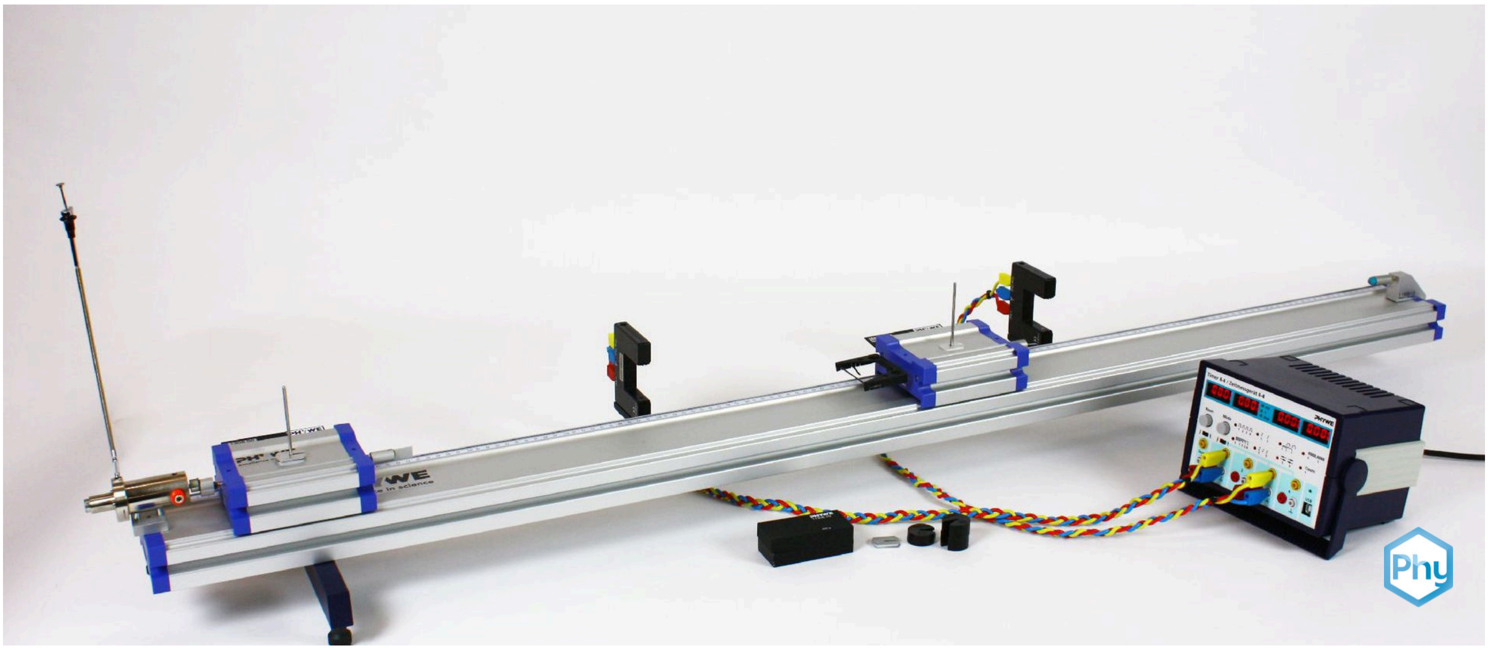
Conservation of momentum in elastic collisions with the demonstration track and the timer 4-4



Physics	Mechanics	Energy conservation & impulse

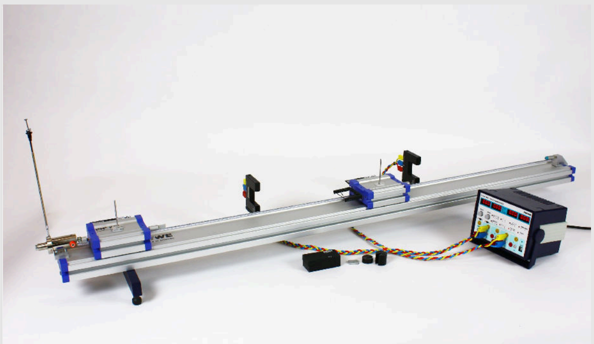
Difficulty level	Group size	Preparation time	Execution time
medium	2	10 minutes	20 minutes

This content can also be found online at:

http://localhost:1337/c/600497e527aa1c00038a12e5

General information

Application



Experiment set-up

The momentum change of a body caused by a force *F* in a short time *t* is called a force impulse. The momentum *p* is defined as the product of force and time and is maintained if there are no frictional losses and the impact is elastic.

This means that in a closed system of different bodies, the latter can transmit or absorb momentum, but the total momentum of the system is constant in time and magnitude, and the energy is thus a conservation quantity.

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Other information (1/2)

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Prior knowledge

The basic concept of an elastic collision and classical mechanics should have already been covered in class.

Scientific principle

If two cars collide elastically, they transfer an impulse to each other and then move on with changed impulses.

The direction of the movements can also be reversed, but the total momentum of the system before the impact remains the same after the impact:

$$p_1 + p_2 = p_1' + p_2'$$

Other information (2/2)

PHYWE

Learning objective

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

$$E_{kin} = E'_{kin}.$$

Tasks

1. Determination of the impulses before and after the elastic impact of a moving car with a stationary car.
2. Determination of the impulses before and after the elastic impact of two moving cars with the same direction of motion.
3. Determination of the impulses before and after the elastic impact of two moving cars with opposite directions of motion.

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Safety instructions

The general instructions for safe experimentation in science lessons apply to this experiment.

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Equipment

Position	Material	Item No.	Quantity
1	Demonstration track, aluminium, 1.5 m	11305-00	1
2	Cart, low friction sapphire bearings	11306-00	2
3	Shutter plate for low friction cart, width: 100 mm	11308-00	2
4	Fork with plug	11202-08	1
5	Rubber bands for fork with plug, 10 pcs	11202-09	1
6	Plate with plug	11202-10	1
7	Needle with plug	11202-06	1
8	Tube with plug	11202-05	1
9	Plasticine, 10 sticks	03935-03	1
10	Weight for low friction cart, 400 g	11306-10	2
11	Slotted weight, black, 10 g	02205-01	4
12	Slotted weight, black, 50 g	02206-01	3
13	End holder for demonstration track	11305-12	1
14	Starter system for demonstration track	11309-00	1
15	Magnet w.plug f.starter system	11202-14	1
16	Light barrier, compact	11207-20	2
17	Holder for light barrier	11307-00	2
18	PHYWE Timer 4-4	13604-99	1
19	Connecting cord, 32 A, 1000 mm, red	07363-01	2
20	Connecting cord, 32 A, 1000 mm, yellow	07363-02	2
21	Connecting cord, 32 A, 1000 mm, blue	07363-04	2
22	Portable Balance, OHAUS CR2200	48914-00	1
23	Slotted weight, blank, 1 g	03916-00	10
24	Slotted weight, silver bronze, 10 g	02205-02	4
25	Slotted weight, silver bronze, 50 g	02206-02	3

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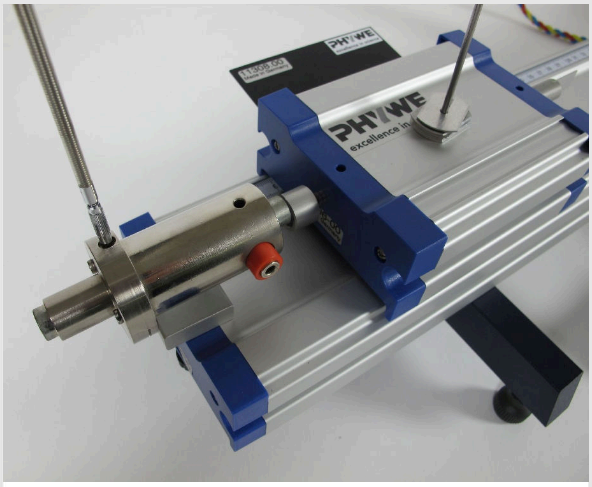
Setup and procedure

Set-up (1/5)



Launching device for shock

1. The track should be aligned as accurately as possible horizontally using the three adjusting screws on the feet.

2. A launching device shall be installed at the left end of the runway.

Note; to start the trolley with initial impulse, the starting device must be mounted in such a way that the trolley receives a force impulse from the ram.

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Set-up (2/5)

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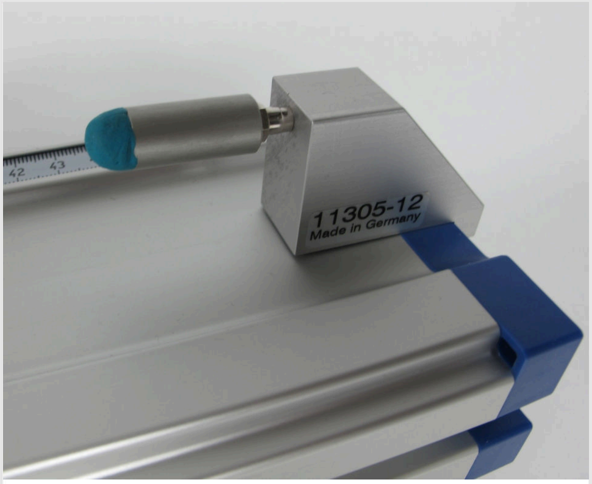

End bracket with plasticine

3. A tube filled with plasticine is attached to the end bracket at the right end of the track to slow the car down without hard impact.

4. The two forked light barriers are mounted with the light barrier holders on the roadway and positioned approximately at the markings for 50 cm and 100 cm. The light barrier which is closer to the starting device is designated as light barrier 1, the other as light barrier 2.

Set-up (3/5)

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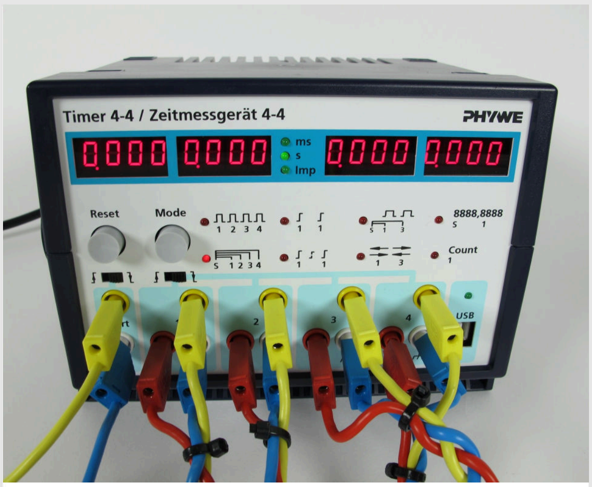

Connecting the light barriers

5. Light barrier 1 is connected to the sockets in field "1", light barrier 2 to the sockets in field "3" of the timing device. The yellow sockets of the light barriers are connected to the yellow sockets of the measuring device, the red sockets to the red sockets and the blue sockets of the light barriers to the white sockets of the time measuring device.

6. The two slide switches on the timing device are set to the right-hand position "falling edge" ( ) to select the trigger edge.

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Set-up (4/5)

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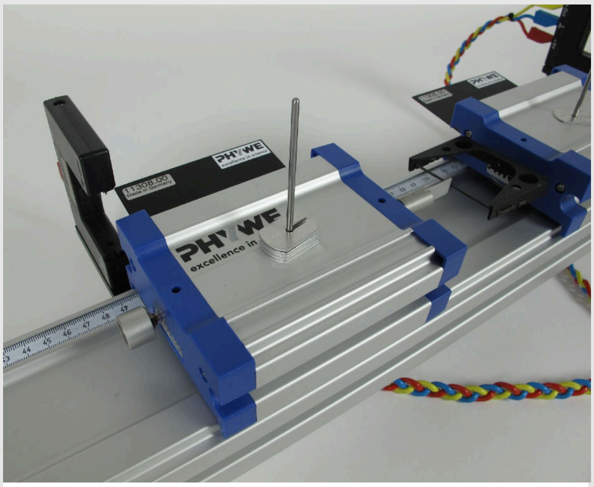


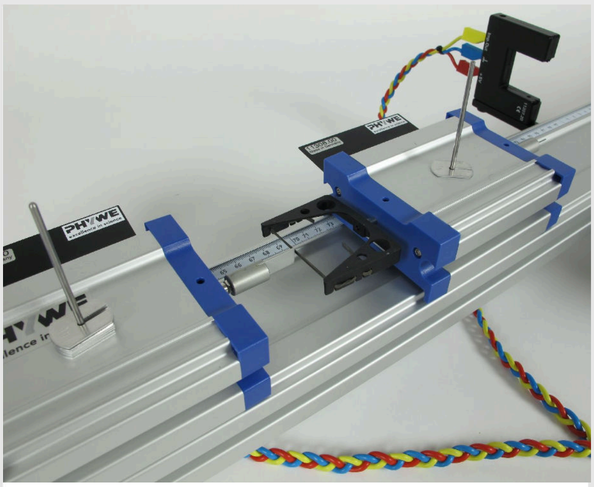
Elastic impact after the light barrier

7. The two measuring cars are placed on the roadway.

- The left wagon, which is closer to the starting device (in the following referred to as wagon 1 with speed v_1 is fitted with the holding solenoid with the plug in the direction of the starting device and with the plate with plug in the direction of travel.

Set-up (5/5)

PHYWE



Completed joint

- The fork with the rubber band is inserted into the sides of the right wagon (wagon 2 with v_2), in the direction of carriage 1 and the needle with plug is inserted facing the end holder.
- In both wagons, the panels for measuring wagons (*b*= 100 mm) are latched onto the side on which the forked light barriers are to be located.

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Procedure (1/6)

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1. To carry out all measurements, the chronometer must be switched to operating mode 6 "Shock" ( ). Only control inputs 1 and 3 are active.

Up to two shading times are measured at each light barrier.

The interruption times at light barrier 1 are shown as the output on the first two displays, the times of light barrier 2 on the rear two displays.

The first interruption of a light barrier is output on the left display, the second on the right display.

2. At the beginning of the measurement, the masses of the wagons must always be determined by means of the balance.

For small corrections (especially when equal masses are desired) the 1 g slot weights can be used.

Procedure (2/6)

PHYWE

3. Before starting any impact test, press the "Reset" button to reset the displays.

4. From all shading times t_i, the speeds $v_i = b \ / \ t_i$ are always to be determined using the aperture length *b* = 100 m.

Since the speeds are vector quantities, the signs of the amounts must be observed. All velocities that are opposite to \ (v_1 \) have the opposite sign to \ (v_1 \).

5. In order to be able to distinguish between the different measured data of the wagons, the shading times are to be designated with t_1 and t_2 for before the impact, or with t_1' and t_2' for after the impact.

The same nomenclature is to be used for the calculated speeds and impulses.

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Procedure (3/6)

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a) Car 1 in motion, car 2 at rest:

1. Light barrier 1 should be positioned approximately at 50 cm and light barrier 2 at 100 cm.

2. Car 1 is placed in the starting device, car 2 is positioned between the two light barriers. It must be ensured that carriage 1 has completely passed through the light barrier when it touches carriage 2. In addition, the impact must be completely finished before the aperture of carriage 2 reaches light barrier 2.

Procedure (4/6)

PHYWE

3. Car 1 is accelerated with the starting device in the direction of car 2. Thereby it gets an initial speed v_1 and bumps into car 2, which then travels at a speed v_2.

If the masses of the wagons differ, wagon 1 will be reflected, or travel backwards at a speed v'_1. The displays of the timing device are shown from left to right: $(t_1/-/t'_2/t'_1)$ and respectively $(t_1/t'_1/t'_2/-)$.

4. The measurement is repeated for different wagon masses and mass ratios.

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Procedure (5/6)

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b) Car 1 and car 2 in motion, same direction:

1. Light barrier 1 should be positioned approximately at 30 cm and light barrier 2 at 100 cm.

2. Car 1 is placed in the starting device, car 2 is positioned between the two light barriers.

3. Car 2 receives a small push with the hand in the direction of the end holder before car 1 is set in motion with the starter. The collision between the cars must occur (and be complete) before carriage 2 has reached light barrier 2 $(v_1 > v_2)$. The displays of the timing device provide from left to right: $(t_1/-/t_2'/t_1')$.

4. Repeat the measurement for different car masses and ratios.

Procedure (6/6)

PHYWE

c) Car 1 and car 2 in motion, opposite direction:

1. Light barrier 1 should be positioned approximately at the lane marking 40 cm, light barrier 2 at 100 cm.

2. The carriages are positioned on opposite sides outside the light barriers and are both given an initial speed. For this purpose, both cars can be pushed by hand or car 1 is accelerated with the starting device.

Alternatively, the end bracket can be replaced by a second starting device so that the test can be carried out under reproducible conditions.

3. The impact between the two wagons may only take place when they have completely passed through the light barriers. The trolleys then move away from each other and pass through the light barriers again. The displays of the timing device provide from left to right: $(t_1/t_1'/t_2/t_2')$.

4. Repeat the measurement for different car masses and ratios.

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Evaluation (1/18)

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Measurement example 1 with same direction, $m_1 = m_2, v_1 \neq, v_2$=0

m_1 in kg	t_1 in s	v_1 in m/s	p_1 in kg·m/s	m_2 in kg	t_2' in s	v_2' in m/s	p_2' in kg·m/s
0,4	0,166	0,602	0,241	0,4	0,175	0,571	0,229
0,54	0,198	0,505	0,273	0,54	0,211	0,474	0,256
0,8	0,242	0,413	0,331	0,8	0,265	0,377	0,302

$p_2'-p_1$ in kg·m/s	E_{kin} in kg·m²/s²	E_{kin}' in kg·m²/s²	$E_{kin}'-E_{kin}$ in kg·m²/s²	δ
−0,012	0,0726	0,0653	−0,0073	0,949
−0,017	0,0689	0,0606	−0,0082	0,938
−0,029	0,0683	0,057	−0,0113	0,913

Evaluation (2/18)

PHYWE

Measurement example 1 with same direction, $m_1 > m_2, v_1 \neq, v_2$=0

m_1 in kg	t_1 in s	v_1 in m/s	p_1 in kg·m/s	m_2 in kg	t_2' in s	v_2' in m/s	p_2' in kg·m/s
0,8	0,174	0,575	0,46	0,4	0,135	0,741	0,296
1	0,172	0,581	0,581	0,4	0,126	0,794	0,317
1,2	0,159	0,629	0,755	0,4	0,111	0,901	0,36

t_1' in s	v_1' in m/s	p_1' in kg·m/s	$(p_1'+p_2')-p_1$ in kg·m/s	E_{kin} in kg·m²/s²	E_{kin}' in kg·m²/s²	$E_{kin}'-E_{kin}$ in kg·m²/s²	δ
0,535	0,187	0,15	−0,014	0,132	0,124	−0,008	0,964
0,411	0,243	0,243	−0,021	0,169	0,156	−0,013	0,947
0,327	0,306	0,367	−0,027	0,237	0,218	−0,019	0,946

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Evaluation (3/18)

PHYWE

Measurement example 1 with the same direction, $m_1 < m_2, v_1 \neq, v_2$=0

m_1 in kg	t_1 in s	v_1 in m/s	p_1 in kg·m/s	m_2 in kg	t_2' in s	v_2' in m/s	p_2' in kg·m/s
0,4	0,16	0,625	0,25	0,8	0,252	0,397	0,317
0,4	0,161	0,621	0,248	1	0,299	0,334	0,334
0,4	0,162	0,617	0,247	1,2	0,342	0,292	0,351

t_1' in s	v_1' in m/s	p_1' in kg·m/s	$(p_1'+p_2')-p_1$ in kg·m/s	E_{kin} in kg·m²/s²	E_{kin}' in kg·m²/s²	$E_{kin}'-E_{kin}$ in kg·m²/s²	δ
0,697	−0,143	−0,057	0,01	0,078	0,067	−0,011	0,864
0,462	−0,216	−0,087	−0,001	0,077	0,065	−0,012	0,887
0,392	−0,255	−0,102	0,002	0,076	0,064	−0,012	0,887

Evaluation (4/18)

PHYWE

The momentum *p* of a body of mass *m* can be calculated with the aid of its velocity *v*:

$$p = m \cdot v \,.\ (1)$$

In the case of a central collision of two masses m_1 and m_2 with the impulses $p_1 = m_1 \cdot v_1$ and $p_2 = m_2 \cdot v_2$ before the impact, and $p_1' = m_1' \cdot v_1'$ and $p_2' = m_2' \cdot v_2'$ after the impact, the law of conservation of momentum applies:

$$m_1 v_1 + m_2 v_2 = m_1 v'_1 + m_2 v'_2 .\ (2)$$

If the speed v_2 is not known before the impact, it can be calculated from the other velocities and masses:

$$v_2 = \frac{m_1 v'_1 + m_2 v'_2 - m_1 v_1}{m_2} .\ (3)$$

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Evaluation (5/18)

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In the case of elastic shocks, in addition to the total momentum *p* the kinetic energy *Ekin* of the total system is also conserved . The law of conservation of energy for the kinetic energy before and after the impact is:

$$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1v_1'^2 + \frac{1}{2}m_2v_2'^2 \text{ . (4)}$$

The two conservation laws (2) and (4) can be used to calculate the velocities after the collision. v_1' and v_2' from the initial velocities v1 and v2:

$$v'_1 = \frac{(m_1-m_2)v_1+2m_2v_2}{m_1+m_2} \text{ , (5)}$$

$$v'_2 = \frac{(m_2-m_1)v_2+2m_1v_1}{m_1+m_2} \text{. (6)}$$

From equations (5) and (6) the following applies for the difference in velocities:

$$v'_2 - v'_1 = v_1 - v_2 \qquad \text{(7)}$$

Evaluation (6/18)

PHYWE

The difference can be understood as a relative speed with which carriage 1 and carriage 2 approach each other, or move away from each other. The relative velocity before and after the impact is the same. Since in the experiment the impacts are never perfectly elastic, the conservation law for the kinetic energy is violated.

Thus equations (5)-(7) lose their strict validity. One can now introduce a coefficient of impact δ (also called coefficient of restitution), which is a measure for the elasticity of the impact:

$$\delta = \frac{v'_1 - v'_2}{v_2 - v_1} \text{ . (8)}$$

This impact number takes the value 1 in the case of a perfectly elastic impact and the value 0 in the case of an inelastic impact. Therefore, the equations (5) and (6) can be transformed into;

$$v'_1 = \frac{(m_1-\delta m_2)v_1+(1+\delta)m_2v_2}{m_1+m_2} \text{ , (9)}$$

$$v'_2 = \frac{(m_2-\delta m_1)v_2+(1+\delta)m_1v_1}{m_1+m_2} \text{. (10)}$$

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Evaluation (7/18)

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If the calculated velocities are compared with the example measured values from measurement examples 1 and 3, it can be clearly seen that they agree very well when inelastic effects due to the number of repeated impacts.

a) Car 1 in motion, car 2 at rest:

$m_1 = m_2$ If the masses of the two cars are equal, the colliding car 1 transfers its momentum p1 completely to car 2 and car 1 stops.

$m_1 > m_2$ If the mass of the impacting carriage 1 is greater than the mass of the carriage at rest, only part of the momentum is transferred. Car 1 continues to move after the impact, but at a slower speed than before the impact.

$m_1 < m_2$ If the mass of the impacting carriage 1 is less than the mass of the carriage at rest, an impulse is transferred which is greater than the impulse of carriage 1 before the impact. From the conservation of momentum it follows that carriage 1 is reflected when it collides with carriage 2.

Evaluation (8/18)

PHYWE

Measurement example 2 with the same direction, $m_1 = m_2, v_1 \neq, v_2 \neq$0

m_1 in kg	t_1 in s	v_1 in m/s	p_1 in kg·m/s	t_1' in s	v_1' in m/s	p_1' in kg·m/s
0,4	0,114	0,877	0,351	0,286	0,35	0,14
0,54	0,114	0,877	0,474	0,283	0,353	0,191
0,8	0,108	0,926	0,741	0,233	0,429	0,343
m_2 in kg	t_2' in s	v_2' in m/s	p_2' in kg·m/s	t_2 in s	v_2 in m/s	p_2 in kg·m/s
0,4	0,117	0,855	0,342	–	0,327	0,131
0,54	0,116	0,862	0,466	–	0,338	0,183
0,8	0,11	0,909	0,727	–	0,412	0,33

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Evaluation (9/18)

Measurement example 2 with same direction $m_1 > m_2, v_1 \neq, v_2 \neq 0$

m_1 in kg	t_1 in s	v_1 in m/s	p_1 in kg·m/s	t_1' in s	v_1' in m/s	p_1' in kg·m/s
0,6	0,175	0,571	0,343	0,33	0,303	0,182
0,8	0,239	0,418	0,335	0,424	0,236	0,189
1,2	0,186	0,538	0,645	0,28	0,357	0,429
m_2 in kg	t_2' in s	v_2' in m/s	p_2' in kg·m/s	t_2 in s	v_2 in m/s	p_2 in kg·m/s
0,4	0,163	0,613	0,245	–	0,211	0,084
0,4	0,21	0,476	0,19	–	0,111	0,044
0,4	0,15	0,667	0,267	–	0,125	0,05

Evaluation (10/18)

Measurement example 2 with $m_1 < m_2, v_1 \neq, v_2 \neq 0$

m_1 in kg	t_1 in s	v_1 in m/s	p_1 in kg·m/s	t_1' in s	v_1' in m/s	p_1' in kg·m/s
0,4	0,161	0,621	0,248	0,3	0,333	0,133
0,4	0,16	0,625	0,25	0,383	0,261	0,104
0,4	0,161	0,621	0,248	0,537	0,186	0,074
m_2 in kg	t_2' in s	v_2' in m/s	p_2' in kg·m/s	t_2 in s	v_2 in m/s	p_2 in kg·m/s
0,6	0,179	0,559	0,335	–	0,367	0,22
0,8	0,191	0,524	0,419	–	0,342	0,273
1	0,211	0,474	0,474	–	0,3	0,3

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Evaluation (11/18)

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b) Car 1 and car 2 in motion, same direction:

1. If the speeds of the two cars are in the same direction, the faster car 1 gives an impulse to the slower car 2.

2. $m_1 = m_2$ If the masses of the two cars are equal, their velocities are reversed after the collision:

$v'_2 = v_1$ and$v'_1 = v_2$. (11)

3. $m_1 > m_2$ and $m_1 < m_2$ During the impact, carriage 1 transfers part of its momentum. Car 2 moves on with increased speed, car 1 reduces its speed or even reverses the direction of movement.

4. From the measurements, the impulse p_2 and the initial velocity v_2 relate to equations (2) and (3).

Evaluation (12/18)

PHYWE

Measurement example 3 with opposite direction $m_1 = m_2, v_1 > 0, v_2 < 0$

m_1 in kg	t_1 in s	v_1 in m/s	p_1 in kg·m/s	t_1' in s	v_1' in m/s	p_1' in kg·m/s
0,4	0,218	0,459	0,183	0,238	−0,420	−0,168
0,54	0,253	0,395	0,213	0,31	−0,323	−0,174
0,8	0,241	0,415	0,332	0,279	−0,358	−0,287
m_2 in kg	t_2' in s	v_2' in m/s	p_2' in kg·m/s	t_2 in s	v_2 in m/s	p_2 in kg·m/s
0,4	0,202	−0,495	−0,198	0,241	0,415	0,166
0,54	0,248	−0,403	−0,218	0,285	0,351	0,189
0,8	0,208	−0,481	−0,385	0,313	0,319	0,256

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Evaluation (13/18)

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Measurement example 3 with opposite direction $m_1 = m_2, v_1 > 0, v_2 < 0$

$(p_1'+p_2')-(p_1+p_2)$ in kg·m/s	E_{kin} in kg·m²/s²	E_{kin}' in kg·m²/s²	$E_{kin}'-E_{kin}$ in kg·m²/s²	δ
0,012	0,091	0,07	−0,021	0,876
0,02	0,086	0,061	−0,025	0,843
0,022	0,161	0,092	−0,069	0,757

Evaluation (14/18)

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Measurement example 3 with opposite direction $m_1 > m_2, v_1 > 0, v_2 < 0$

m_1 in kg	t_1 in s	v_1 in m/s	p_1 in kg·m/s	t_1' in s	v_1' in m/s	p_1' in kg·m/s
0,54	0,188	0,532	0,287	0,437	−0,229	−0,124
0,8	0,238	0,42	0,336	0,648	−0,154	−0,123
0,8	0,234	0,427	0,342	0,527	−0,190	−0,152
m_2 in kg	t_2' in s	v_2' in m/s	p_2' in kg·m/s	t_2 in s	v_2 in m/s	p_2 in kg·m/s
0,4	0,209	−0,478	−0,191	0,16	0,625	0,25
0,4	0,177	−0,565	−0,226	0,15	0,667	0,267
0,54	0,22	−0,455	−0,245	0,185	0,541	0,292

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Evaluation (15/18)

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Measurement example 3 with opposite direction $m_1 > m_2, v_1 > 0, v_2 < 0$

$(p_1'+p_2')-(p_1+p_2)$ in kg·m/s	E_{kin} in kg·m²/s²	E_{kin}' in kg·m²/s²	$E_{kin}'-E_{kin}$ in kg·m²/s²	δ
0,031	0,122	0,092	−0,030	0,845
0,033	0,134	0,098	−0,036	0,833
0,044	0,129	0,093	−0,036	0,828

Evaluation (16/18)

PHYWE

Measurement example 3 with opposite direction $m_1 < m_2, v_1 > 0, v_2 < 0$

m_1 in kg	t_1 in s	v_1 in m/s	p_1 in kg·m/s	t_1' in s	v_1' in m/s	p_1' in kg·m/s
0,4	0,217	0,461	0,184	0,168	−0,595	−0,238
0,4	0,216	0,463	0,185	0,188	−0,532	−0,213
0,54	0,249	0,402	0,217	0,184	−0,543	−0,293
m_2 in kg	t_2' in s	v_2' in m/s	p_2' in kg·m/s	t_2 in s	v_2 in m/s	p_2 in kg·m/s
0,54	0,189	−0,529	−0,286	0,365	0,274	0,148
0,8	0,287	−0,348	−0,279	0,594	0,168	0,135
0,8	0,217	−0,461	−0,369	0,508	0,197	0,157

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Evaluation (17/18)

Measurement example 3 with opposite direction $m_1 < m_2, v_1 > 0, v_2 < 0$

$(p_1'+p_2')-(p_1+p_2)$ in kg·m/s	E_{kin} in kg·m²/s²	E_{kin}' in kg·m²/s²	$E_{kin}'-E_{kin}$ in kg·m²/s²	δ
0,011	0,118	0,091	−0,027	0,878
0,015	0,091	0,068	−0,024	0,863
0,016	0,128	0,095	−0,033	0,858

Evaluation (18/18)

c) Car 1 and car 2 in motion, opposite direction:

$m_1 = m_2$With opposite directions of motion and equal masses, the cars reverse their direction of motion during the collision and their velocity magnitudes are reversed after the collision.

$m_1 > m_2$ and $m_1 < m_2$: For unequal masses of the cars, they are reflected and reverse their directions of motion.

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Notes (1/2)

1. To accelerate trolley 1 with the launcher, the ram is pushed in until it locks into place. Since the starting device provides three different sized steps, care must be taken to use the same lock for each experiment so that the same force is transmitted when the starting device is released.

2. Care must be taken that the rubber band is not pushed back so far during the impact that the plate of one carriage touches the fork of the other carriage.

3. Excessively low speeds lead to greater energy losses, especially when using older rubber bands that no longer have much spring force.

Notes (2/2)

4. The correct fit of both panels on the carriages should be checked before each measurement, as they can slip due to abrupt braking.

5. The plasticine should be remodelled in between collisions if necessary, so that the impact of the car is always cushioned in the best possible way.

6. The carriages do not move completely frictionless, a residual friction remains and the total momentum decreases slightly by about 6 %. Another reason for the decrease of the total momentum after the impact may be that the impact is not exactly central.

This results in components of the momentum that are perpendicular to the direction of the path, but these are not taken into account in the evaluation. The impact is also not completely elastic: the kinetic energy decreases here by up to 25 %.

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