Uniformly accelerated motion on an inclined track with the demonstration track and timer 4 – 4

(Item No.: P1198805)

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	10 Minutes	10 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Acceleration, frictionless motion, inclined track, distance-time law, velocity-time law, Newton's second law, gravity, resolution of forces, acceleration due to gravity

Overview

Introduction

An object on an inclined track is subject to constant acceleration in parallel to the track due to the gravitational forces exerted on the object. The aim of this experiment is to confirm the laws of motion for a uniformly accelerated motion by measuring the time that a cart runs on the inclined demonstration track. In addition, the magnitude of the acceleration due to gravity can be verified based on Newton's second law.

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:

$$s(t) = \frac{1}{2} \cdot a \cdot t^2, v(t) = a \cdot t$$

Depending on the angle of inclination of the track, the gravitational force acting on the cart leads to a uniformly accelerated motion proportional to the acceleration due to gravity:

$$a = g \cdot sin(\alpha)$$

Related topics

The laws of motion for a uniformly accelerated motion can also be demonstrated by way of experiment P1198605 "Uniformly accelerated motion with an accelerating mass". In this case, the cart is not accelerated due to the inclination of the track, but by a mass that is suspended from the cart by way of a piece of thread. In the experiment P1198905 "Uniformly decelerated motion", the cart is also subject to acceleration on an inclined track. However, in this case, the acceleration acts on the cart in the opposite direction.

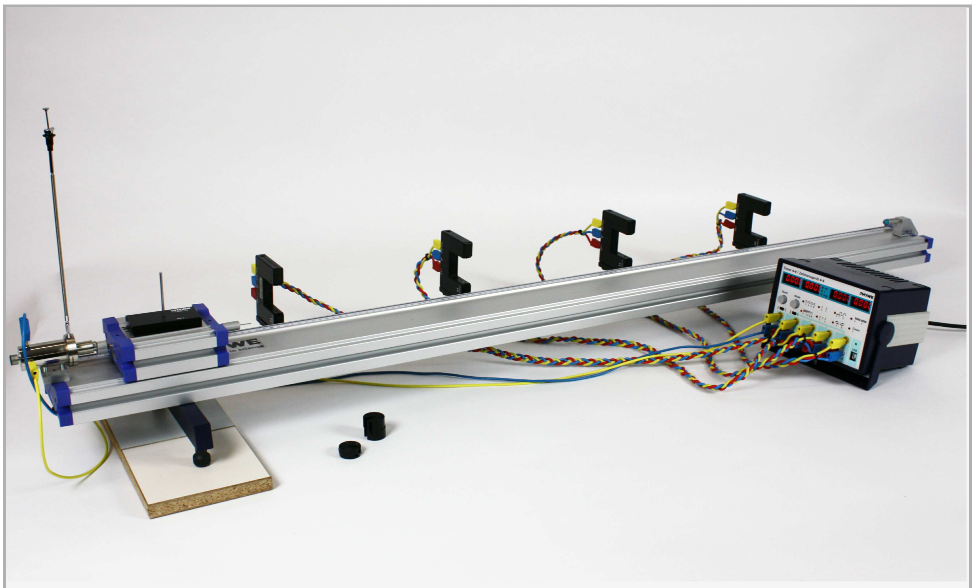

Figure 1: Experiment set-up

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	Portable Balance, OHAUS CS2000E	48911-00	1
7	End holder for demonstration track	11305-12	1
8	Weight for low friction cart, 400 g	11306-10	1
9	Magnet w.plug f.starter system	11202-14	1
10	Shutter plate for low friction cart, width: 100 mm	11308-00	1
11	Supporting blocks,set of 4	02070-00	1
12	Needle with plug	11202-06	1
13	Tube with plug	11202-05	1
14	Slotted weight, black, 50 g	02206-01	2
15	Slotted weight, black, 10 g	02205-01	4
16	Holder for light barrier	11307-00	4
17	Connecting cord, 32 A, 1000 mm, red	07363-01	4
18	Connecting cord, 32 A, 1000 mm, yellow	07363-02	5
19	Connecting cord, 32 A, 1000 mm, blue	07363-04	5
20	Plasticine, 10 sticks	03935-03	1
21	Measuring tape, l = 2 m	09936-00	1
Option:			
	Supporting blocks, 150 mm, set of 4	02070-00	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.
3. Determination of the acceleration due to gravity based on the mass of the cart and the angle of inclination of the track.

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. Position an object (supporting blocks, books, a stack of paper, etc.) under the double-footed base of the track in order to raise it by approximately 1 to 5 cm.
2. Position the starter system at the raised 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).

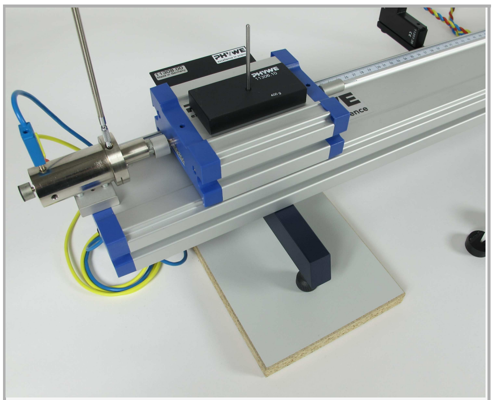

Fig. 2: Raised starter system without an impulse

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 (Fig. 3).

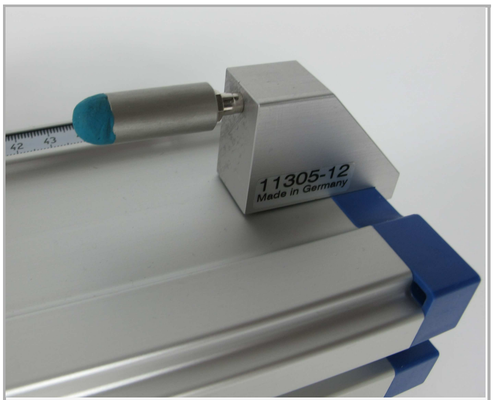

Fig. 3: End holder with plasticine

4. Equip the cart with the magnet with a plug, a needle with a plug, and the shutter plate (w = 100 mm) (see Figs. 2 and 4).

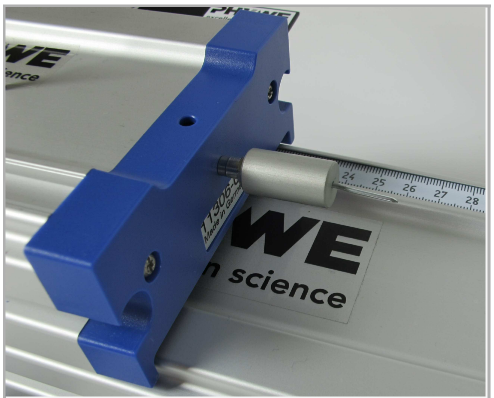

Fig. 4: Front of the cart

5. The mass of the cart can be varied by way of the weights.

6. Install the four light barriers on the track by way of the light barrier holders (Fig. 5). Position the light barriers on the track so that the measuring length is divided into four segments of roughly the same size.

Fig. 5: Installation of the light barriers on the track

7. Connect the light barriers from the left to the right to the sockets in the fields "1" to "4" of the timer as shown in Fig. 6. 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.

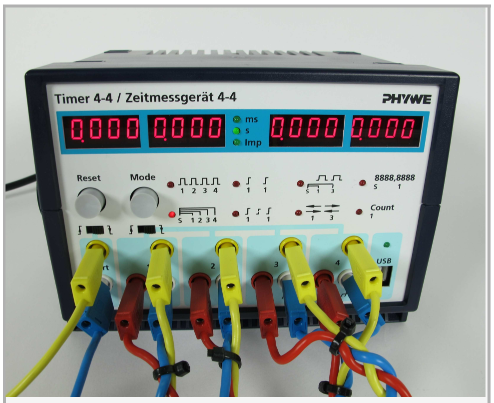

Fig. 6: Connection of the light barriers and starter system

8. 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.

9. In order to select the triggering edge, push the two slide switches of the timer to the right, i.e. to "falling edge" (⤓)

Procedure

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 measuring tape 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 of the cart (see Fig. 7).

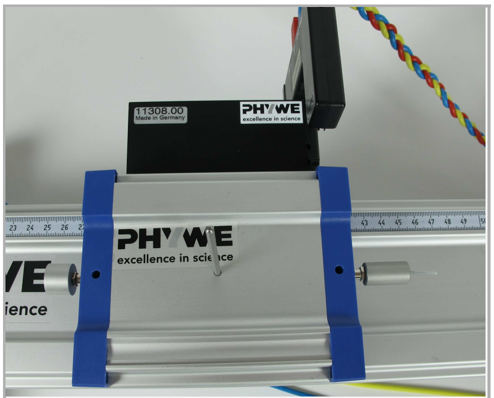

Fig. 7: Interruption of a light barrier by the shutter plate

   - $s_i = x_i - x_0$ 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. Due to the gravity component that is applied to the cart, it is accelerated in a constant manner.
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.
6. Determine the mass of the cart by way of a balance.
7. In order to determine the angle of inclination α of the track, measure the distance between the track bases l and the height h of the object placed under the track (compare Figure 8).

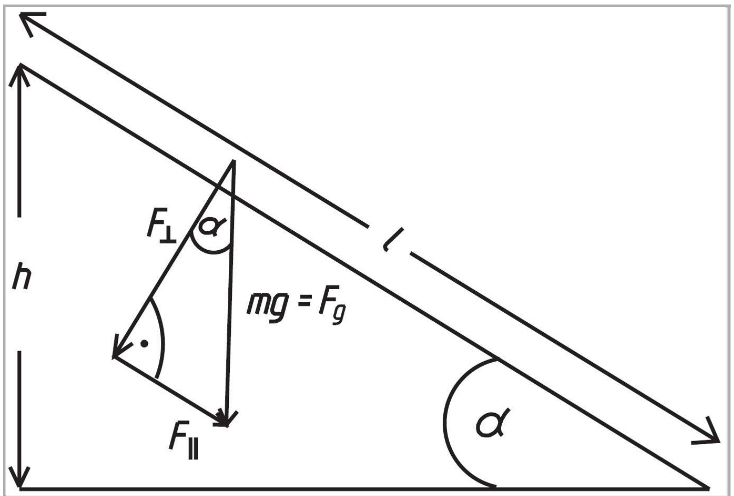

Fig. 8: Determination of the angle of the inclination of the demonstration track

Observation and results

Observation

If the distances between the light barriers are roughly the same, it becomes clear that the runtime differences t_i and the shading time Δt_i become increasingly smaller along the track due to the acceleration of the cart.

Evaluation

a) The distance-time law and the velocity-time law

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 $v_i(t_{im}) = b/\Delta t_{im}$ ith 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 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 and the corresponding velocity:
   - 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 9 and Table 1).

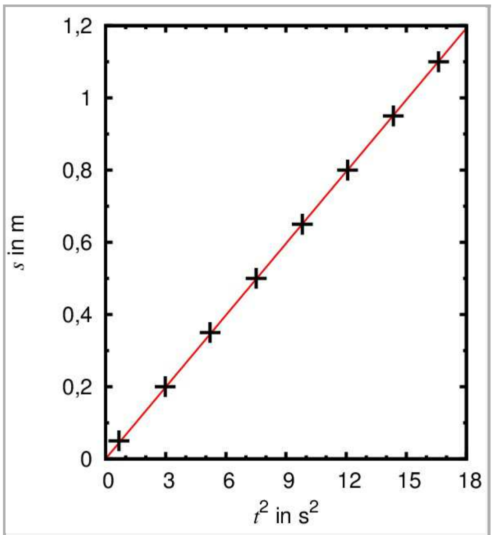

Fig. 9: Distance-time law with s(t) = 0,0663 mt²/s² and thereby, a = 0,133 m/s²

   - 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 10 and Table 1).

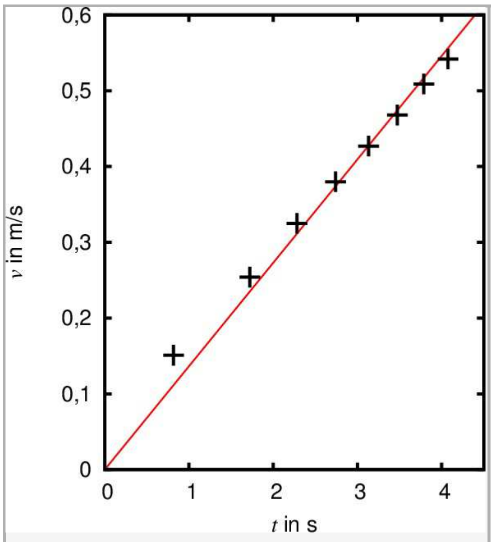

Figure 10: Velocity-time law with v(t) = a · t = 0.136 m/s² · t and, thereby, a = 0.136 m/s

Table 1: Measurement example with a cart mass mc = 800 g, l = 139 cm, h = 1.9 cm, and a shutter plate length 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
0.20	1.724	0.394	0.254	0.147	2.97	0.135
0.50	2.740	0.263	0.380	0.139	7.51	0.133
0.80	3.474	0.214	0.468	0.135	12.07	0.133
1.10	4.075	0.184	0.542	0.133	16.61	0.132
0.05	0.817	0.661	0.151	0.185	0.67	0.150
0.35	2.282	0.308	0.325	0.142	5.21	0.134
0.65	3.132	0.234	0.427	0.136	9.81	0.132
0.95	3.788	0.196	0.509	0.134	14.35	0.132

b) Determination of the gravitational acceleration

The weight force F_g acting on the cart can be resolved into two parts, one component $F_{||}$ in the direction of the track and one component $F_{\perp}$ perpendicular to the track. The component causing an acceleration in the direction of the track increases with an increasing angle of inclination α. $F_{||}$ causes a uniformly accelerated motion. Figure 8 shows the vector resolution of the force by way of a parallelogram of forces. The following applies: $F_{||} = F_g \cdot sin(\alpha)$.

The angle of inclination α results from the height h of the object placed under the track and the distance l between the two track bases: $sin(\alpha) = h/l$. In this measurement example, h = 1.9 cm and l = 139 cm, resulting in α = 0.78°.

In accordance with Newton's second law (compare Figure 8)

$$F_{||} = m \cdot g \cdot sin(\alpha) = m \cdot a$$

and based on the acceleration determined in Figure 9

a = 0.133 m/s²

the following value results for the acceleration due to gravity:

$$g_s = \frac{a}{sin(\alpha)} = 9.73 \text{ m/s}^2$$

Based on the velocity measurements and Figure 10, the following value results for the acceleration due to gravity:

g_v = 9.95 m/s²

Note

1. 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.
2. Mit einer weiteren Erhöhung der Startposition lässt sich die Proportionalität zwischen Beschleunigung und dem Sinus des Neigungswinkels aufzeigen. Durch Wiederholen der Messungen mit verschiedenen Schlitzgewichten auf dem Wagen lässt sich demonstrieren, dass Beschleunigung und Geschwindigkeit des Wagens (Reibungsfreiheit vorausgesetzt) unbeeinflusst von der Masse sind. Dieser Zusammenhang lässt sich auch gut im Rahmen des Versuchs zum freien Fall anführen.