Uniformly accelerated motion with an accelerating mass with the demonstration track and timer 4 – 4

(Item No.: P1198605)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physik	Klasse 7-10	Mechanik	Lineare Bewegung	

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

Additional Requirements:

Experiment Variations:

Keywords:

Acceleration, frictionless motion, forces of interaction, distance-time law, velocity-time law

Overview

Introduction

If a constant force acts on an object, the object is subject to constant acceleration. The aim of this experiment is to use a uniformly accelerated cart in order to demonstrate that its velocity increases linearly over time and that the dependence of the distance on the time can be described by way of a parabola.

Educational objective

If an object undergoes uniform acceleration, the distance that is covered increases in a square manner over time in accordance with the distance-time law. In accordance with the velocity-time law, the velocity is linear:

$s(t) = 0.5 \cdot a \cdot t^2$, $v(t) = a \cdot t$

Related topics

The laws of motion for a uniformly accelerated motion can also be demonstrated by way of experiment P1198805 "Uniformly accelerated motion on an inclined track". During this experiment, the cart is accelerated due to the inclination of the track and not by a mass that is suspended from the cart. In addition, the gravitational acceleration can be determined by way of this experiment.
This experiment does not explicitly describe the influence of the mass of the weight holder and cart on the acceleration. This will be the topic of the subsequent experiments P1199205 "Newton's second law" and P1199405 "Equivalence of inertial mass and gravitational mass".

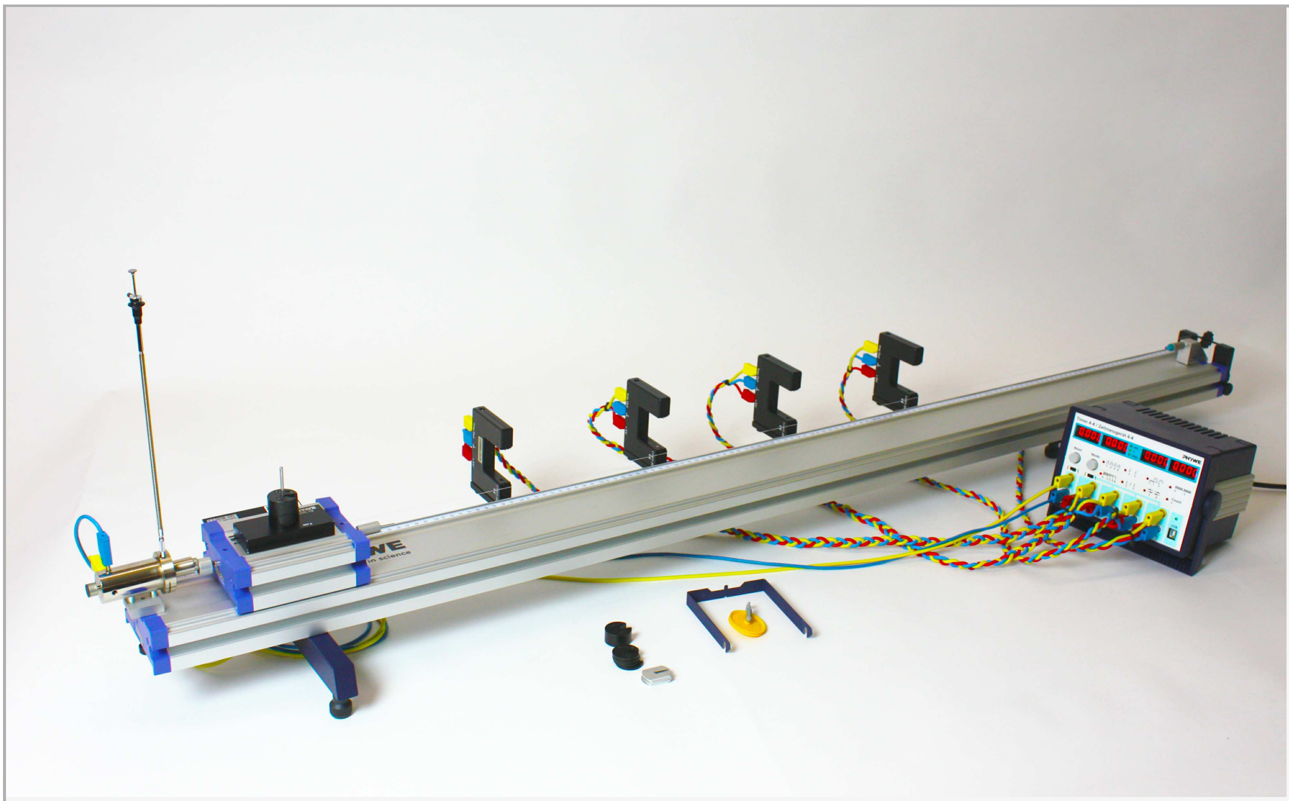

Figure 1: Experiment set-up

Equipment

Position No.	Material	Order No.	Quantity
1	Timer 4-4	13604-99	1
2	Starter system for demonstration track	11309-00	1
3	Demonstration track, aluminium, 1.5 m	11305-00	1
4	Cart, low friction sapphire bearings	11306-00	1
5	Light barrier, compact	11207-20	4
6	End holder for demonstration track	11305-12	1
7	Weight for low friction cart, 400 g	11306-10	1
8	Holder for pulley	11305-11	1
9	Magnet w.plug f.starter system	11202-14	1
10	Pulley for demonstration track	11305-10	1
11	Shutter plate for low friction cart, width: 100 mm	11308-00	1
12	Needle with plug	11202-06	1
13	Weight holder, silver bronze, 1 g	02407-00	1
14	Tube with plug	11202-05	1
15	Holder for light barrier	11307-00	4
16	Slotted weight, black, 10 g	02205-01	4
17	Slotted weight, black, 50 g	02206-01	3
18	Connecting cord, 32 A, 1000 mm, red	07363-01	4
19	Connecting cord, 32 A, 1000 mm, yellow	07363-02	5
20	Connecting cord, 32 A, 1000 mm, blue	07363-04	5
21	Plasticine, 10 sticks	03935-03	1
22	Slotted weight, blank, 1 g	03916-00	
23	Silk thread, l = 200 m	02412-00	1
Option:			
	Pulley, movable, d = 40 mm, with hook	03970-00	1

Tasks

1. Determination of the distance-time relationship based on several measured time values at different distances covered by the cart.
2. Determination of the velocity-time relationship based on a measurement of the light barrier shading times at different positions.

Set-up and procedure

Set-up

Set the experiment up as shown in Figure 1:

1. In order to compensate for slight friction effects, the track must be slightly inclined by way of the adjusting screws at the track bases so that the cart is still just about prevented from rolling to the right.
2. Position the starter system at the left end of the track. Please note that, in order to start the cart without an initial momentum, the starter system must be installed so that the ram moves away from the cart when the starter system is triggered (Fig. 2).

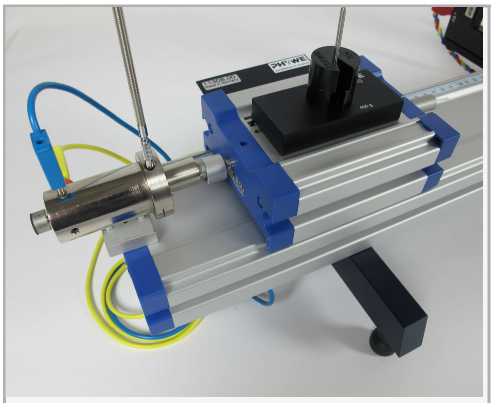

Fig. 2: Starter system without an impulse

3. Attach a plasticine-filled tube to the end holder at the right-hand end of the track in order to stop the cart without a strong impact (see Fig. 3).

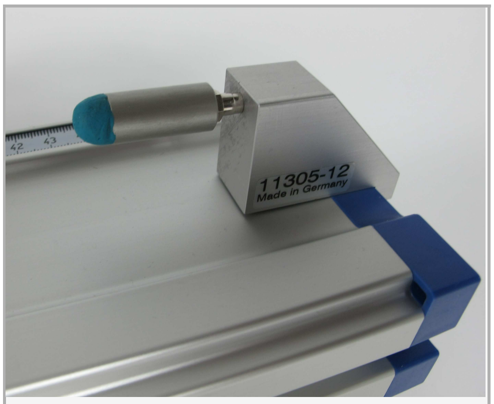

Fig. 3: End holder with plasticine

4. Install the pulley with the holder for the pulley at the right-hand end of the track and add the incremental wheel.
5. Equip the cart with the magnet with a plug and with the shutter plate (w = 100 mm).
6. Insert the end of the thread from above through the vertical hole of the end cap of the cart and secure it in place by plugging the needle with a plug into the front (see Fig. 4).

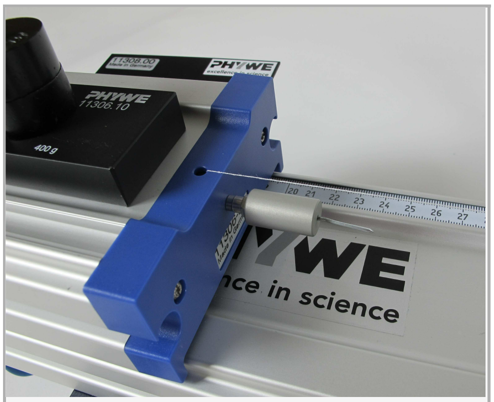

Fig. 4: Fastening of the thread on the cart

7. Lay the thread over the incremental wheel of the pulley and knot its end onto the weight holder so that the latter is suspended freely just below the wheel (see Fig. 5). The force exerting the constant acceleration is the weight holder with 5 to 20 weights
   (1 g each) placed on it. Ensure that the thread is parallel to the track.

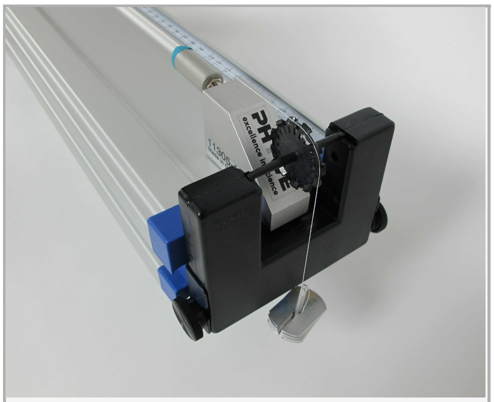

Fig. 5: Positioning of the weight holder

8. The mass of the cart can be varied by way of the black weights (see Fig. 2).
9. Install the four light barriers on the track by way of the light barrier holders and distribute them evenly over the track. Ensure that the back part of the shutter plate on the moving cart can pass through all of the light barriers before the weight holder
   touches the floor.
10. Connect the four light barriers from the left to the right to the sockets in the fields "1" to "4" of the timer. In doing so, connect the yellow sockets of the light barriers to the yellow sockets of the measuring instrument, the red sockets to their red counterparts, and the blue sockets of the light barriers to the white sockets of the timer (see Fig. 6).

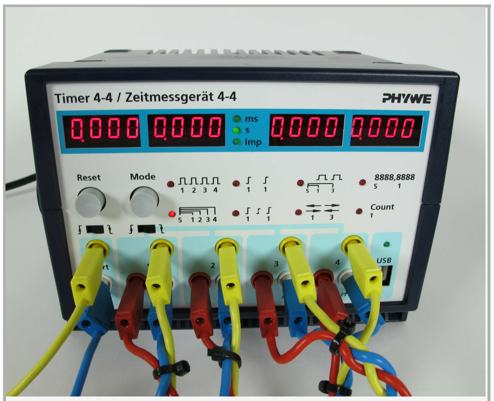

Fig. 6: Connection of the light barriers and starter system

11. Connect the starter system to the two "Start" sockets of the timer. Ensure that the polarity is correct. Connect the red socket of the starter system to the yellow socket of the timer.
12. In order to select the triggering edge, push the two slide switches of the timer to the right, i.e. to "falling edge" (⌐)

Procedure

Durchführung

1. Measure the distances $s_1 \ldots s_4$ of the light barriers with regard to the start position of the cart. In doing so, it must be taken into consideration that the light barriers will be interrupted by the front edge of the shutter plate that is installed on the cart, and not by the cart itself. The exact determination of the distances can be performed as follows:
    - Bring the cart to the start position and read the value (x_0) off the tape measure at the right-hand side end of the cart.
    - Move the cart to a position where the right-hand side end of the shutter plate just about interrupts the light beam of the light barrier *i* and then read the value (x_i) off the tape measure at the right-hand side end of the cart (see Fig. 7).

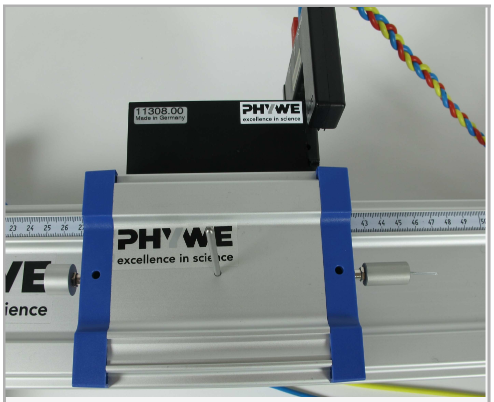

Fig. 7: Interruption of a light barrier by the shutter plate

    - $s_i = x_i - x_0$ is the distance that the cart has covered from the start up to the corresponding light barrier.
2. The cart is released by the starter system and it undergoes constant acceleration until the weight holder touches the floor. Then, it continues to move at constant velocity.
3. First, measure the times $t_1 \ldots t_4$ for covering the distances $s_1 \ldots s_4$ in mode 2 (). Then, perform a measurement in mode 1 () in order to determine the corresponding velocities. During this measurement, the shading times $\Delta t_1 \ldots \Delta t_4$ of the four light barriers are determined. These are then used in order to calculate the average velocity of the cart passing through the light barriers based on the length of the shutter plate (100 mm).
4. Record the times for up to five repetitions. Prior to every recording process, press the "Reset" button in order to reset the display.
5. Reposition the light barriers and perform one additional series of measurements as described hereinabove.

Note

Depending on the mass that is placed on the weight holder, there may be a strong impulse when the cart hits the end holder. Prior to the next measurement, it must be ensured that the shutter plate is properly fastened in the cart and that the thread runs over the
incremental wheel.

Observation and results

Observation

Beobachtung

Für zunehmende Wegstrecken s_i zeigt sich, dass die Abschattzeiten Δt_i aufgrund der Beschleunigung des Wagens immer geringer werden und sich die Geschwindigkeit des Wagens kontinuierlich erhöht, bis der Gewichtsteller den Boden berührt.

Evaluation

Auswertung

1. Use five measurements of $t_1 \ldots t_8$ and $\Delta t_1 \ldots \Delta t_8$ to calculate the mean values $t_{1m} \ldots t_{8m}$ and $\Delta t_{1m} \ldots \Delta t_{8m}$.
2. The shading times are used to determine the velocities $v_i(t_{im}) = b/\Delta t_{im}$ with the shutter plate length w = 0.1 m.
3. In the case of a uniformly accelerated motion, the acceleration a can be determined by way of two different methods. Either by way of the distance-time law $s(t) = 0.5 \cdot a \cdot t^2$ based on the runtime of the cart and the positions of the light barriers or by way of the velocity-time law $v(t) = a(t) \cdot t$ based on the runtime of the cart and the corresponding velocities:
   - In order to verify the distance-time law, enter the measurement values into a (s, t^2) system of coordinates. The acceleration a can be determined graphically based on the gradient of the straight line through the origin ($0.5 \cdot a$) or by way of a calculation (see Figure 8 and Table 1).

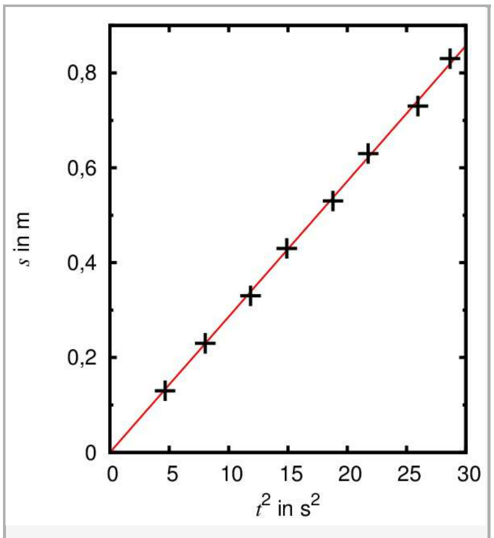

Fig. 8: Distance-time-law with s(t) = 0,0286 mt²/s² and thereby, a = 0,057 m/s²

   - In a (v, t) system of coordinates, plot the velocities against the measured time. The velocity-time law results graphically from the gradient of the straight line through the origin or by calculation (see Figure 9 and Table 1).

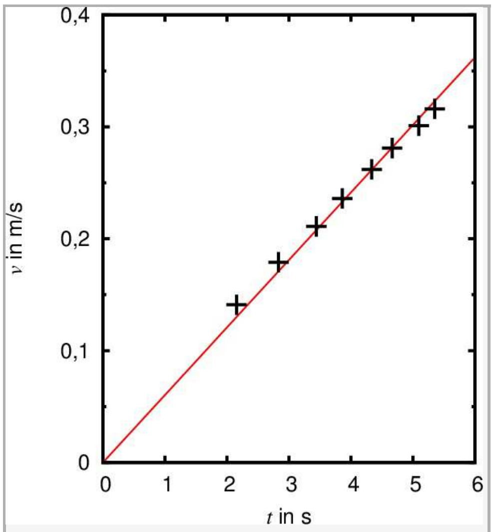

Figure 9: Velocity-time law with v(t) = a · t = 0.060 m/s² · t and, thereby, a = 0.060 m/s²

Table 1: Measurement example with the cart mass mc = 900 g, the accelerating mass m = 7 g, and the length of the shutter plate w = 0.100 m

s in m	t_m in s	Δt_m in s	v in m/s	$a = v/t_m$ in m/s²	$(t_m)^2$ in s²	$a = 2s/(t_m)^2$ in m/s²
0.23	2.833	0.559	0.179	0.063	8.026	0.057
0.43	3.861	0.424	0.236	0.061	14.907	0.058
0.63	4.665	0.356	0.281	0.060	21.762	0.058
0.83	5.353	0.316	0.316	0.059	28.655	0.058
0.13	2.156	0.710	0.141	0.065	4.648	0.056
0.33	3.442	0.474	0.211	0.061	11.847	0.056
0.53	4.336	0.382	0.262	0.060	18.801	0.056
0.73	5.094	0.332	0.301	0.059	25.949	0.056

Note

Anmerkung

1. The experiment can be performed with different cart masses and accelerating masses.
2. If the height of the desktop is not sufficient for realising an accelerated motion along the entire length of the track, the acceleration distance can be doubled by way of the bracket, which is included with the holder for the pulley, and a loose pulley. To do so, fasten the bracket on the holder for the pulley. Then, knot the end of the thread onto this bracket and not onto the weight holder. The loose pulley with the hook from which additional weights can be suspended must be placed on the thread between the incremental wheel and the bracket as shown in Fig. 10.

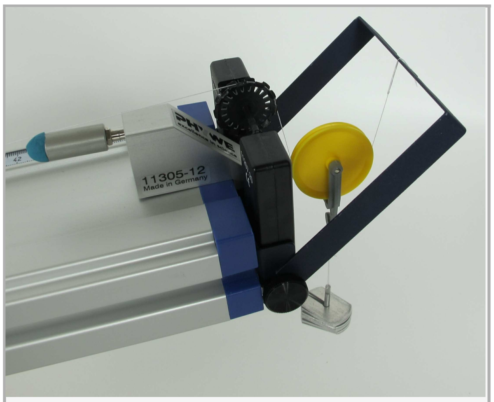

Fig. 10: Loose pulley for expanding the acceleration distance

For the evaluation, it must be taken into consideration that the cart is accelerated by only half of the weight force of the pulley and weights and that the pulley and weights have only half of the velocity of the cart.

3. In order to decrease the distance between the weight holder and the incremental wheel, the thread can be shortened by turning the needle with a plug on the cart several times, thereby winding the thread up.
4. Strictly speaking, the velocities v_i that are calculated based on Δt_i are not instantaneous velocities, since the cart is still subject to acceleration when the shutter plate passes through the light barrier. Consequently, the velocities result from a secant gradient and not from a tangent gradient of the graph of $s(t)$. With $\Delta s = 0.1m$, a systematic error of approximately 2 % must be taken into consideration.