Conservation of momentum in multiple central elastic collisions with the demonstration track and timer 4 – 4 (Item No.: P1199805)

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	20 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Elastic collision, impulse, multiple collisions, conservation of momentum, momentum transfer, conservation of energy, kinetic energy

Overview

Introduction

An impulse acting on an object is defined as the change in momentum caused by a force *F* over a short period of time *t*. The momentum *p* is defined as the product of force and time. It is conserved, even over several collisions, provided that there is no friction and that the collision is elastic.

Educational objective

If two carts collide elastically, they both transfer a momentum to the respective other cart and then continue to move with changed momenta. The momentum can also be transferred over several collisions.

$$p_1 + p_2 + p_3 + \ldots \ = p_1' + p_2' + p_3' + \ldots \ = p_1'' + p_2'' + p_3'' + \ldots \ = \ \ldots.$$

If the collisions are completely elastic, the kinetic energy of the system is also conserved:

$$E_{\text{kin}} \ = E_{\text{kin}}' \ = E_{\text{kin}}' \ = \ \ldots.$$

Related topics

Experiment P1199905 "Conservation of momentum in multiple central inelastic collisions" can be performed for comparison. In addition, the influences of the masses and various initial velocities based on two carts has been described in detail in experiment P1199605 "Conservation of momentum in a central elastic collision".

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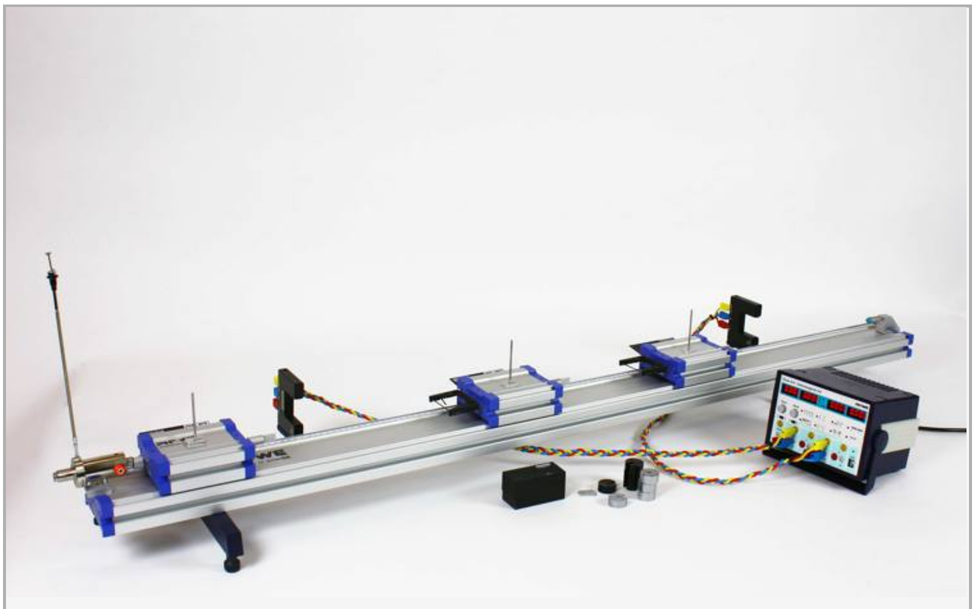

Figure 1: Experiment set-up

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	3
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	3
9	Magnet w.plug f.starter system	11202-14	1
10	Shutter plate for low friction cart, width: 100 mm	11308-00	3
11	Plate with plug	11202-10	2
12	Needle with plug	11202-06	1
13	Fork with plug	11202-08	2
14	Tube with plug	11202-05	1
15	Slotted weight, black, 10 g	02205-01	4
16	Slotted weight, black, 50 g	02206-01	3
17	Holder for light barrier	11307-00	2
18	Connecting cord, 32 A, 1000 mm, red	07363-01	2
19	Connecting cord, 32 A, 1000 mm, yellow	07363-02	2
20	Connecting cord, 32 A, 1000 mm, blue	07363-04	2
21	Slotted weight, silver bronze, 10 g	02205-02	4
22	Slotted weight, silver bronze, 50 g	02206-02	3
23	Plasticine, 10 sticks	03935-03	1
24	Slotted weight, blank, 1 g	03916-00	
25	Rubber bands for fork with plug, 10 pcs	11202-09	1

Tasks

1. Determination of the momenta before and after two elastic collisions between a moving cart and two carts at rest.
2. Determination of the kinetic energy before and after two elastic collisions between a moving cart and two carts at rest.

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 one cart is still just about prevented from rolling to the right. For adjustment purposes, it also possible to let one cart roll along the track with an initial momentum and to compare the light barrier shading times.
2. Position the starter system at the left end of the track. Please note that, in order to start the cart with an initial momentum, the starter system must be installed so that the cart receives an impulse from the ram of the starter system (Fig. 2).

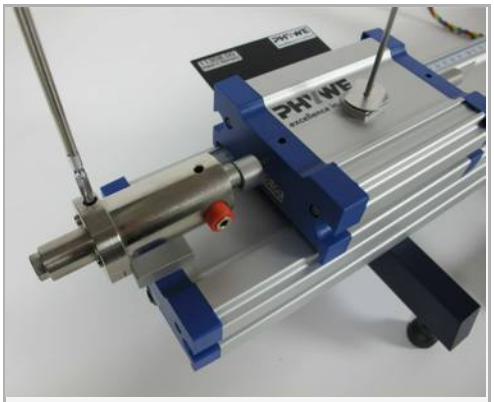

Fig. 2: Starter system for providing the necessary impulse

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).

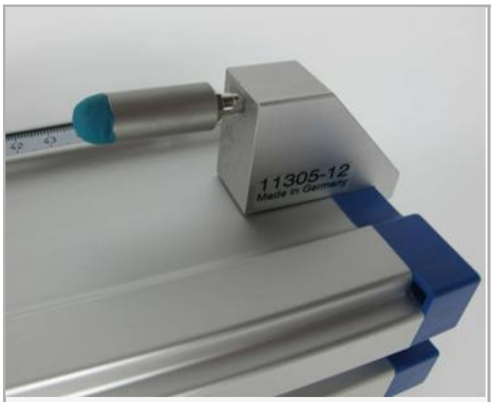

Fig. 3: End holder with plasticine

4. Fasten the two light barriers in the light barrier holders and position them at the 30 cm mark and 120 cm mark on the track. The light barrier that is closer to the starter system is light barrier 1, and the other one is light barrier 2.
5. Connect light barrier 1 to the sockets in field "1" and light barrier 2 to the sockets in field "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. 4).

Fig. 4: Connection of the light barriers

6. In order to select the triggering edge, push the slide switch above field "1" of the timer to the right, i.e. to "falling edge" ( ).
7. Place the three carts on the track.
   - Equip the cart on the left, which is closest to the starter system (hereinafter referred to as cart 1 with the initial velocity v_1), with a magnet with a plug facing the starter system and with a plate with a plug in the direction of motion.
   - Equip the cart in the middle (cart 2) with the fork and rubber band facing cart 1 and with the plate with a plug facing the direction of motion.
   - Equip the cart on the right (cart 3) with the fork and rubber band facing cart 2 and with the needle with a plug facing the end holder.
   - Fasten a shutter plate (w = 100 mm) in all of the carts on the side where the light barriers are located.

Procedure

1. Prior to starting the measurement, determine the masses of the carts by way of the balance. The cart masses may vary slightly due to the different components that are attached to them. However, in this experiment, all three cart masses must be approximately identical, which is why the 1 g weights should be used to perform small corrections, for example as shown in Fig. 7.
2. Set the timer to mode 1 "v(s)" ( ). In this mode, the light barrier shading times are determined. Based on these values, and in combination with the known shutter plate length, the mean velocities with which the carts pass through the respective light barriers are calculated.
3. Prior to every collision experiment, press the "Reset" button in order to reset the displays.
4. Position cart 1 in the starter system (Fig. 2) and cart 2 and cart 3 rather close to one another between the two light barriers (see Fig. 5). Ensure that cart 1 has completely passed through light barrier 1 before it touches cart 2 (compare Fig. 6). In addition, both collisions must be completed before the shutter plate of cart 3 reaches light barrier 2 (compare Fig. 7).

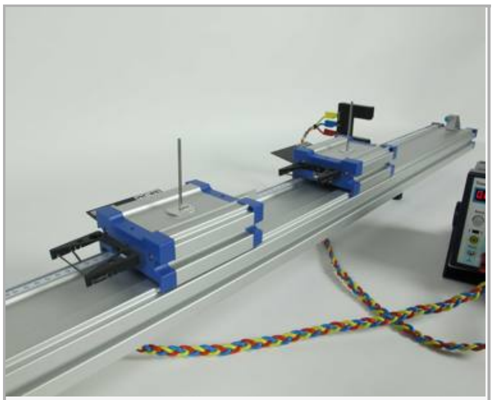
Abb. 5: Aufstellung von Wagen 2 und Wagen 3 in Startposition

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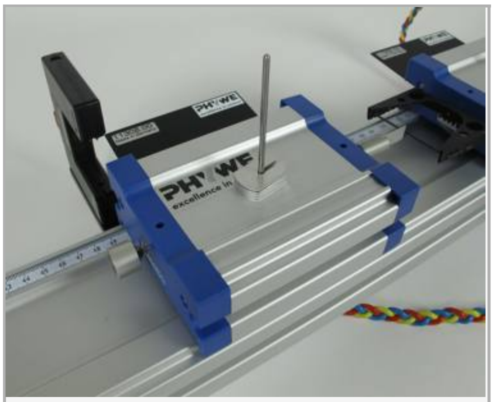

Abb. 6: Durchlaufen von Lichtschranke 1 vor dem ersten Stoß

Abb. 7: Abgeschlossene Stöße vor Erreichen der zweiten Lichtschranke

5. When the starter system is triggered, cart 1 is accelerated in the direction of cart 2. During this process, it receives an initial velocity v_1 and collides with cart 2, which then moves with the velocity v_2'. This cart, in turn, collides with cart 3, which then passes the last light barrier with the velocity v_3''. Quantities with one superscript stroke have been measured after the first collision, and those with two superscript strokes after the second collision.
6. Use the two shading times t_1 and t_3'', together with the shutter plate length w = 100 mm, to determine the velocities $v_i = w/t_i$ before and after the collisions.
7. Record the measuring times during up to five repetitions and take the mean of these values. Then, repeat the measurement for other identical cart masses.

Beobachtung und Ergebnis

Beobachtung

If the masses of the three carts are nearly identical, only one cart at a time is in motion. Cart 1 with the velocity v_1 collides with cart 2, which is at rest, and stops. Cart 2 with the velocity v_2' then collides with cart 3, which is at rest, and stops as well. Cart 3 then moves to the end holder with the velocity v_3'', which corresponds approximately to the initial velocity of cart 1.

Auswertung

1. The velocities v_1 of cart 1 before the collisions and v_3'' of cart 3 after the collisions are used to determine the associated momenta p_1 and p_3''. In addition, the relative difference of the momenta $(p_3''-p_1)/p_1$ before and after the collisions must be stated.
2. Like in the case of elastic collisions between two masses, the law of conservation of momentum also applies to elastic multiple collisions of three masses $m_1, m_2,$ and m_3 before and after each collision:
$$m_1v_1 + m_2v_2 + m_3v_3 = m_1v_1' + m_2v_2' + m_3v_3' = m_1v_1'' + m_2v_2'' + m_3v_3'' \quad (1)$$
3. The velocities v_1 and v_3'' are used to determine the associated kinetic energies E_1 and E_3''. In addition, the relative difference of the kinetic energies $(E_3''-E_1)/E_1$ before and after the collisions must be stated.
4. In the case of elastic collisions, not only the total momentum p but also the kinetic energy of the total system is conserved. The kinetic energy E_{kin} before the collision is equal to the kinetic energies E_{kin}' and E_{kin}'' after the respective collisions. The resulting law of conservation of energy is:
$$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 + \frac{1}{2}m_3v_3^2 = \frac{1}{2}m_1v_1'^2 + \frac{1}{2}m_2v_2'^2 + \frac{1}{2}m_3v_3'^2 = \frac{1}{2}m_1v_1''^2 + \frac{1}{2}m_2v_2''^2 + \frac{1}{2}m_3v_3''^2 \quad (2$$
.
5. The conditions for this experiment have been simplified. Due to the fact that the masses are all equal ($m = m_1 = m_2 = m_3$) and that there are always two carts at rest ($v_2 = v_3 = 0, v_1' = v_3' = 0$, and $v_1'' = v_2'' = 0$), the following special cases result from the general formula (1) and (2):
$$mv_1 = mv_2' = mv_3'' \quad \text{and} \quad (3)$$
$$\frac{1}{2}mv_1^2 = \frac{1}{2}mv_2'^2 = \frac{1}{2}mv_3''^2 \, . \quad (4)$$
6. The correctness of the law of conservation of momentum in equation (3) is confirmed by the determined momenta before and after the collisions during this experiment (see also the measurement example in Table 1). Within the scope of the measuring accuracy, the total momentum decreases only slightly by approximately 4 %, which is due to friction.
7. The collisions during this experiment are never completely elastic, which is why the kinetic energy decreases slightly during each collision. However, the measurements show that the kinetic energy is nearly completely conserved after two collisions in accordance with equation (4) (in the measurement example, the kinetic energy decreases by approximately 7 %).

Table 1: Measurement example with an identical mass m of all of the carts. The exact masses for the first measurement were m_1 = 0.400 kg, m_2 = 0.400 kg, and m_3 = 0.399 kg.

m in kg	t_1 in s	t_3'' in s	v_1 in m/s	v_3'' in m/s
0.400	0.167	0.173	0.599	0.578
0.800	0.238	0.247	0.420	0.405
0.520	0.195	0.202	0.513	0.495

p_1 in kg·m/s	p_3'' in kg·m/s	$(p_3''-p_1)/p_1$ in %	E_1 in kg·m²/s²	E_3'' in kg·m²/s²	$(E_3''-E_1)/E_1$ in %
0.240	0.231	−3.5	0.0717	0.0668	−6.8
0.336	0.324	−3.6	0.0706	0.0656	−7.2
0.267	0.257	−3.5	0.0684	0.0637	−6.8

Anmerkung

1. In order to accelerate cart 1 with the starter system, the ram must be pushed in until it locks into place. Since the starter system offers three different levels, it must be ensured that the same locking position is used for all the experiments so that the same force is transferred.
2. Ensure that during the collisions the rubber bands are not pushed back to such an extent that the plate of one cart touches the fork of another cart.
3. Low velocities combined with old rubber bands having only little spring force lead to higher energy losses.
4. The correct position of the shutter plates on the carts should be checked prior to every measurement, since they may be dislocated when the carts are abruptly stopped.
5. The carts do not move completely without friction. There is still some residual friction and the total momentum decreases slightly. Another reason for the decrease in total momentum after the collision may be that the collision is not exactly central. This results in momentum components that are perpendicular to the track. However, these are not taken into consideration during the evaluation. In addition, the collision is not completely elastic, which is reflected by the fact that the kinetic energy decreases.