Newtonsche Grundgleichung - Beschleunigung als Funktion der Masse mit SMARTsense (Item No.: P1004369)

Curricular Relevance

Area of Expertise: Physics
Education Level: Age 16-19
Topic: Mechanics
Subtopic: Kinematics and dynamics
Experiment: Newton's second law - acceleration as a function of mass with SMARTsense

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	20 Minutes	10 Minutes	2 Students

Additional Requirements:

- Tablet

Experiment Variations:

- Classic student experiment: Newton's second law: acceleration as a function of mass (P1004300)
- Classic student experiment: Newton's second law: acceleration as a function of mass with the 2-1 timer (P1004305)

Keywords:

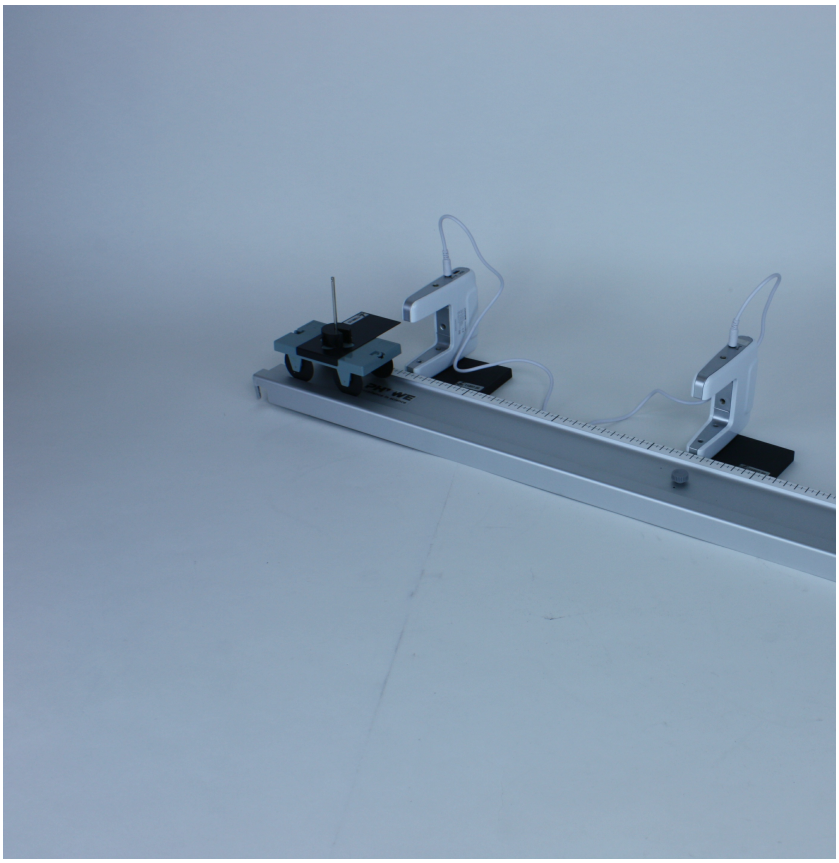
force, Newton's laws, uniform acceleration

Information for teachers

Introduction

Application
Newton's equation of motion, also known as Newton’s second law, is a fundamental equation in mechanics. Mechanical systems in space and time can be completely described with this equation.

Rocket launch



Experiment set-up

Educational objective
The aim of this experiment is to lead the students in an experimental manner to the simplified formulation of Newton's second law $F = m \cdot a$.

Tasks

1. The students accelerate a cart of variable mass m on a track with the help of a constant tractive weight F and they measure the time t that the cart needs to cover a distance s of 50 cm. For this purpose, the students increase the total accelerating mass (cart mass + tractive mass) in several steps from 65 g to 185 g.
2. The students evaluate the measurement data, which results in a linear relationship between acceleration and accelerating mass $a = a(\frac{1}{m})$ based on which they determine the gradient.
3. The students determine the dimension of the gradient k of the line, thereby realising that it includes the tractive force F of the tractive weight.
4. This knowledge should lead the students to the formula $F = m \cdot a$.

Prior knowledge
The students should be familiar with the concepts of acceleration, force, and velocity.
They should be able to determine the gradient of a straight line and the dimension of the gradient in a mathematical manner.

Principle
The measurement cart on the track is accelerated in a uniform manner by a mass that is connected to the cart by way of a thread via a pulley and that produces a force in the gravitational field.
The actual value of the acceleration a can be calculated based on the tractive force F and on the accelerating mass m with the help of Newton's second law $F = m \cdot a$.

Note
In order to adjust the correct inclination of the track (for friction compensation), a second light barrier can be used as follows: Push the cart with one hand and measure the shading time of the first light barrier. Reset the measurement value before the cart reaches the second light barrier and measure the second shading time. Compare it to the first one.
Due to the fact that a certain amount of time passes before the cart interrupts the first light barrier and also due to the fact that it reaches this light barrier with an initial velocity, the times that are measured tend to be too short and the acceleration value too high.

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Safety instructions

For this experiment, the general notes and instructions concerning safe experimentation in science classes apply.

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Versuch: Newtonsche Grundgleichung - Beschleunigung als Funktion der Masse mit SMARTsense **(Item No.: P1004369)**

Introduction

Application and task

What is the relationship between mass and acceleration?

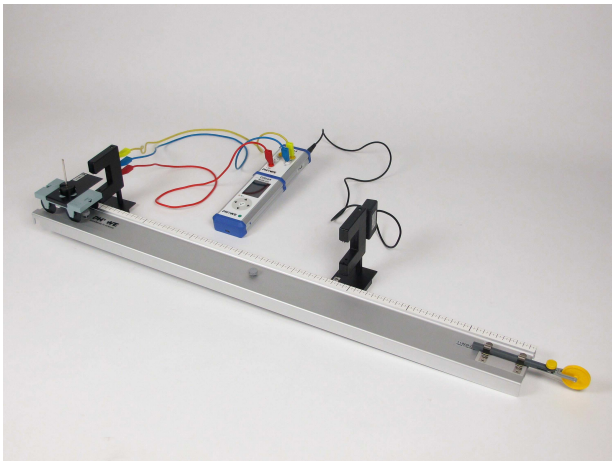
Introduction
This experiment will lead you to Newton's second law, a famous equation of one of the pioneers in physics.

Application
Newtonian mechanics can be described by Newton's laws.
When a new train is designed, the engineers can use Newton's second law for a quick estimate of the required engine power and most suitable drive system.

Strong thrust and a small mass result in strong acceleration.

Tasks

1. Release the cart and measure the time t that it requires for covering the distance s with different masses on the cart.
2. Evaluate the measurement data (using the formula for uniformly accelerated motion) to such an extent that you obtain a diagram in which the acceleration a of the cart is plotted as a function of the reciprocal of the accelerating mass $1/m$. Determine the gradient k of the straight line.
3. Determine the dimension of the gradient k and compare your result with the tractive force F.
4. Represent the relationship by way of a formula und describe its meaning in your own words.



Experiment set-up

Material

Position No.	Material	Order No.	Quantity
1	Track, l 900 mm	11606-00	1
2	Meter scale, demo. l=500mm, self adhesive	03005-00	2
3	Cart for measurements and experiments	11060-00	1
4	Shutter plate for cart	11060-10	1
5	Holding pin	03949-00	1
6	Cobra SMARTsense - Photogate, 0 ... ∞ s	12909-00	1
7	Adapter plate for Light barrier compact	11207-22	2
8	Silk thread, l = 200 m	02412-00	1
9	Weight holder, silver bronze, 1 g	02407-00	1
10	Slotted weight, black, 50 g	02206-01	3
11	Slotted weight, black, 10 g	02205-01	4
12	Slotted weight, blank, 1 g	03916-00	4
13	Rod for pulley	02263-00	1
14	Pulley,movable,dia.40mm,w.hook	03970-00	1

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Set-up and procedure

Set-up

Connect the pulley to the associated rod (Fig. 1).

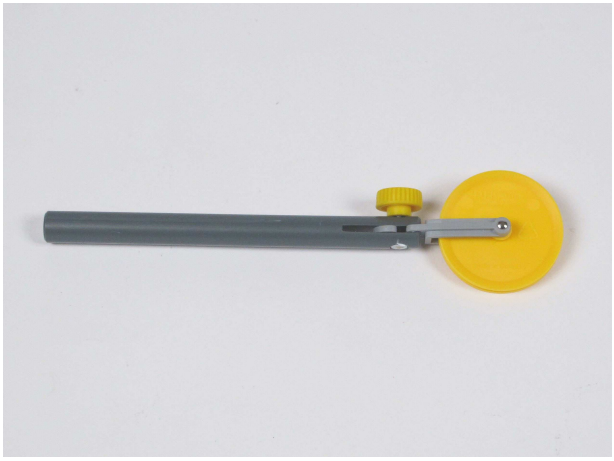


Fig. 1

Push the rod carefully under the holding clamps located at one end of the track. To do so, slacken the holding clamps slightly with your fingers so that the plastic rod will not be damaged by the sharp metal edges. Position the track on the desktop so that the pulley is located at the edge of the table and can be rotated freely (Fig. 2).

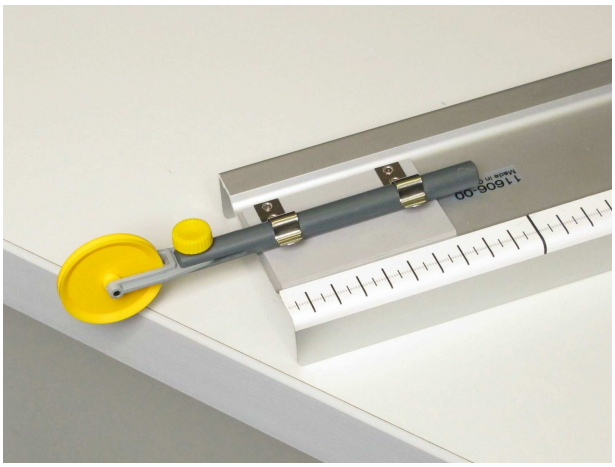


Fig. 2

Fasten the shutter plate to the experiment cart by way of the holding pin (Fig. 3).

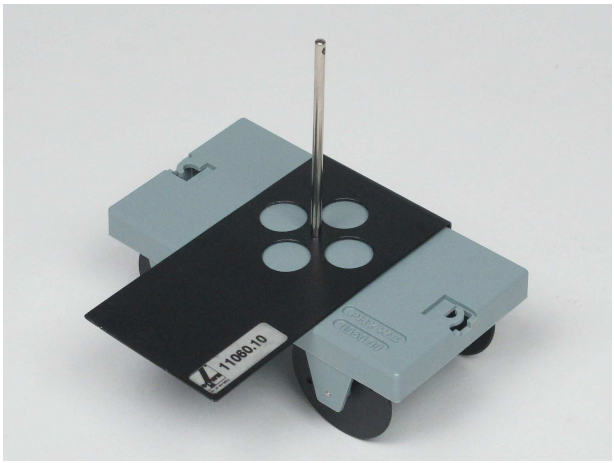


Fig. 3.

Incline the track so that the cart continues its motion with the exact same velocity, if possible, when it is pushed by hand into

the direction of the pulley. To do so, position the adjusting screw at the other end of the track on slotted weights and adjust the inclination with the screw (Fig. 4).

Fig. 4

Insert a piece of thread through the hole of the holding pin under the cart (Fig. 5), lead it from under the cart on top of the cart and knot it onto the holding pin (Fig. 6).

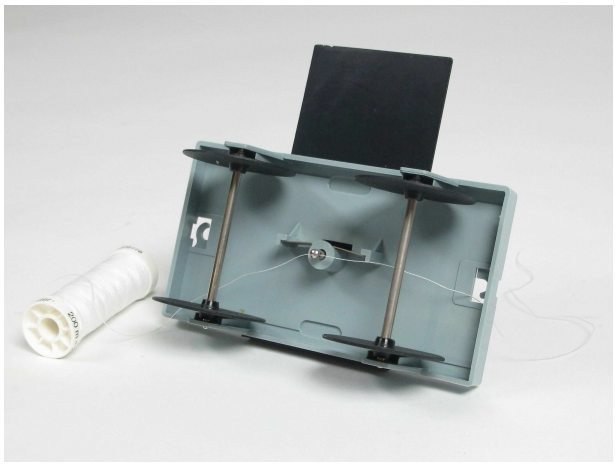


Fig. 5

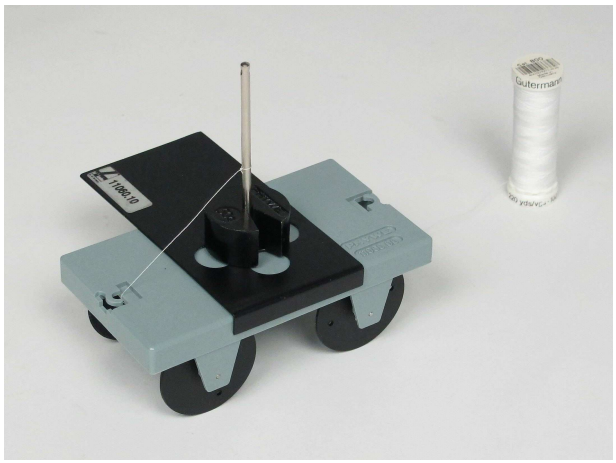


Fig. 6

Knot the other end onto the weight holder (1 g) (Fig. 7) and add four 1 g weights. Adjust the length of the thread so that the weight holder will not reach the floor until the cart has passed through the light barrier and the lower end of the track.

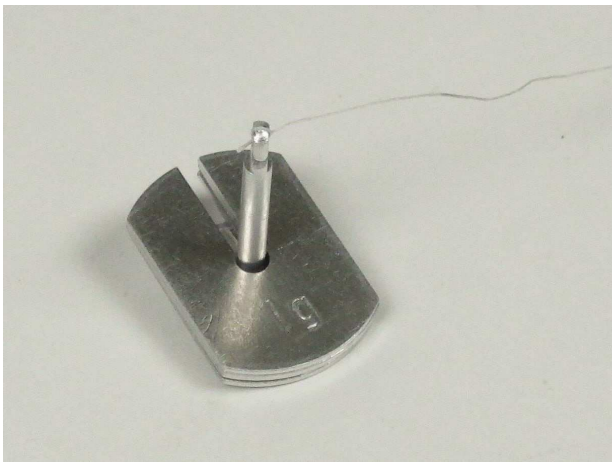


Fig. 7.

Lay the thread that connects the cart to the weight holder over the pulley.
Ensure that the thread runs above the axis of the carts and parallel to the track.

Connect the adapter plates to the light barriers with a spacer bolt so that they can be set up next to the track and that the shutter plate on the cart can pass through the light barriers without touching them (Fig. 8).
Position the light barrier A approximately at the 8.2-cm mark of the rule (measured from the upper end of the track) and the

other light barrier B at a distance of 50 cm from the first one.

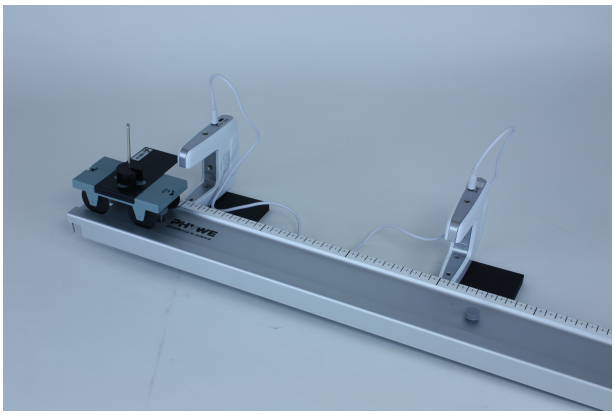
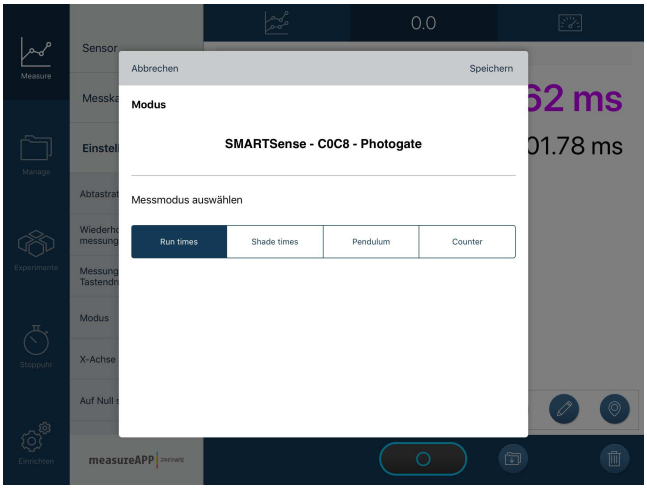


Fig. 8.

Connect the light-barriers with the stereo jack-cable and switch both of them on. Select then the photogate in measureAPP in the menu "sensor". Pick the option "Run times" in the menu that opened. (Fig. 9).



With this setting, the light barrier measures the time t that the cart needs for passing them after measurement was started.

Procedure

Push the cart to the upper end of the track. Viewed from above, the cart should be flush with the end of the track (Fig. 10). Ensure that the light barrier is not interrupted at this point!

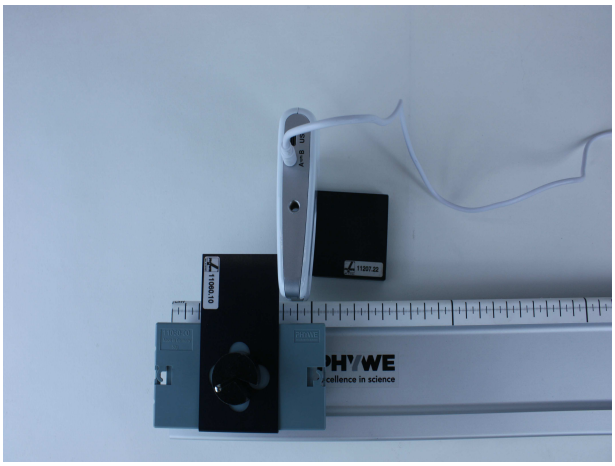


Fig. 10.

Check whether the thread runs over the pulley and whether the pulley can rotate freely.
Change the display to numerical mode 0.0 (fig. 11).
Start the measurement by pressing on .
Release the cart without pushing it and catch it behind the stop light barrier.

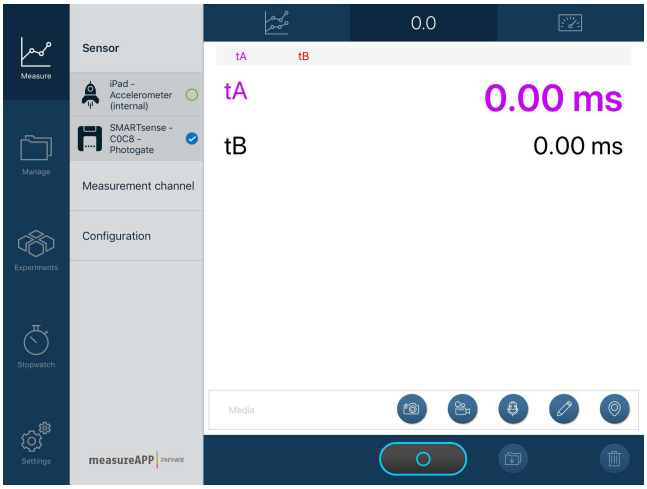


Fig. 11.

Read the time t_A and t_B and enter the difference (which is then the runnig time) converted into seconds into table 1 of the experiment report.

Increase the accelerated weight from 65 g (cart alone) to 85 g, 115 g, 135 g, 165 g and 185 g with the 10 g and 50 g slotted weigths.

Prior to every measurement start, check whether the thread runs over the pulley and ensure that the start light barrier is not interrupted until the cart is released.

Report: Newton's second law - acceleration as a function of mass with SMARTsense

Ergebnis - Tabelle 1

Enter the measured motion times *t* into the second column.

Calculate the reciprocal values of the accelerated masses m and enter them into the third column.

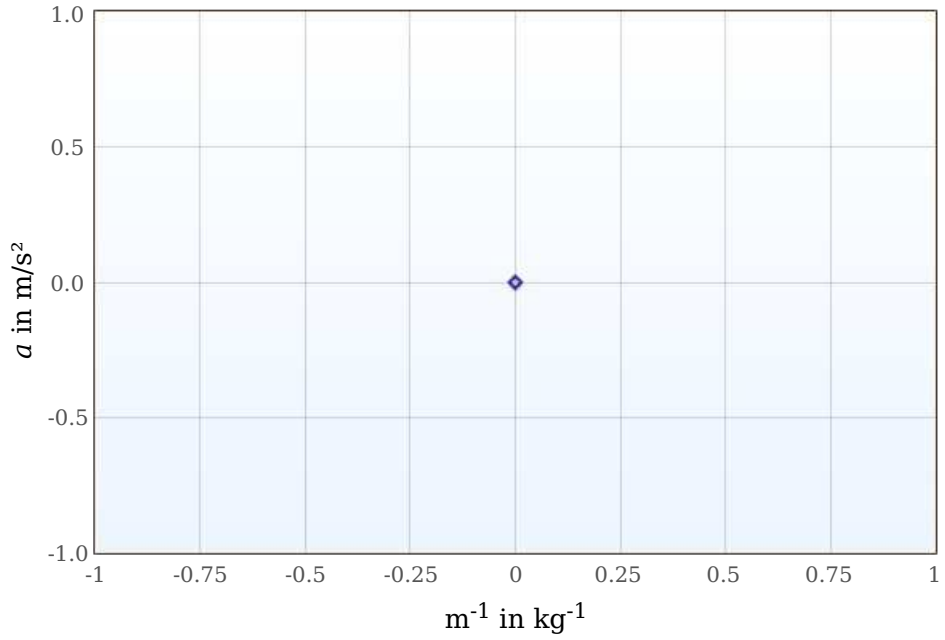
Calculate the square values of the times *t* and enter them into the t^2 column. The times were measured with two significant figures. Consequently, all of the calculated values are to be stated with two valid figures.

Use the law of uniformly accelerated motion $s=1/2 \cdot a \cdot t^2$ to calculate the acceleration *a* and enter the values into the corresponding column.

The meaning of the last column will be explained in the next question.

m in kg	*t* in s	m^{-1} in kg^{-1}	t^2 in s^2	$a=2s/t^2$ in m/s^2	$m=F/a$ in kg
0.065	1 ±0.1	1 ±0	1 ±0.2	1 ±0.15	1 ±0.012
0.085	1 ±0.1	1 ±0	1 ±0.3	1 ±0.11	1 ±0.016
0.115	1 ±0.1	1 ±0	1 ±0.3	1 ±0.11	1 ±0.03
0.135	1 ±0.2	1 ±0	1 ±0.6	1 ±0.11	1 ±0.04
0.165	1 ±0.2	1 ±0	1 ±0.8	1 ±0.09	1 ±0.05
0.185	1 ±0.2	1 ±0	1 ±0.8	1 ±0.08	1 ±0.05
		0		0	

Number1



Evaluation - Question 1

In the graph of table 1, the acceleration *a* is plotted against the reciprocal of the accelerated mass 1/*m*. What statements can be made based on the diagram?

- [ ] The greater the accelerated mass is, the greater the acceleration will be.
- [ ] In the case of an infinite mass, the acceleration is zero.
- [ ] The acceleration is proportional to the accelerated mass.
- [ ] The smaller the accelerated mass is, the greater the acceleration will be.
- [ ] The acceleration and the reciprocal of the mass are proportional to one another.

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Evaluation - Question 2

Determine the dimension of the gradient k of the straight line in the diagram and select the correct unit.

- ☐ [k] = kg
- ☐ [k] = kg·m/s² = N
- ☐ [k] = N/m² = Pa
- ☐ [k] = kg·m²/s² = Nm = J
- ☐ [k] = s
- ☐ [k] = 1
- ☐ [k] = m

Evaluation - Question 3

Calculate the value of the gradient k and state it with the unit that you have selected in the previous question.

Evaluation - Question 4

Compare the determined gradient k to the tractive force F = 0.005 kg·9.81 N/kg = 0.049 N. What can you see?

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Evaluation - Question 5

Which of the following equations results from the diagram with the determined proportionality factor *k* and the finding of the previous question?

- [ ] $F = m \cdot a$
- [ ] $F = m/a$
- [ ] $a = 1/F \cdot m$
- [ ] $F = a/m^2$

Evaluation - Question 6

Describe the relationship between the accelerated mass *m*, tractive force *F*, and acceleration *a* in your own words.

Use sentences of the type "The more/less..., the more/less..." or "The greater/higher/smaller/lower..., the greater/higher/smaller/lower...".

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Evaluation - Question 7

Following its rearrangement, the equation can also be used for calculating the mass *m*. Enter these calculated masses into the last column in table 1. Compare the calculated masses to the respective cart mass *m*.

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