The Relationship between Acceleration and Force

(Item No.: P6200500)

Curricular Relevance

Area of Expertise: Physics
Education Level: Age 14-16
Topic: Mechanics
Subtopic: Linear Motion
Experiment: The Relationship between Acceleration and Force

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	10 Minutes	30 Minutes	2 Students

Additional Requirements:

- Tablet PC with DigiCart App

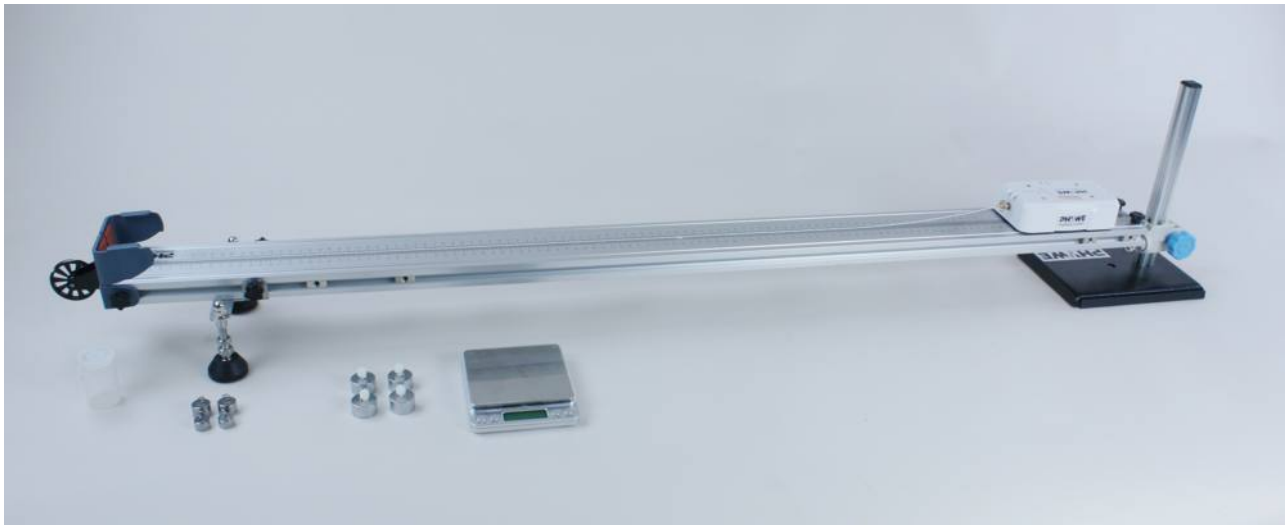
Experiment Variations:

Keywords:

Force, Acceleration, Dynamics

Information for teachers

Introduction



Overview experimental setup.

Educational objective
In this experiment the students learn something about the physical connection between force and acceleration. This connection is expressed physically in Newton's second law.

Task
1) Record force-time and velocity-time diagrams for different forces with constant mass of the DigiCart via the DigiCart App. Analyze the relationship between force and acceleration.

2) Record force-time and velocity-time diagrams at constant force and variable mass of the DigiCart. Analyze the relationship between acceleration and mass.

Prior knowledge
This experiment requires the concept of acceleration as well as Newton's second law.

Principle
Acceleration

Acceleration is one of the basic concepts of kinetics. It indicates how fast an object changes its speed and is measured in the unit $\frac{\mathrm{m}}{\mathrm{s}^2}$.

The concept of acceleration is based on average acceleration. If Δv denotes the change of velocity in a period of time of Δt, you can use

$$\bar{a} = \frac{\Delta x}{\Delta t}$$

to calculate the average acceleration $\bar{a}$.

Force

According to the second Newton's law, the force F can be calculated for a motion with constant mass m by the formula

$$F = m \cdot a,$$

where a is the acceleration of the body. So for a constant mass $F \sim a$ holds, while for a constant force we have $a \sim \frac{1}{m}$.

Equipment

Position No.	Material	Order No.	Quantity
1	DigiCart white		1
2	1.2 m track		1
3	Height adjustable holder		1
4	DigiCartAPP		1
5	Weight 20g		2
6	Weight 10g		2
7	Weight 50g		4
8	Plastic screw		4
9	Film box with cord		1
10	Brass screw for force sensor		1
11	Scale		1

Safety information

For this experiment, the general instructions for safe experimentation in science teaching apply.

Introduction

Application and task

Application
Motions are influenced by forces. If a force acts on a body, this has consequences for its movement.

In this experiment you will learn something about the physical connection between force and acceleration. This relationship is expressed physically in Newton's second law.

Task
1) Record force-time and velocity-time diagrams for different forces with constant mass of the DigiCart via the DigiCart App. Analyze the relationship between force and acceleration.

2) Record force-time and velocity-time diagrams at constant force and variable mass of the DigiCart. From this, analyze the relationship between acceleration and mass.

Equipment

Position No.	Material	Order No.	Quantity
1	DigiCart white		1
2	1.2 m track		1
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11	Scale		1

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Set-up and procedure

Set-up

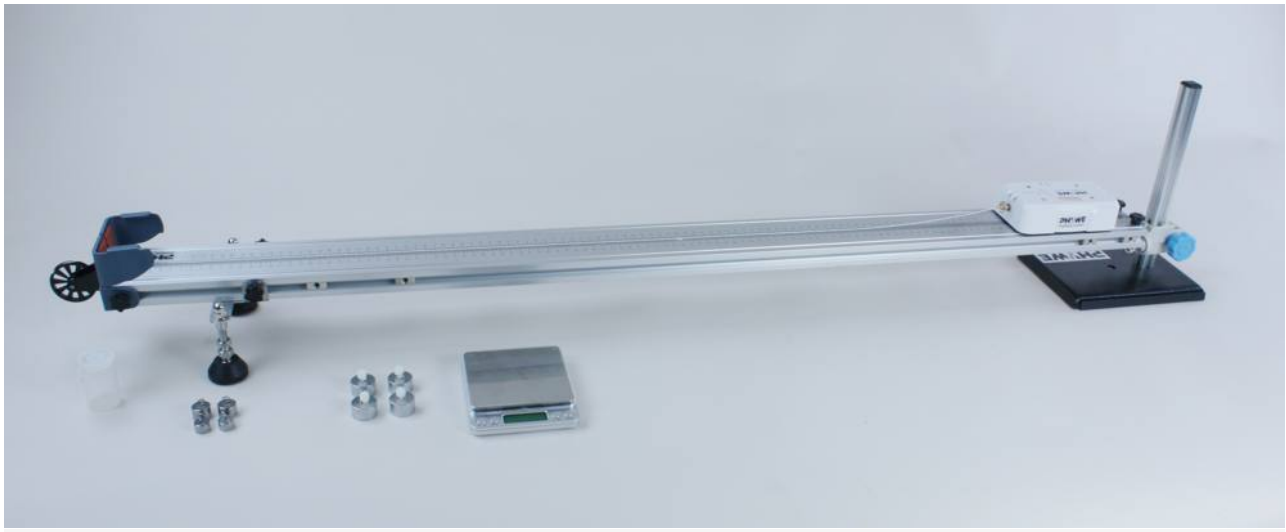


Figure 1: Overview of experimental setup.

- Use the scale to weigh the weight of the DigiCart. Make sure you also weigh the brass screw on the force sensor.
- The track must be positioned so that the impeller protrudes beyond the edge of the table. The table should be about 1 m high.
- Place the track in a horizontal position and place the DigiCart on it. Place a 10 gram weight in the film box and close it with the lid. Fasten the cord of the film box to the force sensor of the DigiCart using the brass screw and guide the cord over the impeller at the end of the track.
- Place the film box on the edge of the table.
- Start the DigiCart App.
- Select experiment 5 from the overview. The measurement window opens.
- Connect the DigiCart to the app (see Figure 2). Two steps are required. First, press the ON switch on the DigiCart for at least 3 seconds. Then open the connection window in the app via the bluetooth symbol (1.). The DigiCart should now be displayed there. If not, you can update the list by clicking on scan (2.). Now, one taps the DigiCart from the list once and establishes the connection via the connect button (3.). You can now hide the window again by pressing the close button (4.).

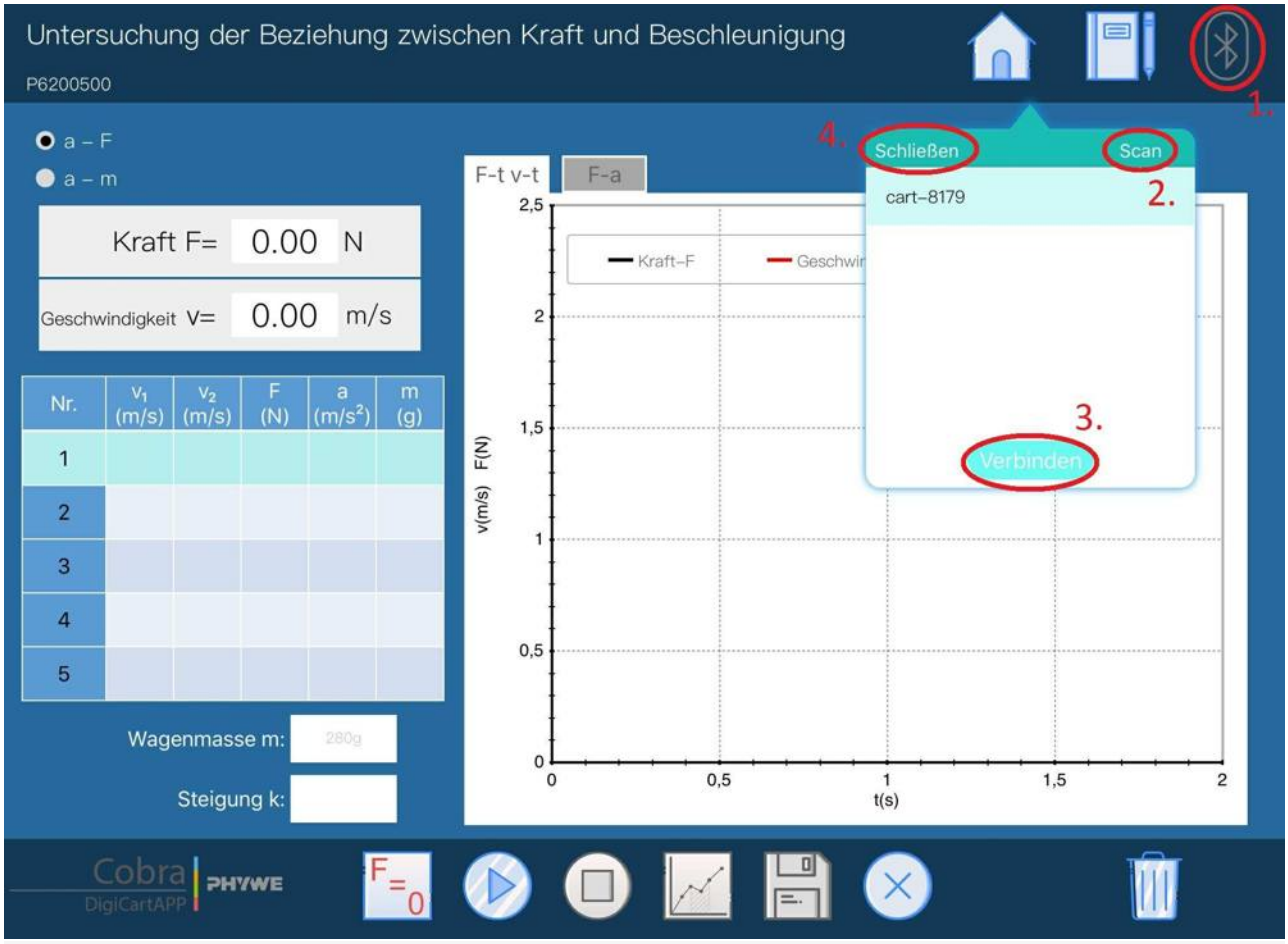


Figure 2: Connecting to the DigiCart.

Procedure

Part 1

- Figure 3 shows the steps for the measurement process.
- Click on the button "a - F" (1.) in the upper left part of the window.
- The force and speed display below (2.) shows the momentary force and speed.
- The force at the sensor is now set to zero via the calibration button (3.). It must be ensured that the thread is not tensioned and that no force is acting on the sensor.
- The DigiCart is placed and held at the height-adjustable end.
- The film box with the weight is removed from the table and hangs freely over the edge of the table.
- Start the measurement by clicking on start measurement (4.).
- Let go of the DigiCart. The falling weight causes the DigiCart to move.
- Stop the measurement by clicking on stop measurement (5.) as soon as the DigiCart reaches the end of the path.
- Click on select measuring range (6.) to select a measuring range in the force-time or velocity-time diagram for which the acceleration and the mean force are to be calculated. The selection is made by sweeping the interval with the finger.
- Save the measurement by clicking the save button (7.). The values are now written to the left table.
- Increase the weight of the film box by 10 grams. Then repeat the last 8 steps. Then increase the weight of the film can by another 10 grams and repeat the steps from the top until you have made five measurements. For the fifth measurement there should be 50 grams in the film box.
- To delete a row from the table, touch it and then click the delete button (8.). By a further measurement the row can be filled with new values.
- Now tap on the tab "F-a" (9.) above the diagram.

- Continue reading in section evaluation part 1.

Figure 3: Measurement procedure - Part 1

Part 2

- Figure 4 shows the steps for the measurement process.
- Click on the button "a - m" (1.) in the upper left part of the window.
- The film box is filled with a weight of 10 grams and placed on the table.
- The force at the sensor is now set to zero via the calibration button (2.). It must be ensured that the thread is not tensioned and that no force is acting on the sensor.
- In the car mass window (3.), enter the mass of the DigiCart measured during preparation in grams.
- The DigiCart is placed and held at the height-adjustable end of the track.
- The film can with the weight is removed from the table and hangs freely over the edge of the table.
- Start the measurement by clicking on start measurement (4.).
- Let go of the DigiCart. The falling weight causes the DigiCart to move.
- Stop the measurement by clicking on stop measurement (5.) as soon as the DigiCart reaches the end of the track.
- Click on select measuring range (6.) to select a measuring range in the force-time or velocity-time diagram for which the acceleration and the mean force are to be calculated. The selection is made by sweeping the interval with the finger.
- Save the measurement by clicking the save button (7.). The values are now written to the left table.
- Increase the weight of the DigiCart by 50 grams. Use the plastic screws and the 50 gram weights. Then repeat the measurement. Remember to enter the current car mass in the car mass field (3.).
- Then increase the weight of the DigiCart by a further 50 grams and repeat the measurement until the table is filled.
- If you want to repeat a measurement, click on the corresponding line of the table and then on the delete button (8.).
- Then click on the tab "a - m" (9.) above the diagram.

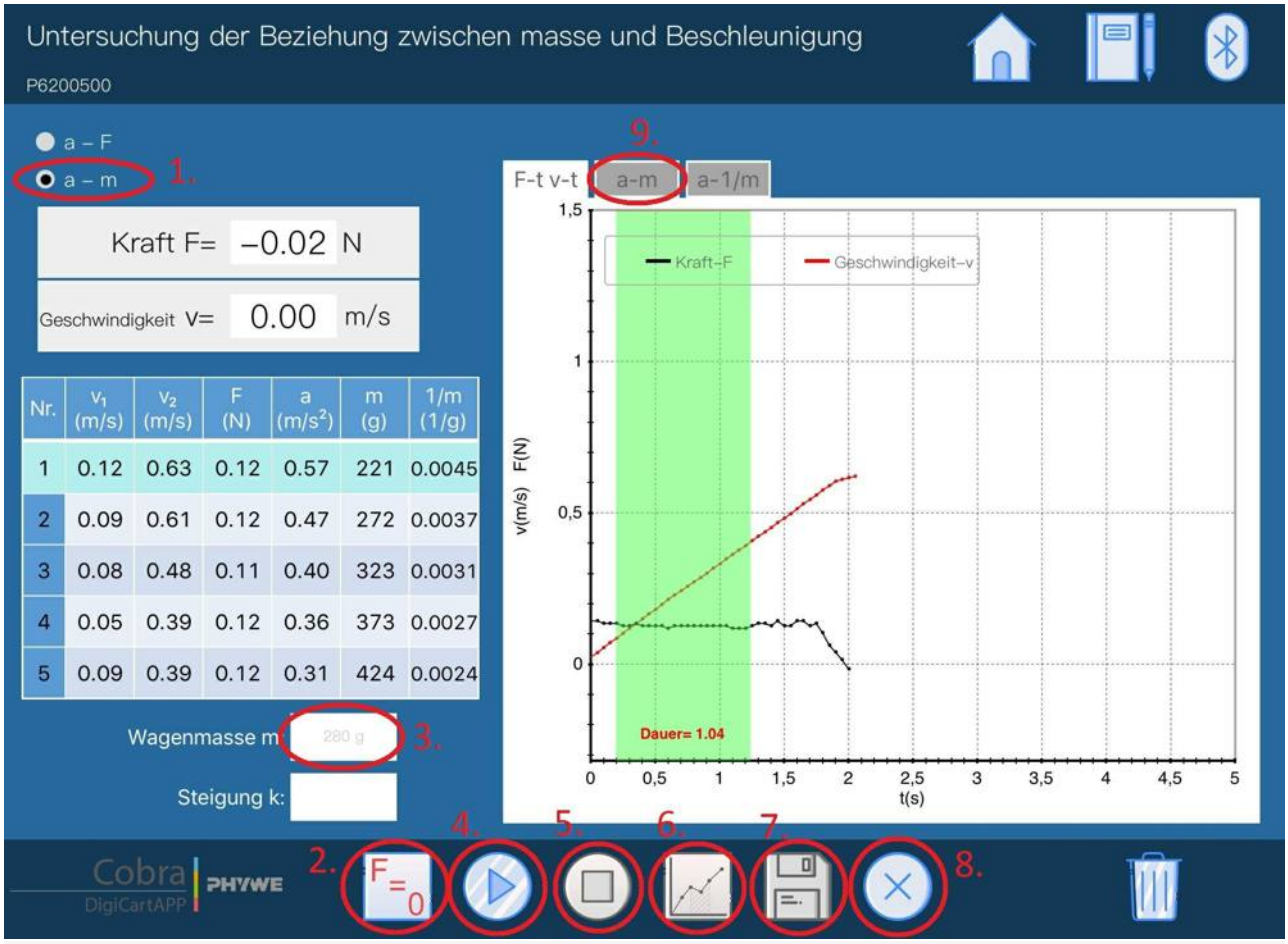


Figure 4: Measurement procedure - Part 2

Evaluation

Part 1

- Figure 5 shows the steps for the evaluation.
- The table on the left (1.) shows the calculated average acceleration and the average force for each measurement. These measurement pairs are already entered as points in the force-acceleration diagram.
- By tapping on the straight line button (2.) a straight line is placed through the points. The slope of it is displayed in the slope field (3.). Note that this value is given in kilograms.

Since the points lie well on the straight line, the relationship between force and acceleration is linear. In addition, the straight line runs through the origin. Therefore, with an acceleration of zero, the force is zero. The value of the slope corresponds to the mass of the DigiCart used. This is confirmed by Newton's second law, which describes this relationship.

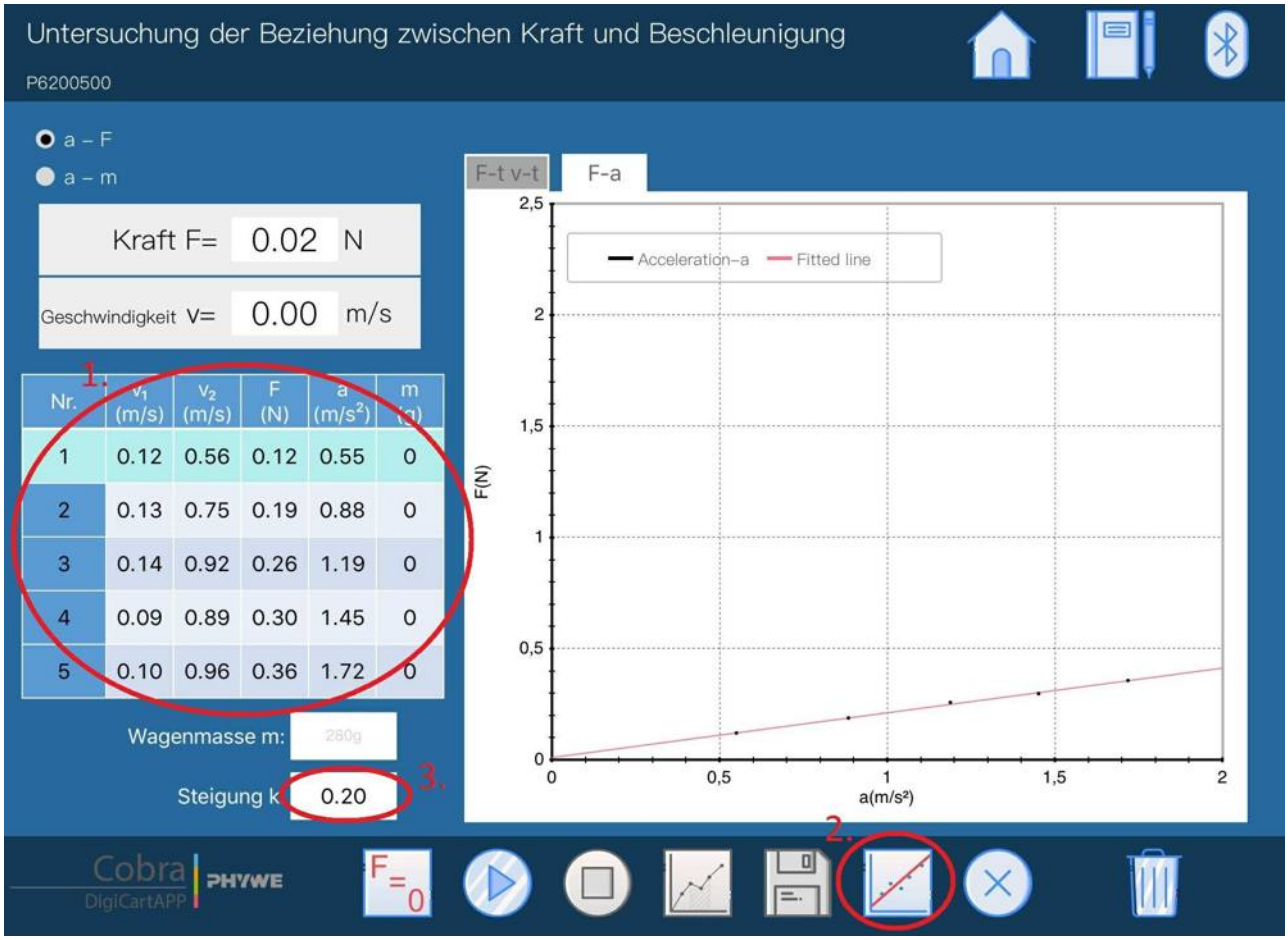
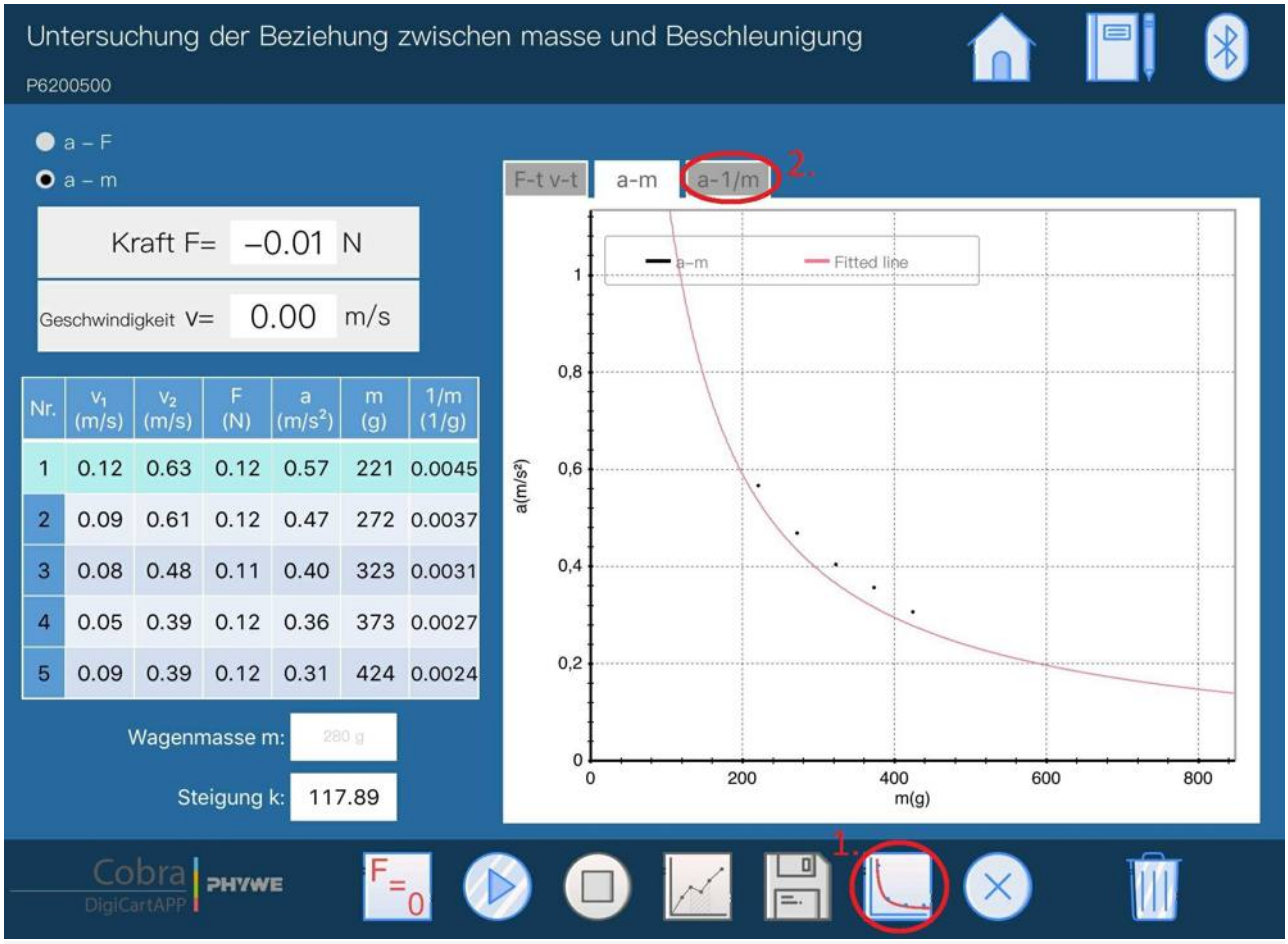


Figure 5: Evaluation procedure - Part 1

Part 2

- Figure 6 shows the steps for the evaluation.
- In this diagram, the acceleration is plotted as a function of the mass of the DigiCart. The points from the table are already entered. The button draw graph (1.) is used to draw a curve through the points.
- Now click on the tab "a - 1/m" (2.) above the diagram.
- Figure 7 shows the steps for further evaluation.
- In this diagram, the acceleration is plotted as a function of the inverse mass of the DigiCart. The points from the table are already entered. With the help of the button draw straight line (1.) a straight line is placed through the points. The slope of the straight line is displayed in the slope field (2.).

Only if acceleration is plotted as a function of inverse mass 1/m, a straight line will result. The gradient of this straight line corresponds to the value of the effective force F. This is a further confirmation of Newton's second law, which predicts this behaviour.



Nr.	v_1 (m/s)	v_2 (m/s)	F (N)	a (m/s^2)	m (g)	1/m (1/g)
1	0.12	0.63	0.12	0.57	221	0.0045
2	0.09	0.61	0.12	0.47	272	0.0037
3	0.08	0.48	0.11	0.40	323	0.0031
4	0.05	0.39	0.12	0.36	373	0.0027
5	0.09	0.39	0.12	0.31	424	0.0024

Figure 6: Evaluation procedure - Part 2a

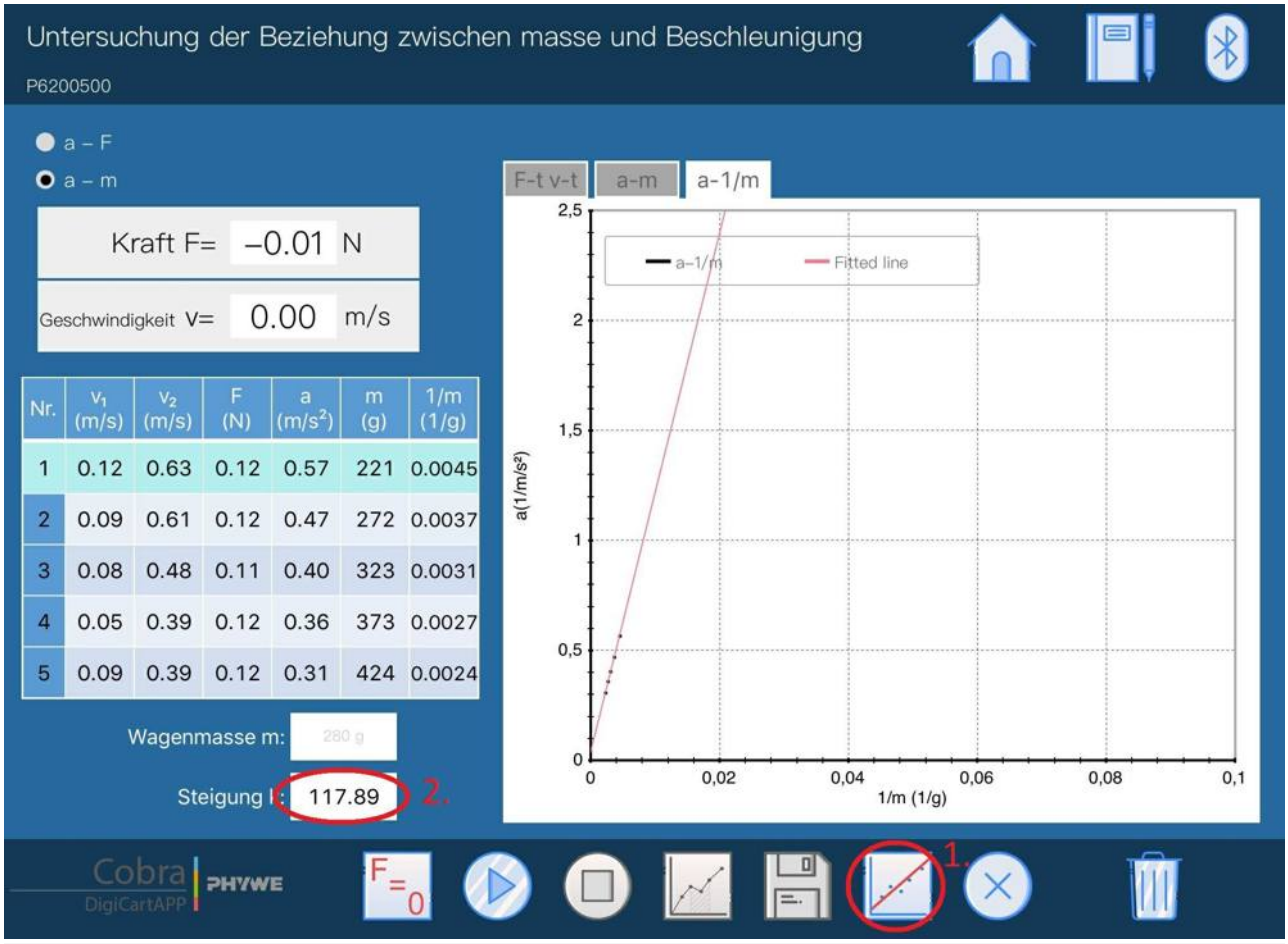


Figure 7: Evaluation procedure - Part 2b

The relationship between force and acceleration

Results - Evaluation 1 (1 point)

Which unit has the slope of the straight line determined in the first part of the experiment?

Score is granted based on the occurrence of the following keywords:

- Kilogram.

Scoring Mode: Automatic Scoring with Keywords on Finding ONE

Results - Evaluation 2 (1 point)

Which unit has the slope of the straight line determined in the second part of the experiment?

Score is granted based on the occurrence of the following keywords:

- Millinewton.

Scoring Mode: Automatic Scoring with Keywords on Finding ONE

Results - Evaluation 3 (1 point)

What is the relationship between force and acceleration?

Score is granted based on the occurrence of the following keywords:

- A linear one. If the acceleration is twice as large, it is also the force.

Scoring Mode: Automatic Scoring with Keywords on Finding ONE

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Results - Evaluation 4 (1 point)

What is the relationship between acceleration and mass (for a constant force)?

Score is granted based on the occurrence of the following keywords:

- An inverse. If the mass is twice as large, the acceleration is halved.

Scoring Mode: Automatic Scoring with Keywords on Finding ONE

Results - Evaluation 5 (1 point)

What does Newton's second law say?

Score is granted based on the occurrence of the following keywords:

- F=m*a.

Scoring Mode: Automatic Scoring with Keywords on Finding ONE

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