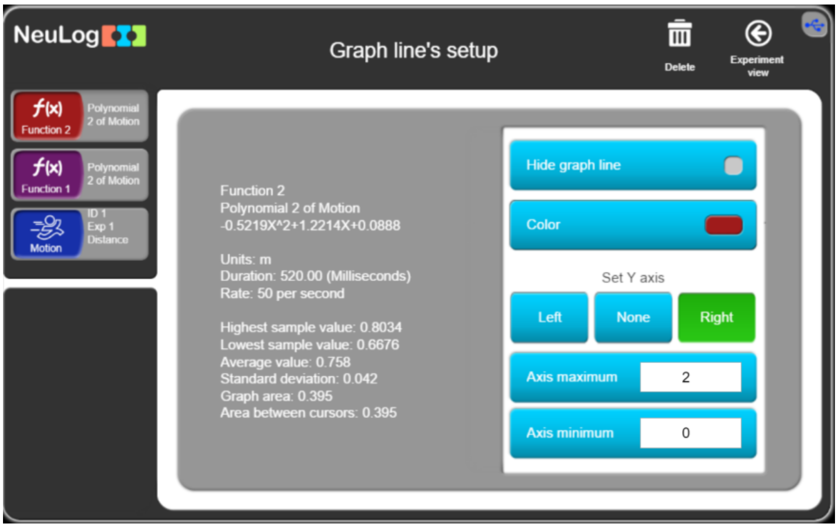
acceleration **$a_A = 0.4\ m/s^2$**

37. Repeat the same analysis for the deceleration [phase after the slowing distance.









The coefficient of X^2 = -0.52, meaning:
Deceleration **a_D = 1.04 m/s^2**

38. Click **Export**  and select **Save value table (.CSV)** to save the graph data.

Final Calculations

39. The cart's total mass is 400g (0.4Kg), considering the cart mass itself weighs 100g.

40. Using Newton's second law:

$$F = m \cdot a$$

$$F_D = 0.4 \times 1.04 = 0.416 \text{ N}$$

$$\mathbf{F_F = m \cdot a_D = 0.4Kg \cdot 1.04m/s^2 = 0.416}$$

(Absolute value used, considering opposite directions).

Recorded Data Table

Parameter	Cart (100 g) + slotted masses (300 g) m_C = 0.4Kg
m_H [Kg]	0.06
m_C [Kg]	0.4
$(m_H + m_C)$ [Kg]	0.46
a_A [m/s^2]	0.4
a_D [m/s^2]	–1.04

41. Calculate the gravitational acceleration based on these experimental results.

$$g = \frac{(m_H+m_C)a_A+m_C a_D}{m_H}$$

$$g = \frac{(0.06+0.4)\times0.4-0.4\times1.04}{0.06}$$

$$g = 10 \text{ m/s}^2$$

This result is very close to the accepted value of 9.82 m/s^2

Repeating the Experiment

42. Copy the table below.

Parameter	**Cart (100 g) + slotted masses (250 g) m_C = 0.35Kg**	**Cart (100 g) + slotted masses (200 g) m_C = 0.3Kg**
m_H [Kg]		
m_C [Kg]		
$(m_H + m_C)$ [Kg]		
a_A [m/s^2]		
a_D [m/s^2]		
Calculated g [m/s^2]		

43. Remove 50g from the cart and repeat the measurements.

44. Fill the second column of the table with new results.

45. Remove another 50g and repeat the experiment.

46. Complete the third column in the table.

Summary questions

1. How is the friction force affected by the cart's mass? Explain.

2. How is acceleration affected by **changes in** the cart's mass? Explain.

3. Does the cart's position change **during acceleration**? Why or why not?.

Conclusion: The Importance of Experimentation

This experiment provides **practical insight** into Newton’s second law by demonstrating how force, mass, and acceleration are interrelated.

By analyzing real-world data and comparing it to theoretical values, students can better grasp fundamental physics concepts and their applications in engineering and motion dynamics.