Newton's law of reaction (“actio = reactio”, Newton's third law) with the demonstration track and timer 4 – 4 (Item No.: P1199305)

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
Easy	10 Minutes	20 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Interaction, conservation of momentum, unidimensional vectorial quantity, “actio = reactio”, Newton's third law

Overview

Introduction

If no external force acts on a closed system of objects, the total momentum p of the system is conserved and the centre of gravity of the system remains constant. If the only interaction between the objects is elastic collisions, the energy is also conserved. If one object exerts a force F on a second object, an opposite force $-F$ acts on the first object. In this experiment, this will be demonstrated by way of two carts on the demonstration track.

Educational objective

The law of interaction (also known as the action-reaction law) states that an object that exerts a force on another object is subject to an equal and opposite force.

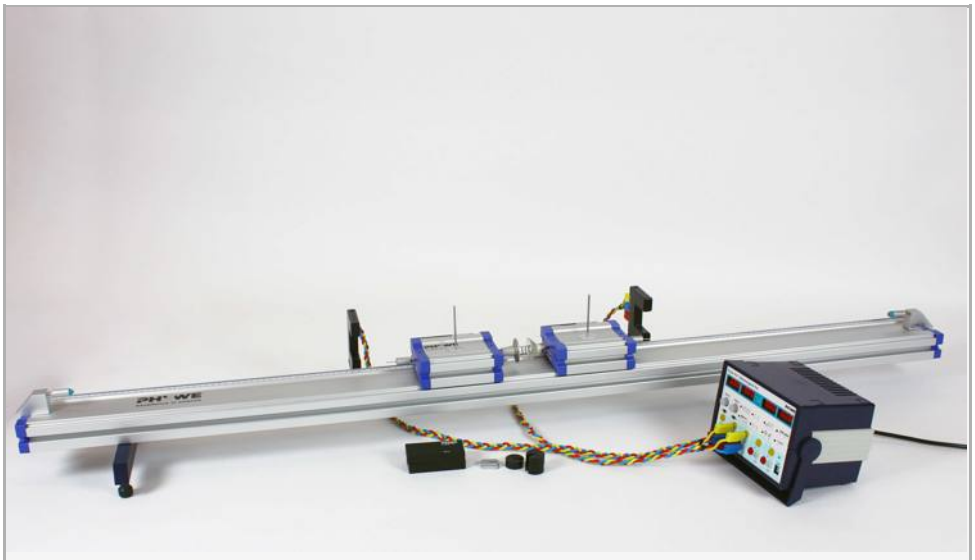

Figure 1: Experiment set-up

Student's Sheet

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Equipment

Position No.	Material	Order No.	Quantity
1	Timer 4-4	13604-99	1
2	Demonstration track, aluminium, 1.5 m	11305-00	1
3	Cart, low friction sapphire bearings	11306-00	2
4	Light barrier, compact	11207-20	2
5	Equiforce launcher	11311-00	1
6	Portable Balance, OHAUS CS2000E	48911-00	1
7	End holder for demonstration track	11305-12	2
8	Weight for low friction cart, 400 g	11306-10	2
9	Shutter plate for low friction cart, width: 100 mm	11308-00	2
10	Needle with plug	11202-06	2
11	Tube with plug	11202-05	2
12	Slotted weight, black, 50 g	02206-01	3
13	Slotted weight, black, 10 g	02205-01	4
14	Holder for light barrier	11307-00	2
15	Connecting cord, 32 A, 1000 mm, blue	07363-04	2
16	Connecting cord, 32 A, 1000 mm, red	07363-01	2
17	Connecting cord, 32 A, 1000 mm, yellow	07363-02	2
18	Plasticine, 10 sticks	03935-03	1
19	Slotted weight, blank, 1 g	03916-00	

Tasks

1. Determination of the velocity of carts at rest that are simultaneously subjected to an impulse by the equiforce launcher.
2. Determination and comparison of the momenta of both carts.

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. Install the end holders on both ends of the track and equip each of them with a plasticine-filled tube in order to stop the carts without a strong impact (see Fig. 2).

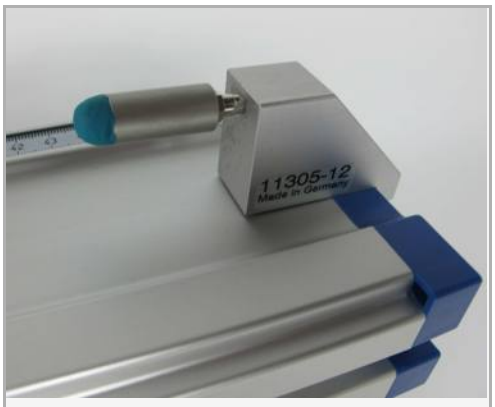

Fig. 2: End holder with plasticine

3. Use the light barrier holders to install two light barriers on the track, one at the 50 cm mark and the other one at the 100 cm mark (see Fig. 3).

Fig. 3: Installation of the light barriers on the demonstration track

4. Connect the light barriers to the sockets in the fields "1" and "2" 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

5. Equip each of the carts with a needle with a plug, one part of the equiforce launcher, and a shutter plate (w = 100 mm). The needles with a plug must point in the direction of the respective end holders, while the equiforce launcher parts must

face each other (see Fig. 5).

Figure 5: Equipment of the carts and alignment in their respective start position

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

Procedure

1. In order to be able to distinguish the velocities and momenta of the carts, the following nomenclature is used: Everything related to the cart on the left-hand side gets the index 1 and everything that is related to the cart on the right-hand side gets the
index 2.
2. Determine the mass of the two carts by way of a balance. If both cart masses are to be identical, corrections can be made with the 1 g weights.
3. In order to determine the instantaneous velocities of the carts passing through the light barriers, perform the measurements in mode 1 ( ). When a shutter plate enters the light beam of the corresponding light barrier, the measurement of the shading times Δt_1 or Δt_2 will be started. They will be stopped once the shutter plates leave the light beam.
4. In order to start the experiment, push the carts against one another and position them centrally at the 75 cm mark between the light barriers (Fig. 5). After approximately five seconds, the suction cup will have sufficiently been aerated via a throttle disc so that the spring can accelerate the two carts.
5. Record the times for up to five repetitions. Prior to every recording process, press the "Reset" button in order to reset the displays.
6. Repeat the measurement for various combinations of cart masses.

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Observation and results

Observation

After the equiforce launcher has been triggered, the carts move away from each other into opposite directions. In the case of equal masses, both carts have the same velocity. If their masses differ from each other, the lighter cart moves more quickly than the heavier one.

Evaluation

1. Based on the measured times Δt_1 and Δt_2 and on the masses m_1 and m_2 calculate the velocities
   $v_i = \frac{b}{\Delta t_i}$
   and momenta
   $p_i = m_i \cdot v_i$
   of the two carts after the triggering of the equiforce launcher, while taking the shutter plate length w = 100 mm into consideration.
2. In the case of equal masses, both carts have the same velocity with an opposite direction of motion. In the case of unequal masses, the velocities vary. If the momenta of the carts are compared, it becomes clear that they both have the same value, but opposite directions. This means that, when the starter system is triggered, both carts receive the same momentum. The law of conservation of momentum applies:
   $\vec{p}_1 + \vec{p}_2 = m_1 \cdot \vec{v}_1 + m_2 \cdot \vec{v}_2 = m_1 \cdot |\vec{v}_1| - m_2 \cdot |\vec{v}_2| = 0$,
   It is confirmed by the measurement results in Table 1 within the scope of the measurement accuracy.
3. Apparently, the spring transfers the same impulse to the carts during the start. The force F_1 that cart 1 exerts on cart 2 prior to the triggering of the starter system equals the force $-F_2$ that cart 2 exerts on cart 1 ("actio = reactio").

Table 1: Measurement example for determining the momenta p_1 and p_2

m_1 in kg	m_2 in kg	Δt_1 in s	Δt_2 in s	v_1 in m/s	v_2 in m/s	p_1 in kg·m/s	p_2 in kg·m/s	$(p_1+p_2)/p_1$ in %
0.406	0.406	0.236	0.236	0.424	−0.424	0.172	−0.172	0.0
0.406	0.406	0.235	0.235	0.426	−0.426	0.173	−0.173	0.0
0.406	0.406	0.236	0.236	0.424	−0.424	0.172	−0.172	0.0
0.406	0.406	0.241	0.242	0.415	−0.413	0.168	−0.168	0.4
0.406	0.406	0.248	0.249	0.403	−0.402	0.164	−0.163	0.4
0.806	0.806	0.365	0.363	0.274	−0.275	0.221	−0.222	−0.6
0.806	0.806	0.371	0.374	0.270	−0.267	0.217	−0.216	0.8
0.806	0.806	0.361	0.366	0.277	−0.273	0.223	−0.220	1.4
0.806	0.806	0.361	0.360	0.277	−0.278	0.223	−0.224	−0.3
0.806	0.806	0.367	0.371	0.272	−0.270	0.220	−0.217	1.1
0.406	0.806	0.215	0.472	0.465	−0.212	0.189	−0.171	9.6
0.406	0.806	0.216	0.474	0.463	−0.211	0.188	−0.170	9.5
0.406	0.806	0.214	0.466	0.467	−0.215	0.190	−0.173	8.8
0.406	0.806	0.213	0.465	0.469	−0.215	0.191	−0.173	9.1

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0.406	0.806	0.215	0.471	0.465	−0.212	0.189	−0.171	9.4
0.806	0.406	0.447	0.210	0.224	−0.476	0.180	−0.193	−7.2
0.806	0.406	0.450	0.212	0.222	−0.472	0.179	−0.192	−6.9
0.806	0.406	0.457	0.214	0.219	−0.467	0.176	−0.190	−7.6
0.806	0.406	0.450	0.212	0.222	−0.472	0.179	−0.192	−6.9
0.806	0.406	0.467	0.218	0.214	−0.459	0.173	−0.186	−7.9
0.446	0.556	0.249	0.318	0.402	−0.314	0.179	−0.175	2.4
0.446	0.556	0.243	0.309	0.412	−0.324	0.184	−0.180	2.0
0.446	0.556	0.250	0.321	0.400	−0.312	0.178	−0.173	2.9
0.446	0.556	0.244	0.309	0.410	−0.324	0.183	−0.180	1.6
0.446	0.556	0.242	0.307	0.413	−0.326	0.184	−0.181	1.7
0.906	0.496	0.468	0.237	0.214	−0.422	0.194	−0.209	−8.1
0.906	0.496	0.466	0.236	0.215	−0.424	0.194	−0.210	−8.1
0.906	0.496	0.490	0.245	0.204	−0.408	0.185	−0.202	−9.5
0.906	0.496	0.486	0.244	0.206	−0.410	0.186	−0.203	−9.0
0.906	0.496	0.472	0.237	0.212	−0.422	0.192	−0.209	−9.0

Note

Systematic errors occur due to friction. This is particularly the case with high masses and low velocities. The error rate may be further increased by differences in the track length covered by the carts if the carts are not positioned centrally between the light barriers. I
the preceding experiments with only one cart, friction has been compensated for by a slight inclination of the track. However, this is not possible for this experiment with two carts and two directions of motion.

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