Motion of a Cart on an Inclined Plane Experiment

Physics

Objectives

- Understand the four kinematic equations of motion.
- Study the motion of a cart on an inclined plane.
- Investigate motion with constant 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
▪ Track rider
▪ Cart with hook
▪ Reflector plate
▪ Utility stand
▪ Right-angle clamp
▪ Extension clamp
▪ Rough and smooth wooden block with hook (or something to lift the track)

- These items are included in the NeuLog Mechanics kit (MEC-KIT).

Introduction

Motion is described using four fundamental parameters: displacement, velocity, acceleration and time. The kinematic equations allow us to predict unknown motion parameters if others are given. These equations apply only when acceleration remains constant, a condition known as linear motion.

Kinematic Equations

In linear motion, velocity increases or decreases according to the following equation:

1. $\mathbf{V_t = V_0 + a \cdot t}$

Where:

- V_t = velocity at time t V_{time}
- V_0 = initial velocity
- a = acceleration
- t = time

Displacement S is given by the integral of velocity over time, and in linear motion, it follows the equation:

$$\mathbf{S = \int V_t \, dt}$$

2. $\mathbf{S = V_0 \cdot t + \frac{1}{2} \cdot a \cdot t^2}$

$$S = V_0 t + \tfrac{1}{2} a t^2$$

Velocity is also defined as the derivative of displacement:

$$\mathbf{V = \frac{dS}{dt}}$$

By substituting equation (1) into equation (2) and simplifying, we obtain the third kinematic equation:

3. $\mathbf{V_t^2 = V_0^2 + 2 \cdot a \cdot S}$

4. $\mathbf{S = \frac{V_0 + V_t}{2} \cdot t}$

In this activity, we will measure the motion of a cart on an **inclined plane** using a **motion sensor** and examine how the experimental results fit these equations.

The Value of Experimentation

Studying the motion of a cart on an inclined plane allows us to **experimentally validate the laws of motion** and observe real-world applications of Newtonian mechanics.

Procedure

Experiment setup

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

2. Place the wooden block on the table.

3. Position the 1m track on top of the block to create an inclined plane.

4. Place the track rider on the lower part of the track.

5. Assemble the cart with the reflector plate.

6. Position the cart at the lower side of the track.

7. Set up the utility stand with the right-angle clamp near the lower end of the track.

8. Attach the motion sensor with the USB module to the utility clamp so it detects the reflector plate (minimum size: 10 x 10cm).

Sensor setup

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

10. Ensure 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.

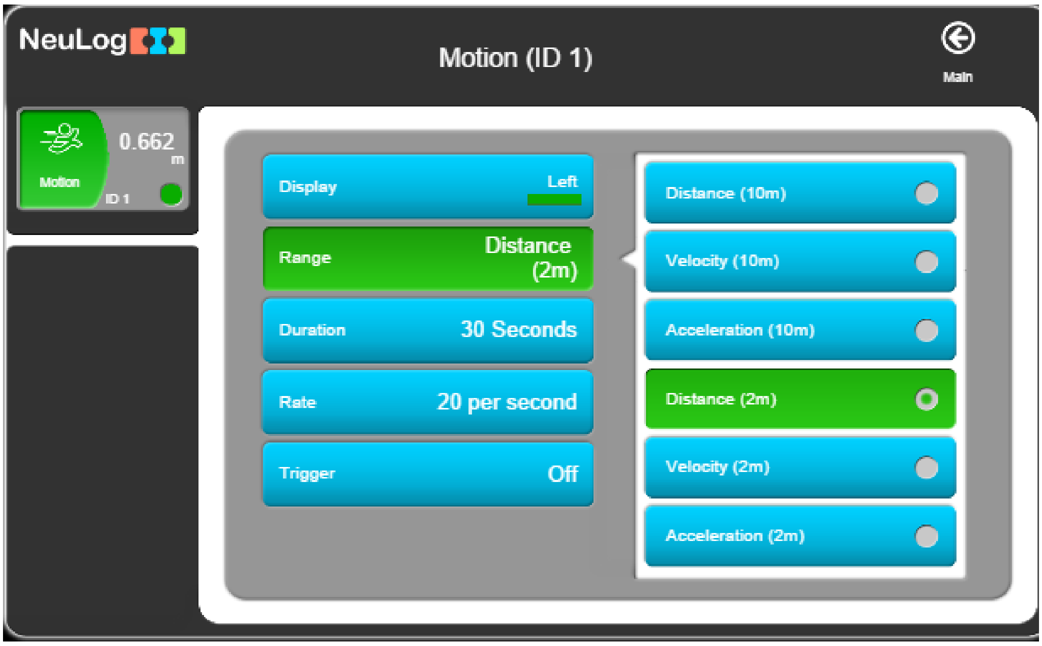
11. Run the NeuLog application and verify sensor identification.

Settings

12. Click on the **Sensor's Module** box.

13. Click on the **Range** button.

14. Select Distance (2m) to set the sensor mode to position mode.



15. Click the  icon to return to the main display.

16. Click the **Run Experiment** icon  and set:

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

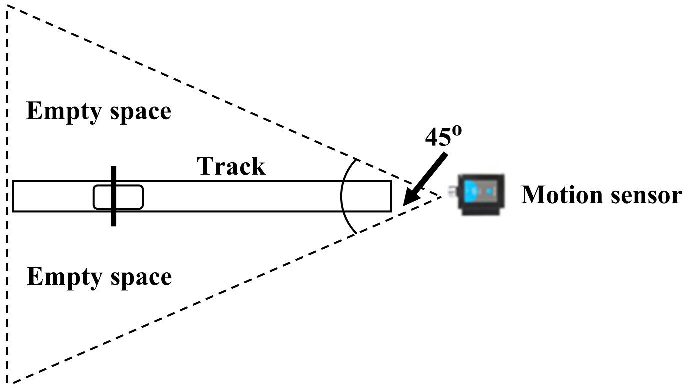
Testing and measurements

Note:

The **motion sensor** emits an **ultrasonic pulse** and measures the time for the echo to return.

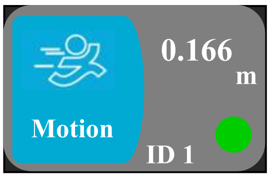
The sound beam angle is approximately 45°. The sensor detects the first **returning** echo **and records the corresponding time**.

Ensure there are **no objects in the beam range** to prevent interference.



17. Ensure motion sensor **alignment** with the cart's path.

    Ensure that the position (distance from the sensor) values are displayed in the sensor's module box before proceeding with the experiment.



18. Verify that the sensor is 20 cm from the cart and tracks its motion throughout.

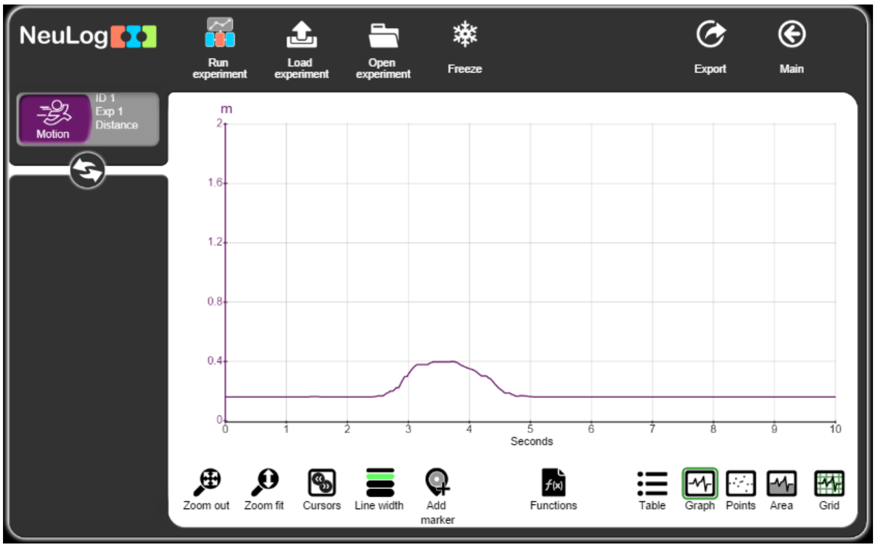
19. Place the cart on the starting position and click on the **Record** icon  to start the measurement.

20. Push the cart slightly up the incline and let it move freely (~15 cm).

    Observe the motion and recorded graph.

21. Your graph should resemble the example below.

Use the **Zoom fit** icon  if necessary to adjust the view



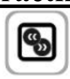
22. If the graph is incorrect, ensure the cart moves against the motion sensor at all the times. Remove any obstacles affecting sensor readings.

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

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

24. How should the velocity and acceleration graphs appear?
Sketch the expected graphs based on the experiment's conditions.

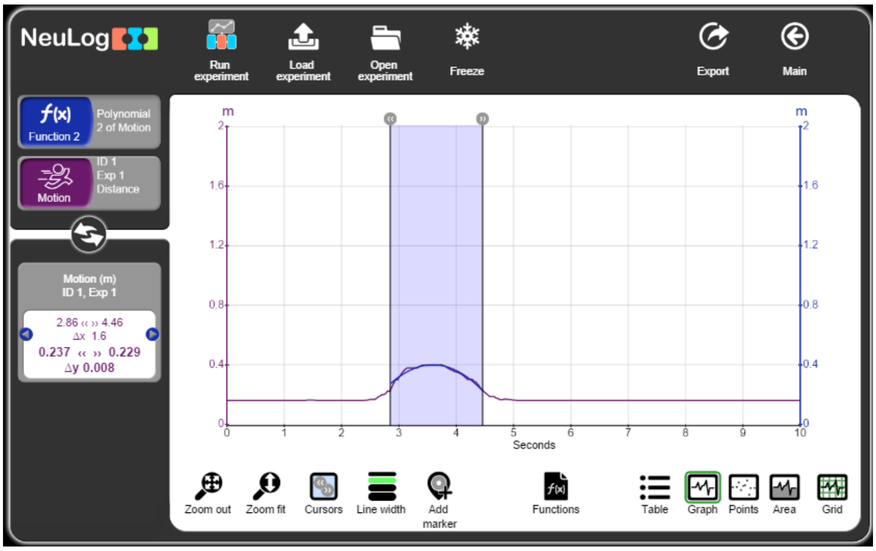
Data Analysis: Extracting acceleration from the Displacement Graph

25. Click **Cursors** icon  and highlight the relevant range of the cart movement.

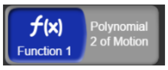
26. Click **Functions** icon  and set **Parameter K** to 2.

27. Click on the **functions** button and then click on **Polynomial K of A**.

28. Your graph should resemble to the following.



Polynomial Fit Analysis

29. Click on the polynomial module box 

and examine the equation. For the sample experiment, the equation is:

Function 1
Polynomial 2 of Motion
-0.2483X^2+1.7932X-2.8363

28. Since displacement follows:

$$S = V_0 \cdot t + \frac{1}{2} \cdot a \cdot t^2$$

We equate:

$$\frac{1}{2} \cdot a \cdot t^2 = -0.2483t^2 \qquad (t^2 = X^2)$$

Solving for acceleration:

a(acceleration) = –0.2483 · 2 = –0.4966 m/s²

This is the **average acceleration**.

We observe that the cart moves **up more in shorter time than it moves down** due to frictional resistance.

- The **gravitational force** pulls the cart downward at all times, making acceleration negative
- When moving **up**, friction **adds** to gravity.
- When moving **down**, friction **subtracts** from gravity.

<u>Extracting velocity from the displacement graph</u>

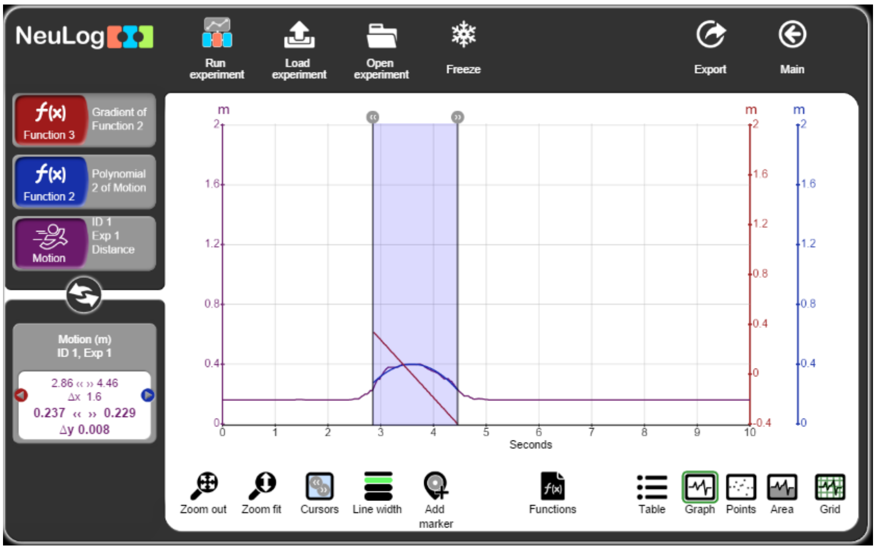
30. Click on the **Functions** icon .

31. The software allows us to generate and analyze new functions from an existing function graph.

    Select **Data set A** and choose **Function 1**.

32. Click on the Functions button and select **Gradient of A**.

33. You will obtain the **velocity graph**:



- The velocity changes linearly from 0.3 to -0.4 m/s.
- When the cart reaches its peak, velocity is 0 m/s.

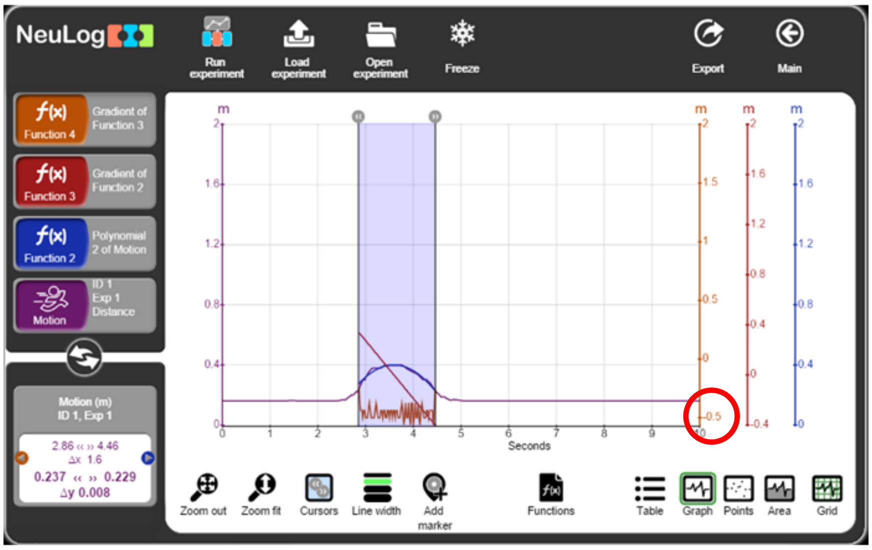
Extracting acceleration from the velocity graph

34. Click on the **Functions** icon .

35. Select **Data set A** and choose **Function 2**.

36. Click on the Functions button and select **Gradient of A**.

37. The resulting **acceleration graph**:



- The velocity graph is a straight line, and the acceleration graph is also **a straight line (with some noise)**.
- Acceleration is **constant and equals to around -0.5 m/s²**.
- Applying **Linear fit** on the velocity graph before using the **Gradient** function will eliminate the noise.

Summary questions

1. Find V_0, the highest value on the velocity graph.

2. Find ΔS for the first part of the graph (cart moving up) by using **cursors** and the bottom-left data window.

3. Find the ΔS for the first part of the graph (cart moving up) by using the equation:

$$S = \frac{V_0 + V_t}{2} \cdot t$$

Given Vt = 0, extract t from the graph and compare values.

4. Write the velocity equation using values of V_0 and a.