Motion Parameters of a Moving Cart
Experiment

Physics

Objectives

- Understand key motion parameters.
- Study the relationship between distance, velocity, and acceleration of a moving cart.

This experiment provides students with hands-on experience measuring and analyzing motion, helping them visualize abstract physics concepts. For teachers, the structured setup and clear measurement steps ensure a smooth learning experience and measurable outcomes.

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
▪ Magnet in plastic case	2
▪ Sellotape	1
▪ Cart with hook (or spring)	1
▪ Reflector plate	1
▪ Utility stand	2

▪ Right-angle clamp	3
▪ 20" rod	1
▪ Extension clamp	1
▪ Rod with pulley	1
▪ 10g slotted mass	2
▪ 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

The experiment focuses on three main motion parameters:

1. **Distance (S):** Represents how far an object moves from its starting point.
2. **Velocity (V):** The rate of change in distance over time, calculated as:

$$\frac{\Delta S}{\Delta t} = V$$

$$\mathbf{V(average)} = \frac{\mathbf{S(final) - S(initial)}}{\mathbf{t(final) - t(initial)}}$$

3. **Acceleration (a):** The rate of change in velocity over time, calculated as:

$$\frac{\Delta V}{\Delta t} = a$$

$$\mathbf{a(average)} = \frac{\mathbf{V(final) - V(initial)}}{\mathbf{t(final) - t(initial)}}$$

The formula above describes **average acceleration** (or constant acceleration). To calculate the **object's momentary acceleration** (a(t)), we use the ratio of a very small section of velocity change to the corresponding time difference.

In this experiment, a cart will move back and forth on a track, and we will observe and analyze how its distance, velocity and acceleration change over time. The following formulas describe velocity and distance as functions of time:

Velocity:

$$\mathbf{V = at + V_0}$$

Distance:

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

Where:

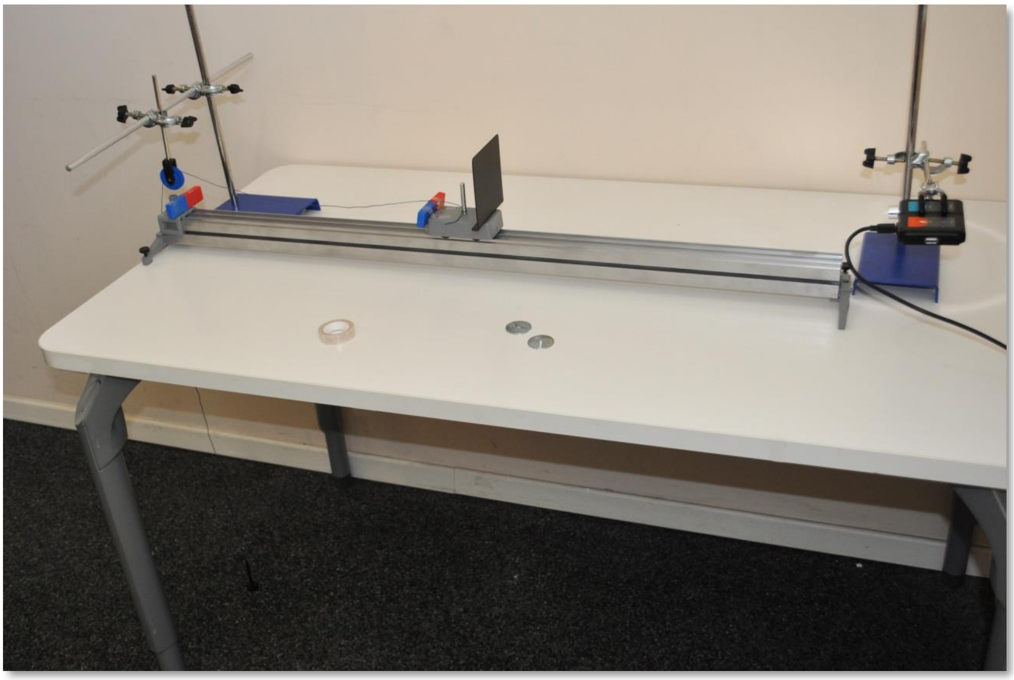
- V_0 = Initial velocity of the cart.
- S_0 == Initial distance from the reference point.
- a = Acceleration of the cart.
- t = Time elapsed

This hands-on experiment allows students to apply these formulas to real-world data, helping them understand how motion parameters interrelate and how they can be visually represented through graphs. For teachers, this provides an opportunity to guide students in connecting theoretical physics principles with practical observations.

Procedure

Experiment setup

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



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

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

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

5. Tape magnets to both the cart and track rider so they repel each other, or use a cart with a return spring.

6. Position the track so that one end is near the table's edge. Attach the rod with the pulley (facing downward) to the utility stand using two right-angle clamps and a 20" rod.

7. Tie one end of the 150cm thread to the cart's mass holder rod.

8. Pass the other end of the thread over the pulley and tie it to the slotted mass hanger.

   Ensure the cart has 30-40 cm of track remaining when the mass hanger touches the floor.

9. Attach the motion sensor (connected to the USB-200 module) to the utility stand.

   Align the motion sensor with the reflector plate, ensuring they remain aligned as the cart moves. The reflector plate's size should be at least 10 x 10 cm.

Sensor setup

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

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

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

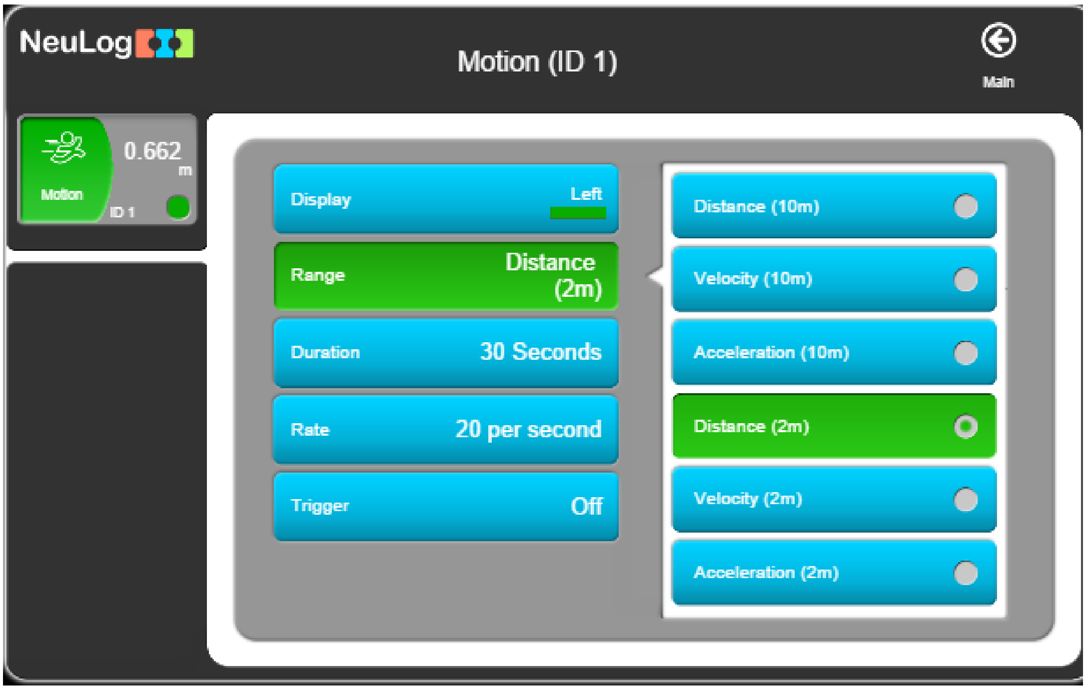
12. Run the NeuLog application and check that the motion sensor is detected.

Settings

13. Click the **Sensor's Module** box.

14. Click the **Range** button.

15. Select the **Distance (2m)** button to set the sensor to position mode.



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

17. Click on the **Run Experiment** icon and set the:

Experiment duration: **5 seconds**
Sampling rate: **20 per second**

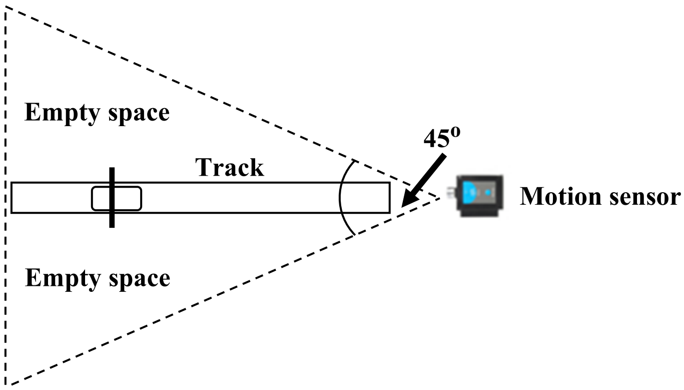
Testing and measurements

Note:

The motion sensor operates using **ultrasonic sound waves** that are inaudible to the human ear. It measures the distance to an object by sending a short pulse of sound and recording the time it takes for the echo to return. Key points to note:

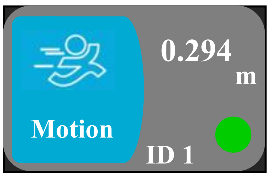
- **Beam angle:** Approximately 45°, meaning the sensor detects objects within this range.
- **First echo:** The sensor measures the time of the **first received echo**, which is why it's crucial to remove any items within the beam range that could reflect sound waves and cause inaccurate readings.

Make sure to remove any items located in the beam range.



18. Ensure the motion sensor is correctly aligned with the cart's path.

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



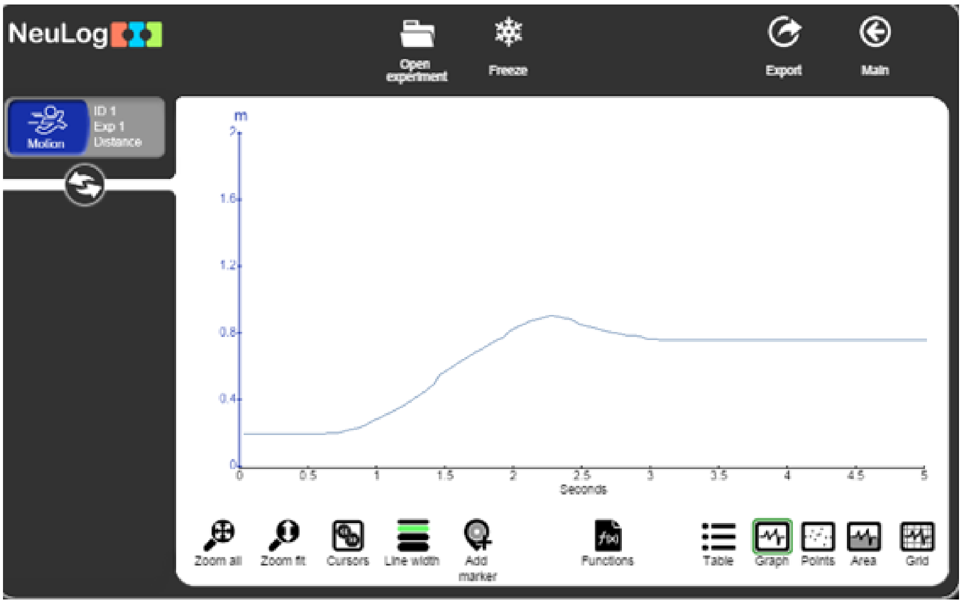
19. Move the cart from the starting point (30 cm from the sensor) to the track's edge, confirming the sensor track its distance.

20. Place two 10g slotted masses on the mass hanger.

21. Return the cart to the starting position and verify the hanger is elevated.

22. Click **Record** icon  to start measurement and release the cart.
    The hanger should pull the cart forward.

23. Your graph should be similar to the following (use the **Zoom fit** icon  if needed):



24. If the graph differs significantly from the expected results, check the cart's alignment with the motion sensor and ensure no objects are reflecting the sensor's ultrasonic pulses.

25. Click the **Export** icon  and then on the **Save value table (.CSV)** button to save your graph.

26. Click the  icon to go back to the graph.

27. Observe the graph and analyze it according to the cart movement.
When the cart accelerates, decelerates, stops, goes back and stops again.

28. How do the velocity graph and acceleration should look like?

Velocity and Acceleration Analysis

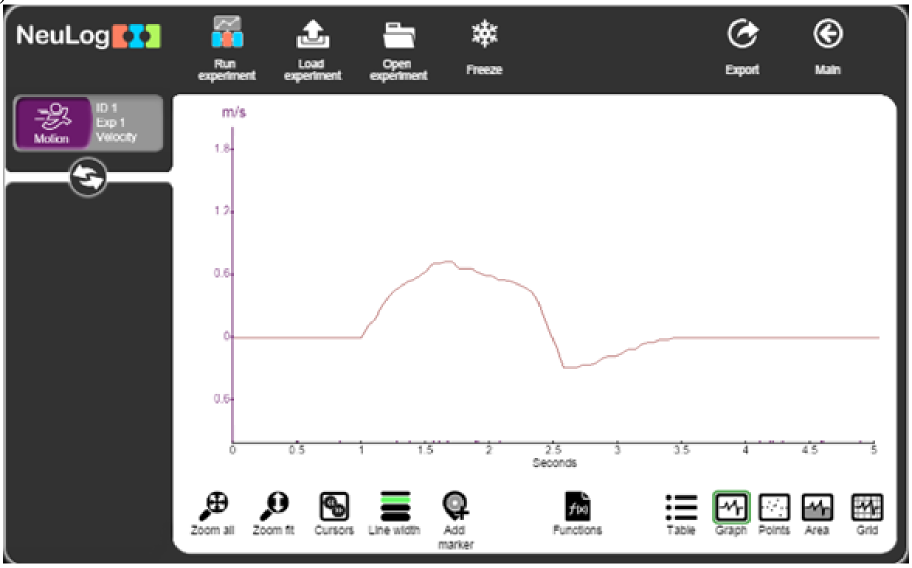
This section guides you through analyzing the cart’s movement using the NeuLog application. Follow each step to record, export, and interpret the velocity and acceleration data.

29. **Switch to Velocity Mode:**
• Click on the sensor's **Module box** and change the sensor’s mode to **Velocity (2m)**.
• Return the cart to the starting position and verify that the slotted mass hanger is elevated.

30. **Start Measurement:**

- Click the **Record** icon  to start recording.
- Release the cart and observe its movement as the mass holder pulls it forward.

31. Ensure the graph resembles the expected pattern (use the **Zoom fit** icon  if needed):



32. **Save your results:**

- Click the **Export** icon 
- Select **Save value table (.CSV)** button to save the graph data.
- Click the **Back**  icon to return to the graph.

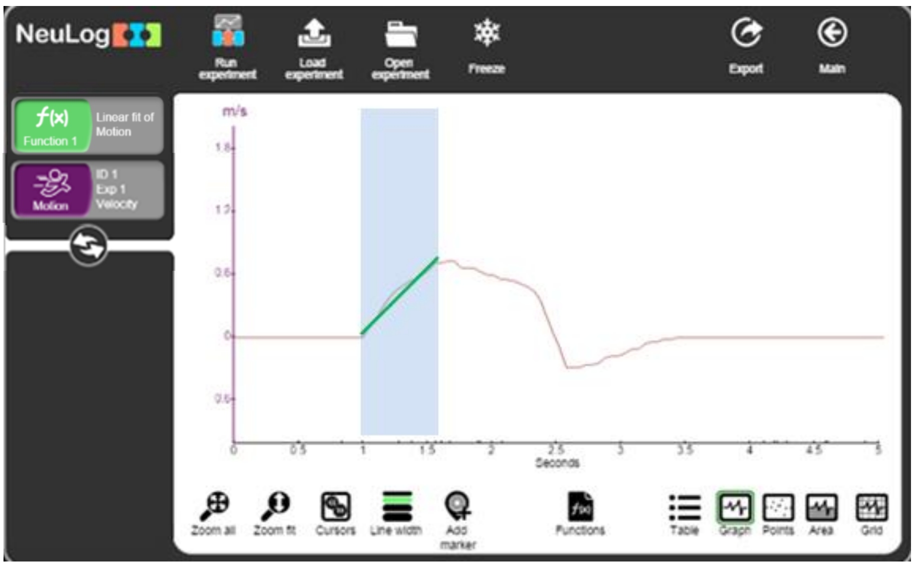
Analyzing Acceleration in Different Motion Phases

You will now analyze five distinct velocity ranges of the cart's movement by using the **Cursors** and **Linear fit** functions to calculate acceleration.

Range 1: Initial Acceleration (Positive)

33. Click the **Cursors**  icon and select the portion of the graph where the cart's velocity increases as it moves away from the sensor.

34. Click the **Functions** icon , then select **Linear fit of A**.



35. Click **the Linear fit module (function 1)** box to view the linear equation

At this range, the cart moves away from the sensor (because of the slotted masses) and its velocity increases; therefore, the acceleration is positive. The slope of the equation (**1.2 m/s^2**) equals the acceleration.

The line equation is: **Y=1.2X -1.125**

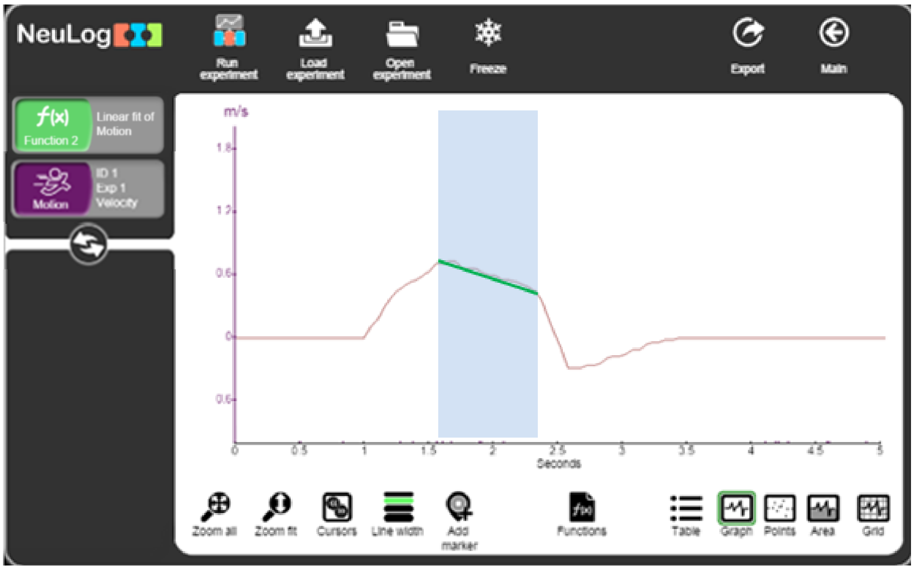
Y(X=0) = -1.125m/s
a = 1.2 m/s^2
V_0 = 0 m/s

36. Click on the **Functions** icon  and then on the **Clear all functions** button.

Range 2: Deceleration (Negative)

37. Select the portion of the graph where the cart continues moving away from the sensor but its velocity decreases as the mass hanger reaches the floor.

38. Click **Functions** button. then **Linear fit of A** button.



39. Click **Linear fit module (function 2)** box; you will see the linear fit equation.

40. At this range, the mass hanger is on the floor. The cart keeps moving away from the sensor but its velocity decreases, therefore the acceleration is negative **(-0.45 m/s^2)**.

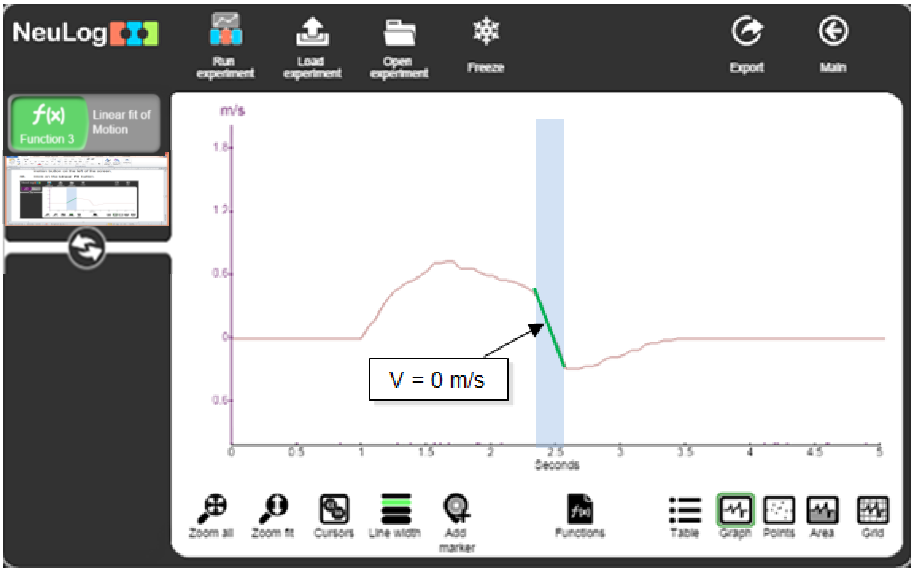
The line equation is: **Y= -0.4536X +1.481**
a = -0.45 m/s^2
V_0 = 1.1 m/s

41. Click on the **Functions** icon  and then on the **Clear all functions** button.

Range 3: Stopping Due to Magnetic Force (Negative)

42. Select the portion where the magnetic force acts on the cart, causing its velocity to decrease to zero.

43. Click **Functions** button. then **Linear fit of A** button.



44. Click **Linear fit module (function 3)** box; you will see the linear fit equation.

45. At this range the magnetic force stops the cart, the velocity decreases to zero at the moment it does not move. The acceleration is still negative but with a larger absolute value **(-2.909 m/s²)**.

The equation is: **Y= -2.909X +7.164**
a = -2.9 m/s²
V_0 = 0.5 m/s

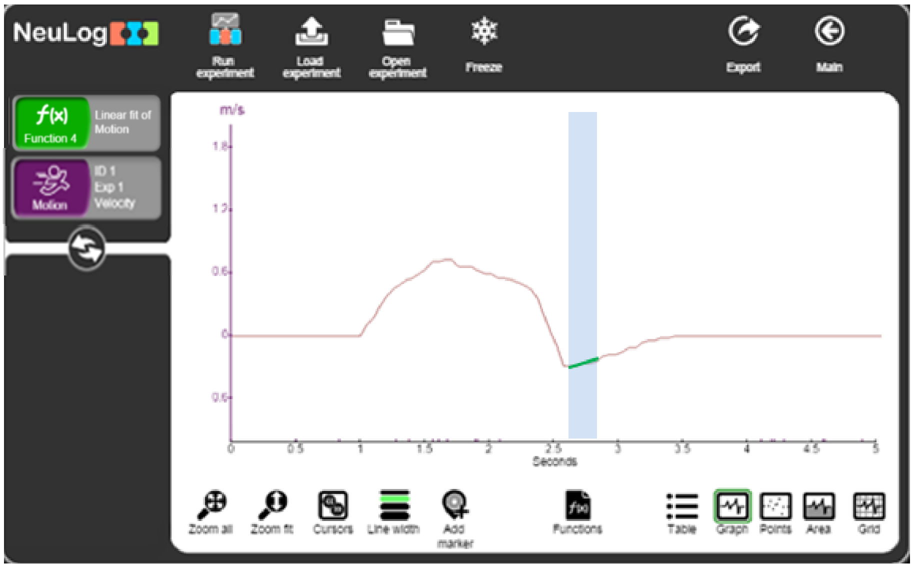
Note: After stopping, the cart accelerates in the opposite direction. Since the velocity direction changes, the acceleration remains negative until the velocity starts increasing again.

46. Click on the **Functions** icon  and then on the **Clear all functions** button.

Range 4: Acceleration in the Opposite Direction (Positive)

47. Select the graph segment where the magnetic force weakens, and the cart moves in the opposite direction while its velocity decreases.

48. Click **Functions**, then **Linear fit of A**.



49. Click on the Linear fit module (function 4) box; you will see the linear fit equation.

50. At this range, the magnetic force becomes weaker, but still pushes the cart away. The velocity decreases but still in the opposite direction, therefore the acceleration is positive (**0.176 m/s²**).

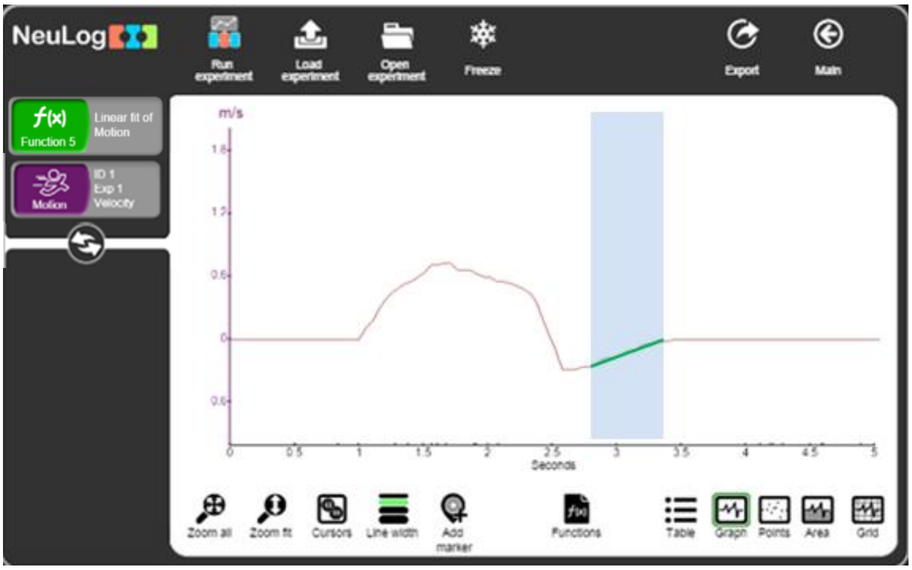
The equation is: **Y= 0.176X - 0.7421**
a = 0.176 m/s²
$\mathbf{V_0 = -0.4}$ **m/s**

51. Click on the **Functions** icon  and then on the **Clear all functions** button.

Range 5: Slowing Down and Stopping Due to Friction (Positive)

52. Select the graph segment where the magnetic force no longer acts, and the cart slows down due to friction until it stops.

53. Click **Functions**, then **Linear fit of A**.



54. Click on the Linear fit module (function 5) box; you will see the linear fit equation.

55. At this range, the magnetic force is not effective; the cart slows down and stops (due to friction force). The velocity decreases but still in the opposite direction, therefore the acceleration is positive (**0.39 m/s^2**). The velocity is zero when the cart stops completely.

    The equation is: **Y= 0.3968X - 1.33**
    a = 0.397 m/s^2
    V_0 = -0.3 m/s

56. The sensor measures distance. From every two samples, it calculates the velocity.

    We only use 20 samples per second because of the time it takes for the echo to return to the sensor.

Note: The velocity reaches zero when the cart comes to a complete stop.

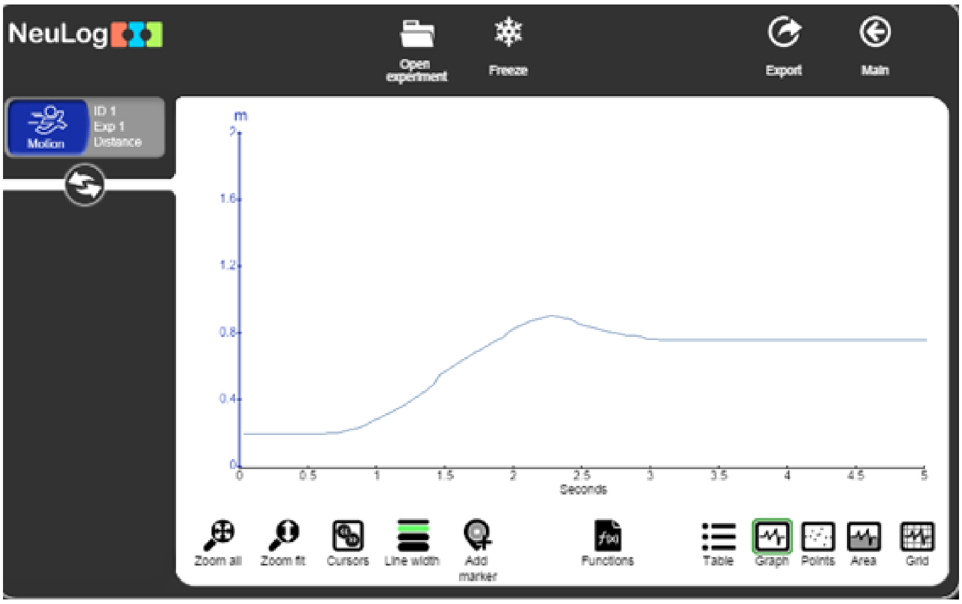
Challenge experiment

57. Remove one 10g mass from the hanger (leaving 10g).
58. Repeat the distance and velocity measurements.

Summary questions

1. Analyze the distance and velocity graphs of the challenge experiment.

2. Export and print the image of the distance graph and mark the velocity ranges 1 to 5 on it.



3. Describe the relationship between distance, velocity, and acceleration in this experiment.

4. Explain why acceleration is positive or negative in different phases.

5. How does reducing the hanger mass affect the cart's acceleration?