Newton's second law with the demonstration track and timer 4 - 4 (Item No.: P1199205)

Curricular Relevance

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

Difficulty
Intermediate

Preparation Time
20 Minutes

Execution Time
10 Minutes

Recommended Group Size
2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Principle of action, change of motion due to the application of force, inertial mass, velocitytime law, fundamental equation of mechanics, Newton's second law

Overview

Introduction

If an object is subject to constant force, it undergoes constant acceleration. Its change in motion is proportional to the accelerating force. The aim of this experiment is to describe the relationships between the acceleration of a cart and its mass or the accelerating force with the aid of the demonstration track.

Educational objective

Newton's second law states that the change in motion of an object is proportional to the force acting upon it:

$\vec{F} = m \cdot \dot{\vec{v}} = m \cdot \vec{a}$.

The relationship between mass and acceleration will be examined for various inertial masses and various accelerating forces.

Related topics

The uniformly accelerated motion with a weight holder has already been examined in experiment P1198605 "Uniformly accelerated motion with an accelerating mass". However, during this experiment, the influence of the mass of the cart and weight holder has not been explicitly examined. Instead, the laws of motion for s(t) and v(t) have been introduced and confirmed.

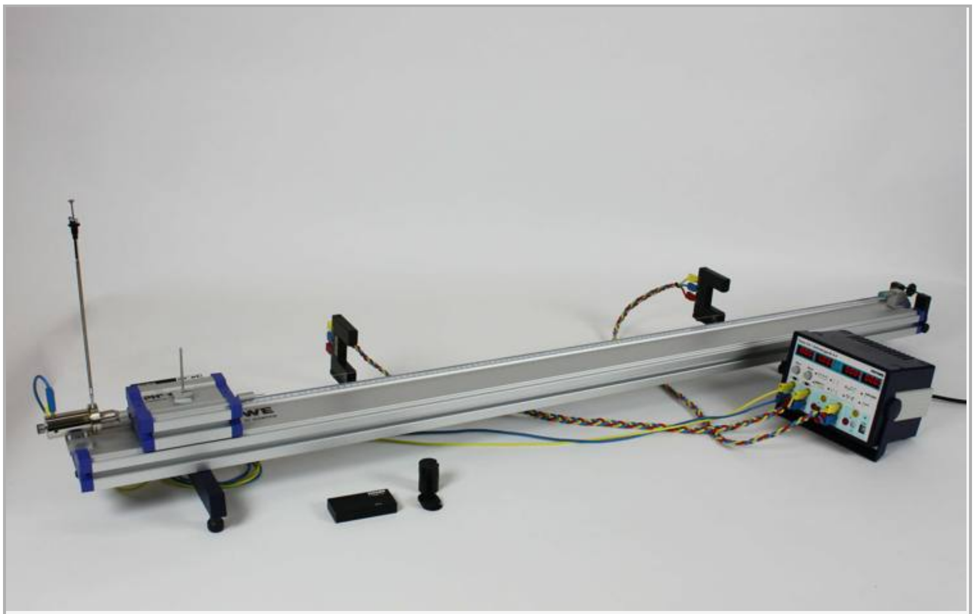

Figure 1: Experiment set-up

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	2
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	Holder for pulley	11305-11	1
11	Pulley for demonstration track	11305-10	1
12	Shutter plate for low friction cart, width: 100 mm	11308-00	1
13	Needle with plug	11202-06	1
14	Weight holder, silver bronze, 1 g	02407-00	1
15	Tube with plug	11202-05	1
16	Slotted weight, black, 10 g	02205-01	8
17	Slotted weight, black, 50 g	02206-01	4
18	Holder for light barrier	11307-00	2
19	Connecting cord, 32 A, 1000 mm, red	07363-01	4
20	Connecting cord, 32 A, 1000 mm, yellow	07363-02	5
21	Connecting cord, 32 A, 1000 mm, blue	07363-04	5
22	Plasticine, 10 sticks	03935-03	1
23	Slotted weight, blank, 1 g	03916-00	
24	Silk thread, l = 200 m	02412-00	1

Tasks

1. Determination of the acceleration as a function of the accelerating mass.
2. Determination of the acceleration as a function of force.

Set-up and procedure

Set-up

Der Aufbau erfolgt gemäß Abbildung 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).

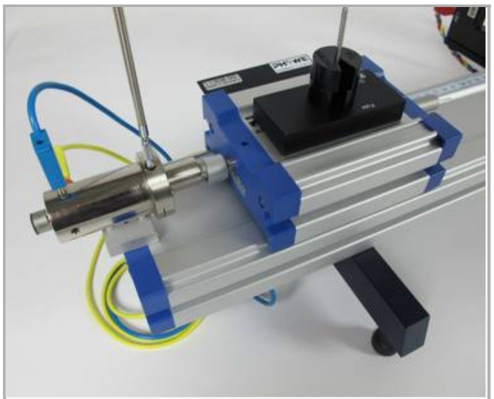

Fig. 2: Starter system without an impulse

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).

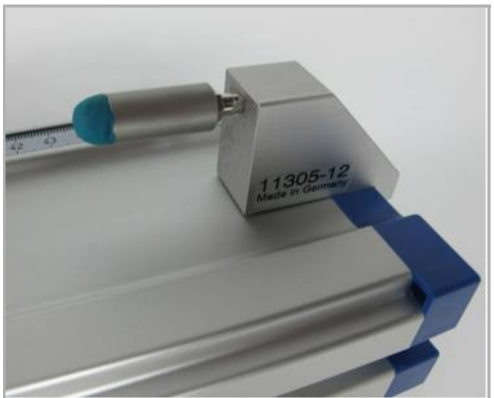

Fig. 3: End holder with plasticine

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).

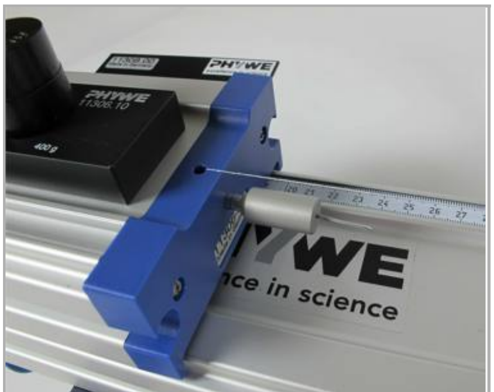

Fig. 4: Fastening of the thread on the cart

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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.

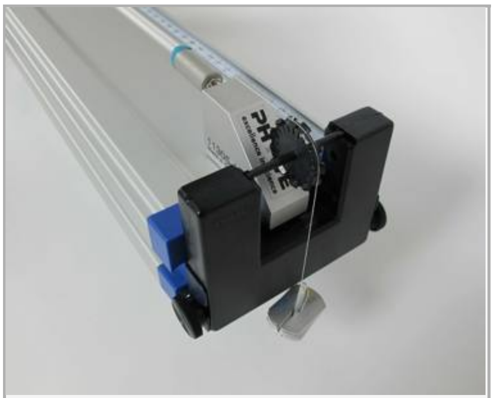

Fig. 5: Positioning of the weight holder

8. The mass of the cart can be varied by way of the black weights.
9. Install two 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 when the cart moves (see Fig. 6).

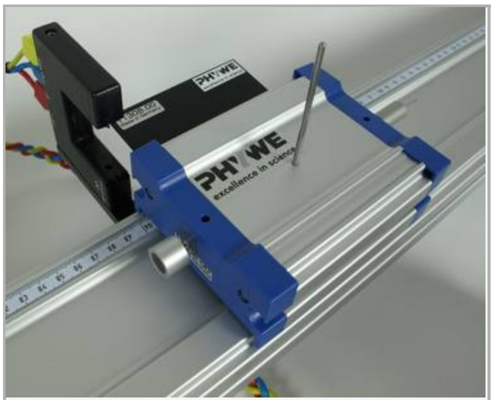

Fig. 6: Release of a light barrier following the passing of the shutter plate.

10. Connect the light barriers to the sockets in the fields "1" and "3" 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. 7).

Fig. 7: 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

1. The weight holder is used to cause the cart to perform a uniformly accelerated motion. During this process, the acceleration of the cart is determined as a function of the entire inertial mass and also as a function of the accelerating mass. As a first step, the mass of the cart without the black additional weights must be determined with the aid of a balance.
2. The cart is released by the starter system and it undergoes constant acceleration until the weight holder touches the floor.
3. In order to determine the acceleration of the cart, one measurement must be performed in mode 5 (). The cart passes through two light barriers. The time t_i for the duration of the light barrier interruption are measured simultaneously. The times that the cart needs for covering the distances are indicated in the digital displays 1 and 3, while the shading times are indicated on displays 2 and 4.
4. The acceleration of the cart results from the velocity time law
$$v(t) = a \cdot t \Leftrightarrow a = \frac{v(t)}{t} = \frac{b \;/\; \Delta t}{t}$$
with the shutter plate length w = 100 mm.
5. In order to determine the acceleration as a function of mass, record a series of measurements in which the mass of the cart is increased in steps of approximately 10–50 g, while the accelerating mass of the weight holder remains constant.
6. When measuring the acceleration as a function of force, the total mass is to remain constant while the accelerating force F_g is changed. This can be realised by a mass transfer from the cart to the weight holder. We recommend placing approximately ten 1 g weights on the cart (see Fig. 8) and transferring them one by one to the weight holder for every measurement. However, the accelerating mass should not exceed 20 g.

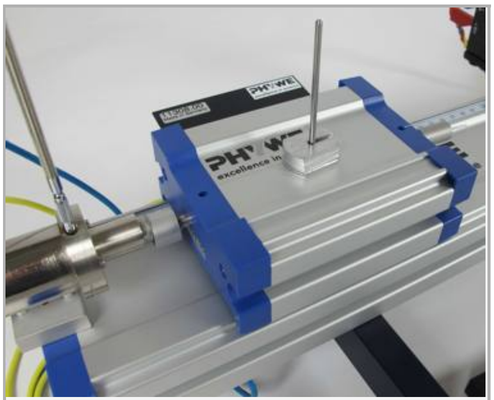

Fig. 8: Additional weights for the force measurement

Observation and results

Observation

When the inertial mass is increased while the accelerating force remains constant, the cart slows down. A transfer of mass causes a change of the acceleration, since, although the total mass remains the same, only the mass of the weight holder causes the acceleration of the cart.

Evaluation

a) Acceleration as a function of the inertial mass

1. Table 1 shows an example measurement for determining the dependence between mass and acceleration. The total mass is the mass of the cart M, comprising its unladen weight M_0 and the additional weights M_Z,plus the constant mass m of the weight holder.
2. In accordance with the velocity-time law, the measured times t_i and Δt_i , combined with the shutter plate length w, directly yield the acceleration a_i acting upon the cart. Within the scope of the measurement accuracy, this acceleration can be regarded as constant at both light barriers so that the following mean value results:
$$a_\mathrm{m} = \frac{a_1 + a_2}{2} .$$
3. Figure 9 shows the acceleration a_m, caused by the mass m = 10 g, as a function of the inertial mass M+m. When the inertial mass increases, the acceleration of the cart decreases.

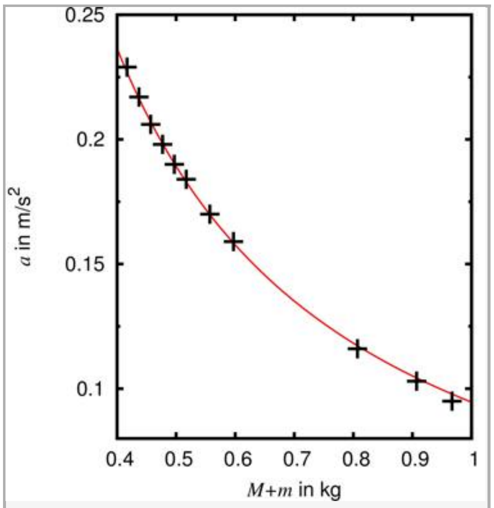

Figure 9: Dependence of the acceleration on the total mass in the case of a constant accelerating mass m = 10g

4. In Figure 10, the same values are plotted as a function of the reciprocal of the inertial mass 1/(M+m). This leads to a linear relationship, which results from Newton's equation of motion. The present case is a one-dimensional motion, which is caused by the force
$$F_g = m \cdot g ,$$
comprising the mass m of the weight holder and the acceleration due to gravity g.

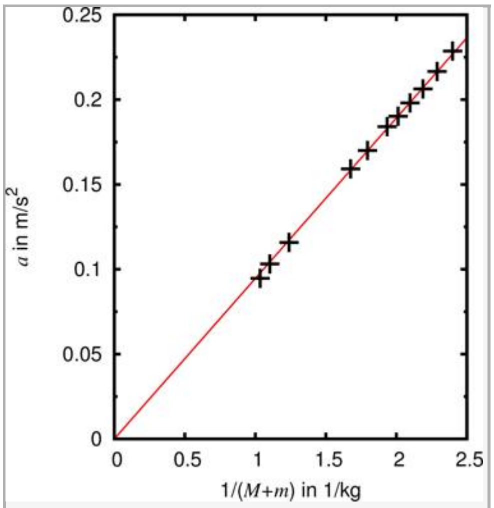

Figure 10: Dependence of the acceleration on the reciprocal of the total mass in the case of a constant accelerating mass m = 10 g

5. Since this mass is directly connected to the cart, the result is an equilibrium of forces
$$F_g = m \cdot g = (M+m) \cdot a = F_B$$
between the weight force F_g and the force $F_B$resulting in the motion of the total system. This leads to the linearity of the acceleration and reciprocal inertial mass as shown in Figure 10:
$$a = \frac{m \cdot g}{M+m} \propto \frac{1}{M+m}\ .$$
The evaluation of the measurement example provides a gradient of 0.0946 kg·m/s² = 0.0946 N, which corresponds rather well to the theoretical value m·g = 0.0981 N.

Table 1: Measurement example with the cart mass M_0 = 397 g and a variable additional weight M_Z, the total mass of the cart $M = M_0+M_Z$, a constant accelerating mass m = 10 g, the shutter plate length b = 0,100 m and a mean acceleration a_m

M_Z in kg	$M+m$ in kg	t_1 in s	Δt_1 in s	t_2 in s	Δt_2 in s	$1/(M+m)$ in kg	a_m in m/s²
0.010	0.417	2.085	0.208	2.758	0.160	2.40	0.229
0.030	0.437	2.143	0.213	2.831	0.165	2.29	0.217
0.050	0.457	2.210	0.218	2.904	0.168	2.19	0.206
0.070	0.477	2.237	0.224	2.958	0.172	2.10	0.198
0.090	0.497	2.290	0.228	3.025	0.175	2.01	0.190
0.110	0.517	2.318	0.232	3.067	0.179	1.93	0.184
0.150	0.557	2.410	0.242	3.190	0.186	1.80	0.170
0.190	0.597	2.479	0.251	3.288	0.193	1.68	0.159
0.400	0.807	2.922	0.292	3.866	0.226	1.24	0.116
0.500	0.907	3.068	0.312	4.074	0.241	1.10	0.103
0.560	0.967	3.225	0.324	4.271	0.250	1.03	0.095

b) Acceleration as a function of force

1. Table 2 shows the values for a measurement of the dependence of the acceleration on the accelerating mass. While the total mass *M*+*m* remains constant, the mass *m* of the weight holder is increased step by step.
2. The linear relationship, which also results from the equilibrium of forces as
$$a = \frac{F_g}{M+m} \propto F_g\ ,$$
is shown in Figure 11. The gradient of the measurement example provides a proportionality factor of 0.986 kg^{-1}, which corresponds to an inertial mass of 1.014 kg and, therefore, approximately to the actual total mass of 0.967 kg.

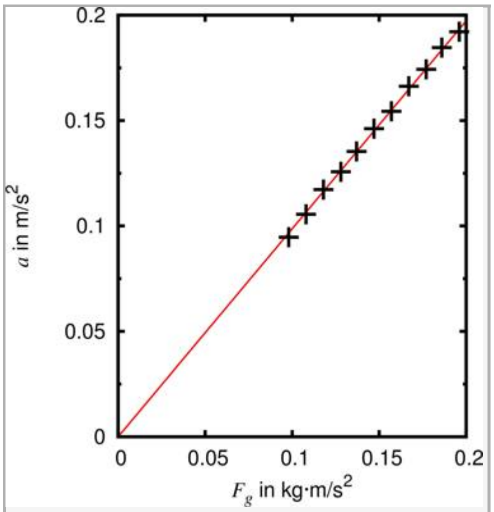

Figure 11: Dependence of the acceleration on the accelerating force Fg = m·g

Tabelle 2: Messbeispiel mit konstanter Gesamtmasse $M+m$ = 967 g, variabler beschleunigender Masse m, Blendenlänge b = 0,100 m und mittlerer Beschleunigung a_m

m in kg	t_1 in s	Δt_1 in s	t_2 in s	Δt_2 in s	$F_g = m \cdot g$ in kg·m/s²	a_m in m/s²
0.010	3.225	0.324	4.271	0.250	0.098	0.095
0.011	3.025	0.309	4.022	0.239	0.108	0.106
0.012	2.847	0.295	3.799	0.228	0.118	0.117
0.013	2.766	0.284	3.681	0.219	0.128	0.126
0.014	2.677	0.273	3.558	0.210	0.137	0.135
0.015	2.555	0.265	3.406	0.203	0.147	0.146
0.016	2.481	0.258	3.310	0.198	0.157	0.154
0.017	2.386	0.249	3.188	0.191	0.167	0.166
0.018	2.350	0.242	3.129	0.185	0.177	0.174
0.019	2.281	0.234	3.055	0.180	0.186	0.185
0.020	2.237	0.230	2.976	0.177	0.196	0.192

Note

1. 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.
2. The shading times Δt_i have been taken into consideration in order to determine the velocity of the cart. Strictly speaking, these calculated velocities are not instantaneous velocities, since the cart is still subject to acceleration when the shutter plate passes hrough the light barrier. This also explains the deviation of the results from the theoretical values in the order of several per cent.