Conservation of momentum in a central inelastic collision with the demonstration track and timer 4 – 4

(Item No.: P1199705)

Curricular Relevance

Area of Expertise: Physik

Education Level: Klasse 7-10

Topic: Mechanik

Subtopic: Lineare Bewegung

Experiment:

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

Additional Requirements:

Experiment Variations:

Keywords:

Inelastic collision, conservation of momentum, conservation of energy, kinetic energy, deformation energy

Overview

Introduction

If two objects in a closed system collide in an inelastic manner, the momentum p is conserved. Both objects continue to move together with a momentum that corresponds to the sum of the individual momenta before the collision. The kinetic energy of the system, however, decreases, since kinetic energy is transformed into deformation energy during the inelastic collision.

Educational objective

When two carts collide in an inelastic manner, they stick together and continue to move in one direction at the same velocity. The momentum of the motion corresponds to the sum of the individual momenta before the collision:

$$p_1 + p_2 = p'$$

The kinetic energy is reduced after the inelastic collision, which is due to the deformation of the plasticine between the two carts. However, the total energy of the system is conserved if the deformation energy ΔE is taken into consideration:

$$E_{\mathrm{kin}} = E'_{\mathrm{kin}} + \Delta E\,.$$

Related topics

Experiment P1199605 "Conservation of momentum in a central elastic collision" can be performed for comparison. In addition, experiment P1199905 "Conservation of momentum in multiple central inelastic collisions" demonstrates inelastic collisions with a third cart.

Student's Sheet

Printed: 13.04.2017 12:17:02 | P1199705

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	2
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	2
9	Magnet w.plug f.starter system	11202-14	1
10	Shutter plate for low friction cart, width: 100 mm	11308-00	2
11	Needle with plug	11202-06	2
12	Tube with plug	11202-05	2
13	Slotted weight, black, 10 g	02205-01	4
14	Slotted weight, black, 50 g	02206-01	3
15	Holder for light barrier	11307-00	2
16	Connecting cord, 32 A, 1000 mm, red	07363-01	2
17	Connecting cord, 32 A, 1000 mm, yellow	07363-02	2
18	Connecting cord, 32 A, 1000 mm, blue	07363-04	2
19	Plasticine, 10 sticks	03935-03	1

Tasks

1. Determination of the momenta before and after an inelastic collision between two moving carts with opposite directions of motion.
2. Determination of the kinetic energies before and after an inelastic collision between two moving carts with opposite directions of motion.

Set-up and procedure

Set-up

Set the experiment up as shown in Figure 1:

1. Precisely align the track horizontally by way of the three adjusting screws at the track bases.
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).

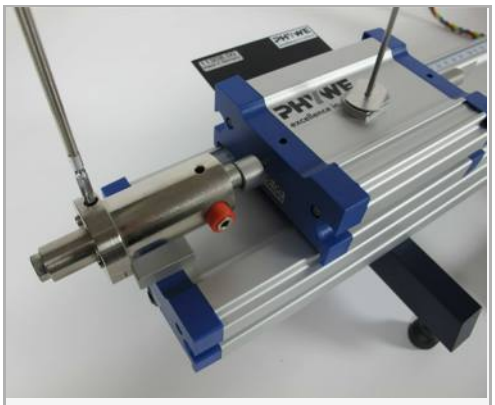

Fig. 2: Starter system for providing the necessary impulse

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).

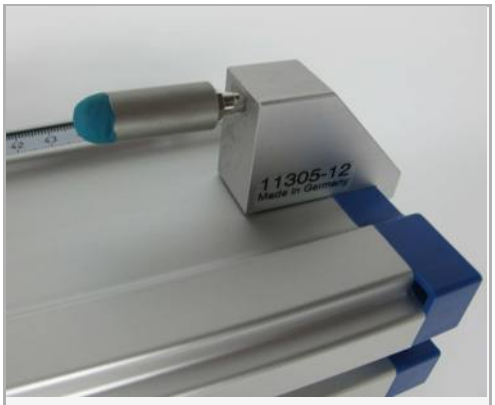

Fig. 3: End holder with plasticine

4. Fasten the two light barriers in the light barrier holders and position them at the 40 cm mark and 100 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).

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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 two carts on the track.
   - Equip the cart on the left, which is closer to the starter system (hereinafter referred to as cart 1 with the velocity v_1), with a magnet with a plug facing the starter system and with a needle with a plug in the direction of motion.
   - Equip the end of the cart on the right-hand side (cart 2 with v_2) that faces cart 1 with a plasticine filled tube and the other side that faces the end holder with a needle with a plug.
   - Fasten a shutter plate (w = 100 mm) in both carts on the side where the light barriers are located.

Procedure

1. In order to perform the experiment, set the timer to mode 6 "collision" ( ). Only the control inputs 1 and 3 are active in this case. Up to two shading times will be measured at each of the light barriers. The times of interruption of light barrier 1 are indicated on the first two displays, and the ones of light barrier 2 on the last two displays. The first interruption of a light barrier (before the collision) is indicated on the respective display on the left, the second one (after the collision) on the respective display on the right.
2. Prior to starting the measurement, determine the masses of the carts by way of the balance. Small corrections (especially if both cart masses are to be identical) can be realised with the aid of the 1 g weights as shown in Fig. 5.

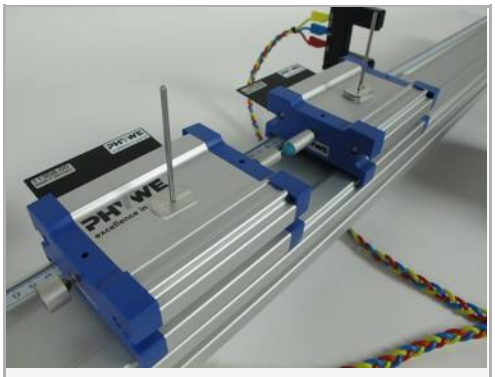

Figure 5: The inelastic collision of the carts takes place between the two light barriers.

3. Prior to every collision experiment, press the "Reset" button in order to reset the displays.
4. Position the carts on opposite ends of the track **beyond the light barriers**. Cart 1 will be accelerated by the starter system and cart 2 will be pushed slightly by hand. After the inelastic collision, both carts move together in the same direction. In order to
prevent them from stopping between the light barriers due to an insufficient total momentum, it must be ensured that one cart receives a considerably higher initial momentum. Since the collision must take place between the light barriers (see Fig. 5), it may be necessary to start the carts one after the other with a slight delay.
5. After the collision, the light barrier in the direction of motion of both carts will be interrupted. It will register only the shading time of the shutter plate on the first cart, since the time of one of the carts has already been measured before the collision. However, since both carts move with the same velocity, this shading time applies to both carts.
6. Use the shading times t_i and the shutter plate length w = 100 mm to determine the velocities $v_i = w/t_i$. Since the velocities are vector quantities, their sign is important. All of the velocities that are opposite to v_1 have the opposite sign of v_1.
7. In order to be able to distinguish the measurement data of the two carts, the shading times prior to the collision are named t_1 and t_2 and the ones after the collision are named t'. The same nomenclature is to be used for the resulting calculated velocities and momenta.
8. Record the measuring times during up to five repetitions and take the mean of these values. Then, repeat the measurement for different cart masses and mass ratios.

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Observation and results

Observation

The two carts collide and then move together in the same direction with the same velocity.

Evaluation

1. The momenta p_1 and p_2 before the collision and $p' = (m_1 + m_2) \cdot v'$ after the collision are calculated based on the cart masses and velocities of the various measurements. Since the carts "stick together" after the inelastic collision, they can be regarded as one cart with a higher mass. A comparison of the total momenta (see the measurement example in Table 1) shows that the law of conservation of momentum applies within the scope of the measuring accuracy:
$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v'$.
2. The kinetic energies E_1 and E_2 of the two carts before the collision and the energy $E_{kin'}$ of the joint motion after the collision are calculated. A comparison of $E_{kin} = E_1 + E_2$ with $E_{kin'}$ shows that the kinetic energy is considerably lower after the collision (see also Table 1). It seems as if the law of conservation of energy is not fulfilled:
$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 \neq \frac{1}{2} (m_1 + m_2) v'^2$.
3. However, in a closed system, the energy is conserved and does not get lost. This discrepancy is due to the fact that, during the collision, energy is used for deforming the plasticine putty. This deformation energy ΔE leads to a decrease in kinetic energy. As a result, the law of conservation of energy is as follows:
$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = \frac{1}{2} (m_1 + m_2) v'^2 + \Delta E$
The absorbed deformation energy ΔE corresponds to the difference between the initial kinetic energy and the remaining kinetic energy after the collision.

Table 1: Measurement example concerning inelastic collisions.

m_1 in kg	m_2 in kg	t_1 in s	t_2 in s	$t_2' = t_1'$ in s
0.400	0.400	0.162	0.591	0.447
0.800	0.400	0.237	0.664	0.461
0.400	0.550	0.162	0.593	0.598

v_1 in m/s	v_2 in m/s	$v_2' = v_1'$ in m/s	p_1 in kg·m/s	p_2 in kg·m/s	$p = p_1 + p_2$ in kg·m/s	p' in kg·m/s
0.617	-0.169	0.224	0.247	-0.068	0.179	0.179
0.422	-0.151	0.217	0.338	-0.060	0.277	0.260
0.617	-0.169	0.167	0.247	-0.093	0.154	0.159

E_1 in kg·m²/s²	E_2 in kg·m²/s²	E_{kin} in kg·m²/s²	E_{kin}' in kg·m²/s²	ΔE in kg·m²/s²
0.076	0.006	0.082	0.020	0.062
0.071	0.005	0.076	0.028	0.048
0.076	0.008	0.084	0.013	0.071

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Note

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. 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.
3. The plasticine should also be reshaped from time to time in order to buffer the impact of the cart to the highest possible extent.
4. The carts do not move completely without friction. There is still some residual friction and the total momentum decreases slightly. This also leads to a loss of energy so that the difference between the kinetic energies before and after the collision does not correspond exactly to the deformation energy ΔE of the plasticine putty.