# Experiment P-4
# Newton's Second Law

Physics

## Objectives

- To study the relationship between force, mass and acceleration according to Newton's second law.
- To use different masses and examine the results.

## Modules and Sensors

- PC + NeuLog application
- USB-200 module
- NUL-213 Motion logger sensor

## Equipment and Accessories

| | |
|---|---|
| 1 m 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 |
| 50 g slotted mass | 3 |
| 100 g slotted mass | 2 |
| Slotted mass for challenge | - |
| Slotted mass holder rod | 1 |
| Slotted mass hanger | 1 |
| 150 cm Thread | 1 |

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

## Introduction

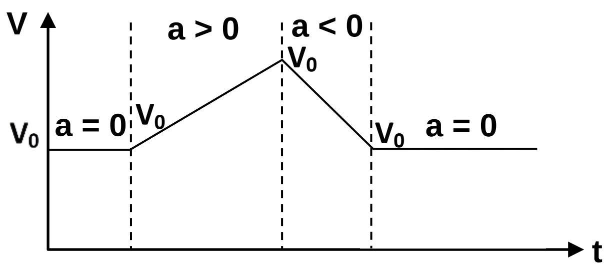
Newton's second law of motion was the first to define accurately the relationship between force, mass and acceleration. The acceleration is linearly proportional to the net applied force in the same direction. The net force is equal to the mass of the object multiplied by its acceleration:

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

The purpose of this activity is to study the relationship between force, mass and acceleration. Slotted masses with a total of 300 g, 250 g, or 200 g will be placed on the cart. A 50 g mass connected to the cart by a thread will be dropped. The cart will be pulled and it will move on the track.

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

The following graph describes the velocity of a cart on a track.




The following formula describes the velocity in each stage:

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

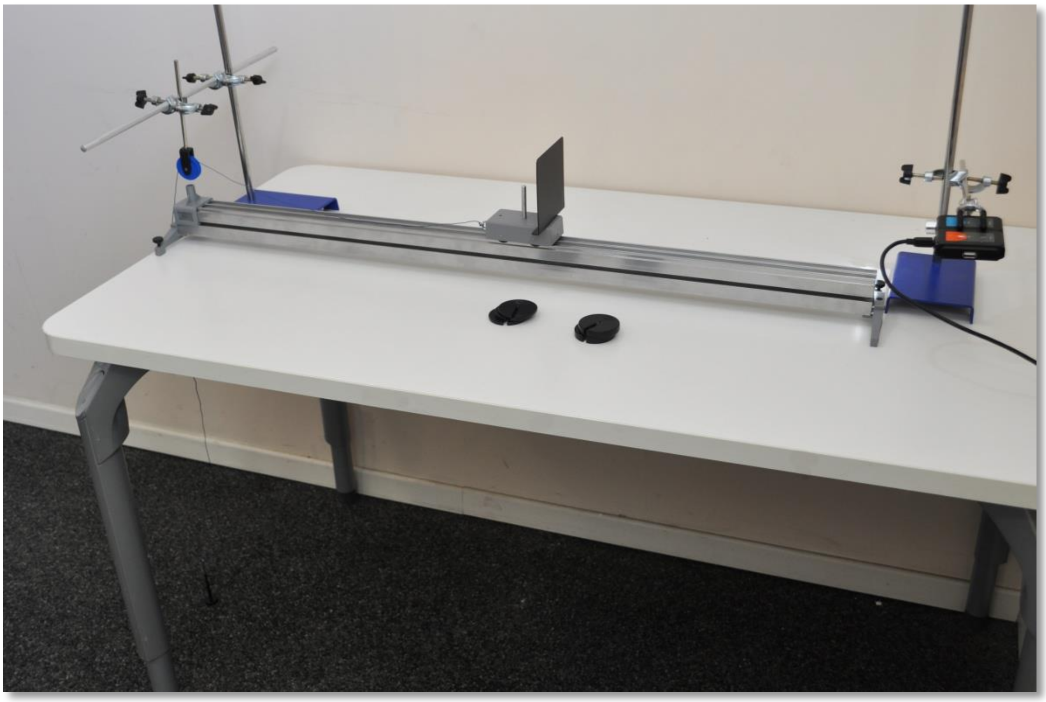
$V_0$ is the initial velocity.
a is the acceleration.

When the force **F** pulls the cart (and mass hanger) its velocity increases and the acceleration is positive. The force **F** is equal to $\mathbf{f_{gravity}}$, the force that gravity exerts on the mass hanger minus $\mathbf{f_{friction}}$, the friction force, which is on the opposite direction. When the mass lands on the floor, the cart is not pulled by it and the velocity decreases because of the friction force $\mathbf{f_{friction}}$ and the acceleration is negative (in positive displacement).

# 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. Place a utility stand in each side of the track.

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

5. One side of the track should be near the end of the table. Install the rod with the pulley (which should be directed to the floor) on the utility stand using two right angle clamps and a 20'' rod.

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

7. Move the other side of the thread through the pulley and tie it to the slotted mass hanger.

   Make sure that when the slotted mass hanger reaches the floor, the cart still has 30-40 cm to move on the track.

8. Attach the motion sensor connected to the USB-200 module to the utility stand.

9. Direct the motion sensor to the cart reflector plate and check that the cart plate is in line with the motion sensor all along its path on the track.

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

**<u>Sensor setup</u>**

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

11. Check that 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.

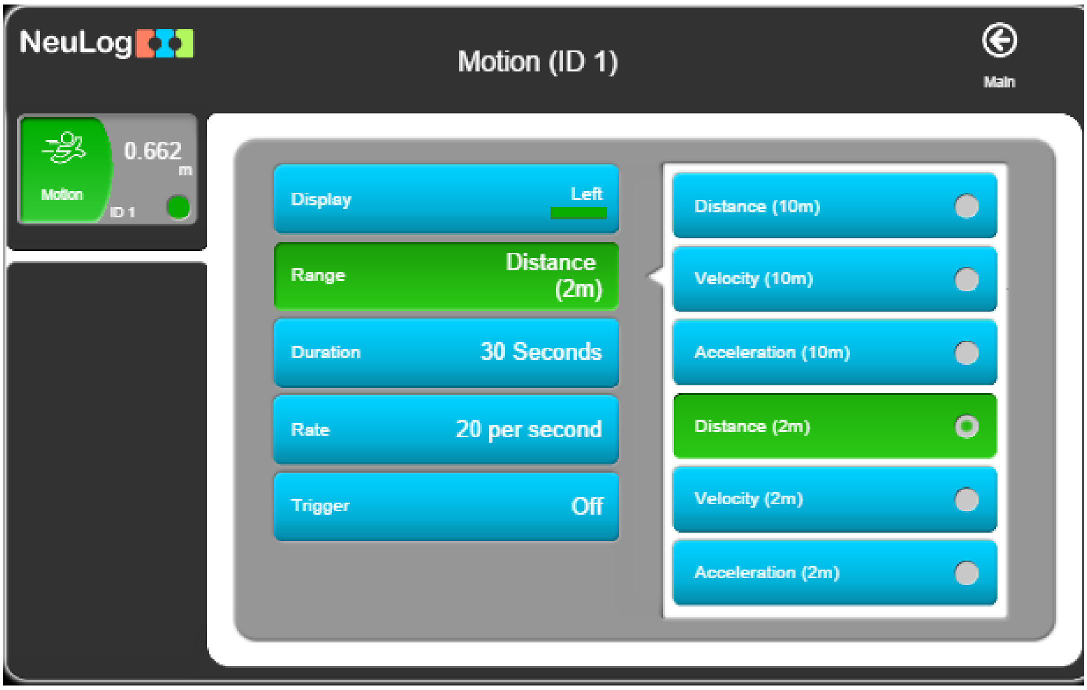
12. Run the NeuLog application and check that the motion sensor is identified.

## Settings

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

14. Click on the **Range** button.

15. Select the Distance (2m) button to change the sensor's mode to position.




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

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

Experiment duration to 5 seconds
Sampling rate to 20 per second

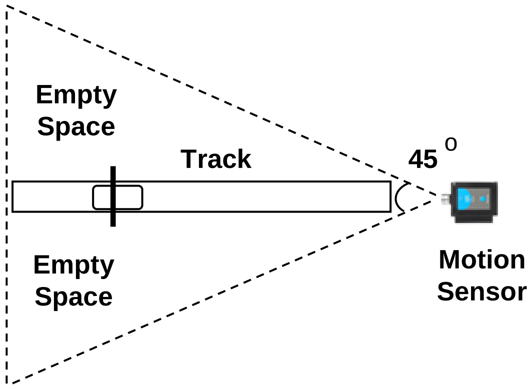
## Testing and measurements

Note:

The sensor measures the distance from an object by sending a short pulse of sound that we cannot hear (ultrasonic) and measures the time it takes the echo to return.

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

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




18. Before starting the experiments, make sure the motion sensor is well 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, which is at 30 cm from the motion sensor, to the edge of the track and make sure the sensor follows the cart distance all the way.

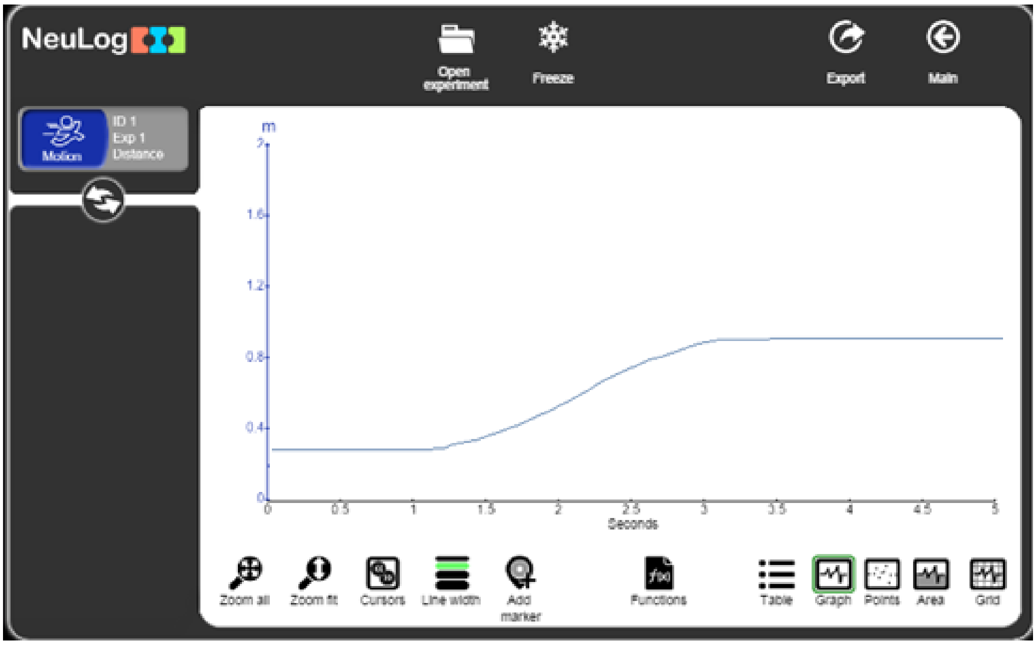
20. Put two 100 g slotted masses and two 50 g slotted masses (300 g all together) on the cart's slotted mass holder rod.

21. Put a 50 g mass on the slotted mass hanger.

22. Place the cart on 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 be similar to the following (use the **Zoom fit** icon if needed):




25. If your graph is not similar to the one above, check that the cart moves against the motion sensor all the time and check that there are no objects sending an echo to the sensor.

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

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

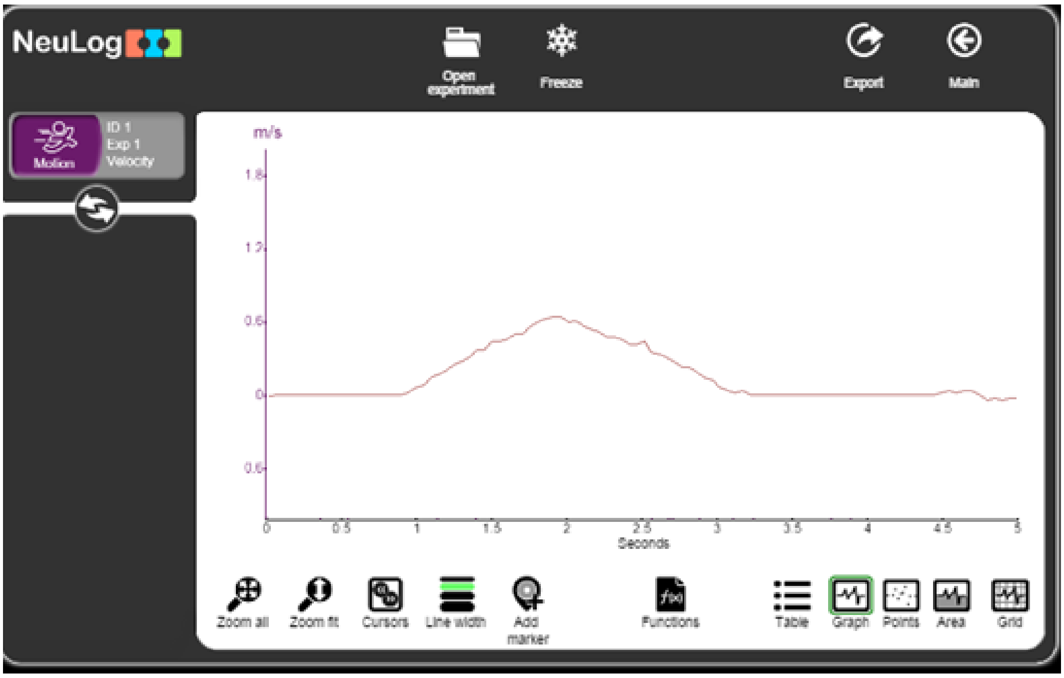
28. How do the velocity and acceleration graphs should look like? Draw the expected graphs.

29. Click on the sensor's **Module box** and change the sensor´s mode to velocity; **m/s**.

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

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

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




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

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

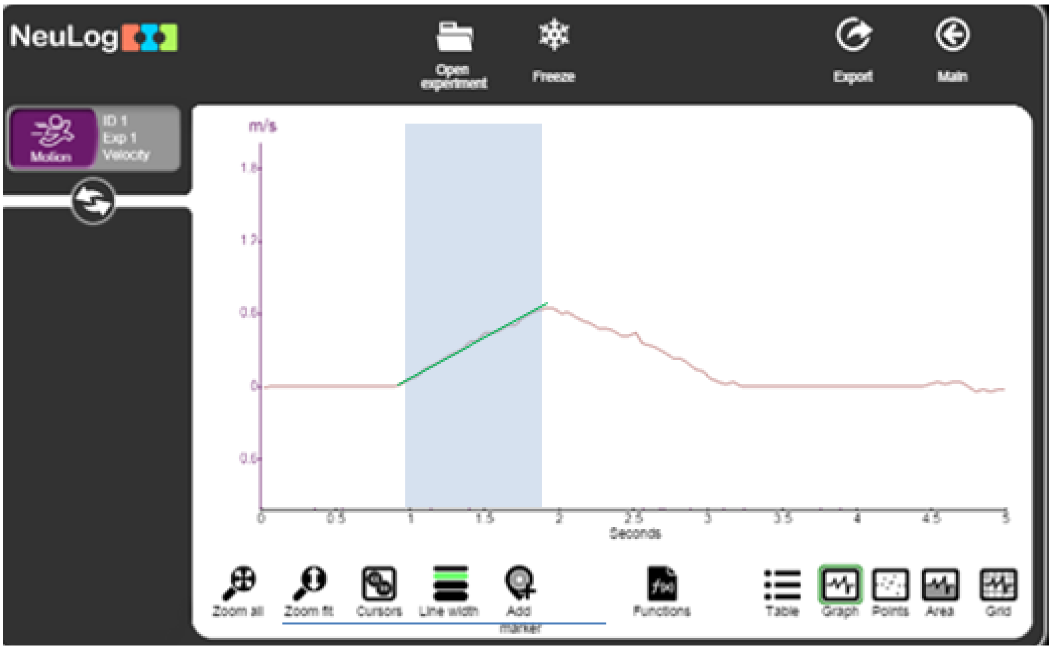
35. The velocity of the cart starts from zero, increases and then decreases when the mass hanger reaches the floor.

36. To calculate the acceleration of the first part, click on the **Cursors** icon  and select the part of the graph that represents the velocity increase of the cart.

37. Click on the **Functions** icon .

38. Click on the **Functions** button on the left of the screen and then on the **Linear fit of A** button.

39. Click on the Linear fit module box; you will see the linear fit equation.



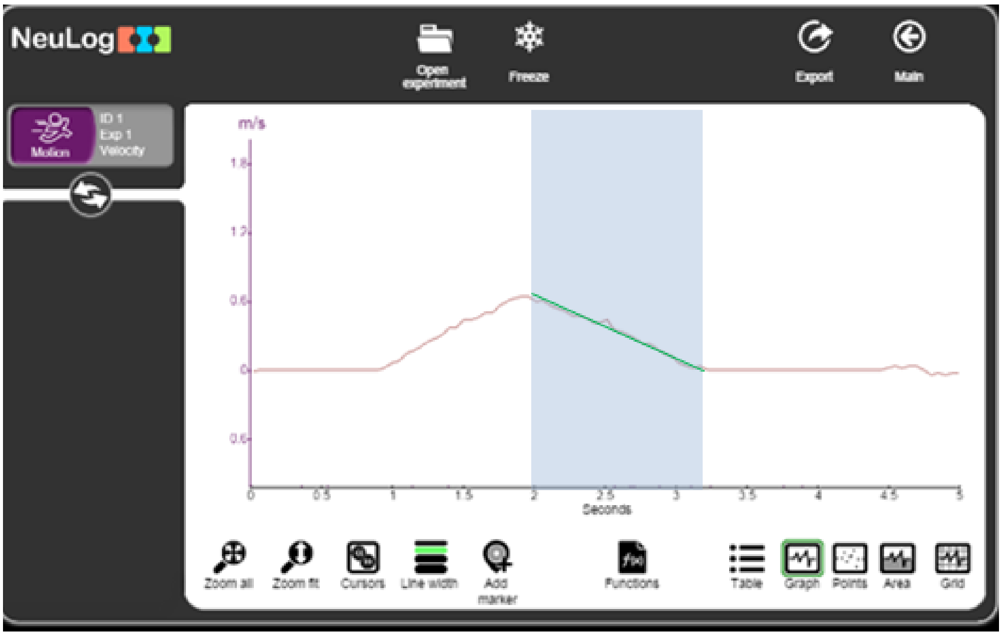

40. At this range, the cart moves away from the sensor (because of the slotted masses) and its velocity increases, therefore the acceleration is positive. The slope of the equation equals to the acceleration.
The equation is: **Y=0.6528X -0.5823**

The acceleration in our example is:

$\mathbf{a_{F\ measured} = 0.65\ m/s^2}$

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

42. We can calculate the friction force using the second part of the graph (repeat the previous steps on the second part):




The equation is: **Y= -0.5251X + 1.676**

$\mathbf{a_{friction} = -\ 0.52 m/s^2}$

43. The cart's total mass (M) is 400 g (0.4 Kg), since the cart's mass itself is 100 g.

$\mathbf{f_{friction} = m \cdot a_{friction} = 0.4\,Kg \cdot 0.52\,m/s^2 = 0.21\,N}$ (we are using the absolute value but remember that it is in the opposite direction).

44. Now that we have determined that the force of friction on the cart is 0.21 N (to the opposite direction), we can calculate the acceleration of the cart $\mathbf{a_{F\ calculated}}$ and compare it to the measured value $\mathbf{a_{F\ measured}}$. This will be done by placing the following values in Newton's second law equation: the force that gravity exerts on the mass hanger, the friction force and the total mass.

According to **Newton's second law**, the cart's acceleration is equal to the force that gravity exerts on the mass hanger minus the friction force, divided by the total weight of the cart and the mass hanger (with the 50 g mass):

$$\mathbf{F} = \mathbf{f}_{gravity} - \mathbf{f}_{friction}$$

If you did not use the absolute value for the friction force and it is negative, add the gravity force (of the mass hanger) to the friction force (the F will stay the same).

M represents the mass of the cart (0.4 Kg with the slotted masses). m represents the mass hanger with the slotted mass (0.05 Kg).

$$\mathbf{m_T} = \mathbf{M} + \mathbf{m}$$

$$\mathbf{F} = \mathbf{m_T} \cdot \mathbf{a_F}$$

$$\mathbf{f}_{gravity} - \mathbf{f}_{friction} = \mathbf{m_T} \cdot \mathbf{a_F}$$

$$\mathbf{a_F} = \mathbf{f}_{gravity} - \mathbf{f}_{friction} / \mathbf{m_T}$$

$$\mathbf{f}_{gravity} = \mathbf{m} \cdot \mathbf{g}$$

$$\boxed{\mathbf{a_F} = ((\mathbf{m} \cdot \mathbf{g}) - \mathbf{f}_{friction}) / \mathbf{m_T}}$$

$\mathbf{m} = 0.05\ \mathrm{Kg}$
$\mathbf{M} = 0.4\ \mathrm{Kg}$
$\mathbf{m_T} = 0.45\ \mathrm{Kg}$
$\mathbf{g} = 9.8\ \mathrm{m/s^2}$
$\mathbf{f}_{friction} = 0.21\ \mathrm{N}$
$\mathbf{m_T} = 0.45\ \mathrm{Kg}$

$$\mathbf{a}_{F\ calculated} = ((\mathbf{0.05\ Kg} \cdot \mathbf{9.8\ m/s^2}) - \mathbf{0.21N})) \ \mathbf{/\ 0.45\ Kg} = \mathbf{0.28\ N / 0.45\ Kg} = \mathbf{0.62\ m/s^2}$$

**The calculated $a_F$ is very close to the measured $a_F$ (0.65 $m/s^2$** in our example)**.**

45. Fill the first column in the table with your results and calculations.

| | Cart (100 g) + Slotted masses (300 g)<br><br>**M = 0.4 Kg** | Cart (100 g) + Slotted masses (250 g)<br><br>**M = 0.35 Kg** | Cart (100 g) + Slotted masses (200 g)<br><br>**M = 0.3 Kg** |
|---|---|---|---|
| m [Kg] | | | |
| $m_T$ [Kg] | | | |
| $a_{friction}$ [$m/s^2$] | | | |
| $f_{friction}$ [N] | | | |
| $f_{gravity}$ [N] | | | |
| $a_{F\ calculated}$ [$m/s^2$] | | | |
| $a_{F\ measured}$ [$m/s^2$] | | | |

This is the data for the example measurement:

| | Cart (100 g) + Slotted masses (300 g)<br><br>**M = 0.4 Kg** |
|---|---|
| m [Kg] | 0.05 |
| $m_T$ [Kg] | 0.45 |
| $a_{friction}$ [$m/s^2$] | -0.52 |
| $f_{friction}$ [N] | 0.21 |
| $f_{gravity}$ [N] | 0.28 |
| $a_{F\ calculated}$ [$m/s^2$] | 0.62 |
| $a_{F\ measured}$ [$m/s^2$] | 0.65 |

46. Remove a 50 g slotted mass from the cart.

47. Repeat the measurement and fill the second column in the table.

48. Compare the calculated $a_F$ with the measured $a_F$.

49. Remove another 50 g slotted mass from the cart.

50. Repeat the measurement and fill the third column in the table.

51. Compare the calculated $a_F$ with the measured $a_F$.

## Challenge experiment

52. Calculate the required hanged mass that balances the friction force of the cart with a 300 g mass.

53. Hang your calculated mass on the mass hanger.

54. Pull the cart to the beginning of the track and push it.

    What should be the velocity of the cart?

55. Run the experiment and check it.

## Summary questions

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

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

3. When the cart accelerates, does the position change linearly or not? Explain.

4. What will happen to the $a_F$ when m=1000 Kg and M=0.5 Kg? Place these values in the equation (assume that the $a_{friction}$ stays the same as the first measurement). What is the meaning of the received value?