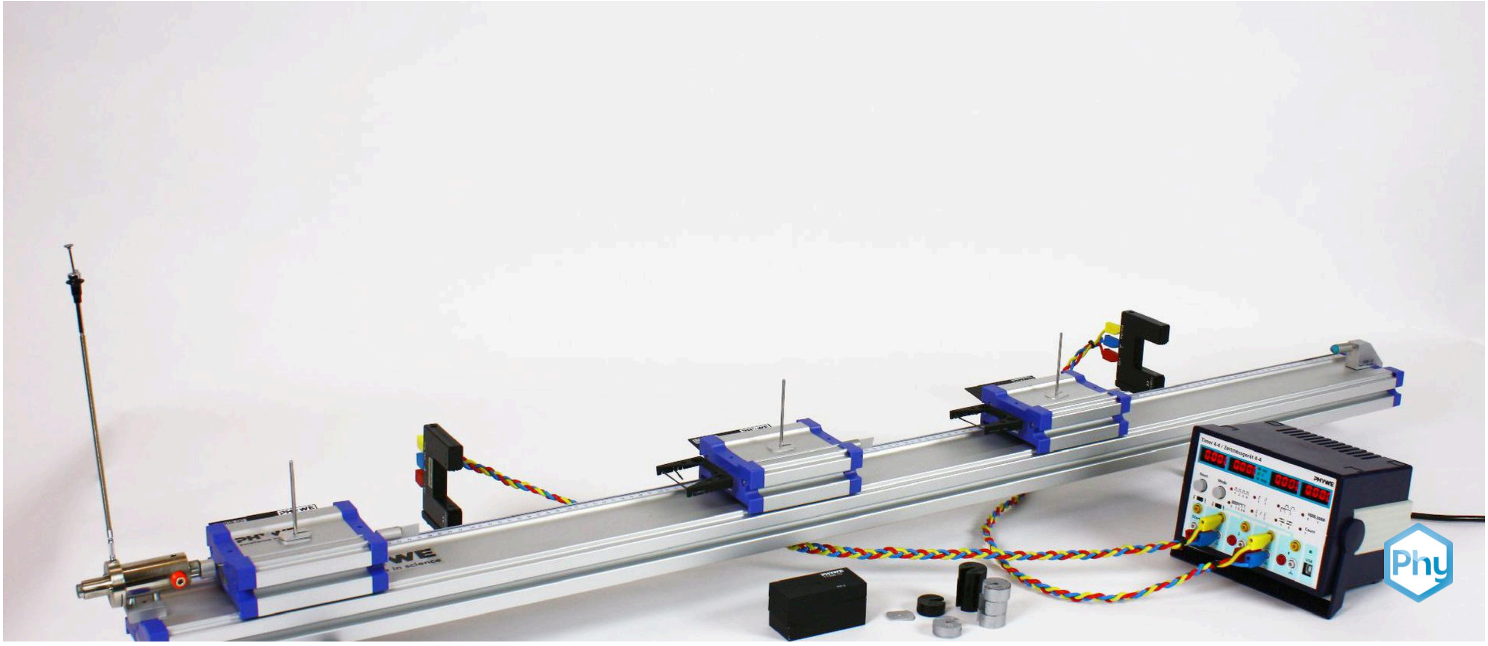
Conservation of momentum in multiple elastic collisions with the demonstration track and the timer 4-4



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/6004981727aa1c00038a12ed

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General information

Application

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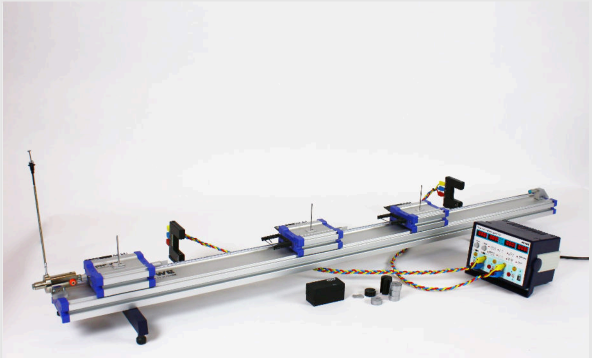

Experiment set-up

The change in momentum on a body caused by a force F in a short time t is called the force impact.

The momentum p is defined as the product of force and time and, if there are no frictional losses and the collisions are elastic, this remains constant over several collisions.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Other information (1/2)

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Prior knowledge

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

Scientific principle

The pulse can also be transmitted over several shocks:

$$p_1 + p_2 + p_3 + \ldots = p'_1 + p'_2 + p'_3 + \ldots = p''_1 + p''_2 + p''_3 + \ldots = \ldots.$$

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

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

Other information (2/2)

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Learning objective

If two cars collide elastically, they transfer an impulse to each other and then continue to move with changed impulses. If the collisions are completely elastic, the kinetic energy of the system is also retained.

Tasks

1. Determination of the impulses before and after two elastic impacts of a moving car with two cars at rest.
2. Determination of the kinetic energy before and after two elastic collisions of a moving car with two cars at rest.

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Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Safety instructions

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

Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Equipment

Position	Material	Item No.	Quantity
1	Demonstration track, aluminium, 1.5 m	11305-00	1
2	Cart, low friction sapphire bearings	11306-00	3
3	Shutter plate for low friction cart, width: 100 mm	11308-00	3
4	Fork with plug	11202-08	2
5	Rubber bands for fork with plug, 10 pcs	11202-09	1
6	Plate with plug	11202-10	2
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	3
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, silver bronze, 10 g	02205-02	4
24	Slotted weight, silver bronze, 50 g	02206-02	3
25	Slotted weight, blank, 1 g	03916-00	20

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Robert-Bosch-Breite 10
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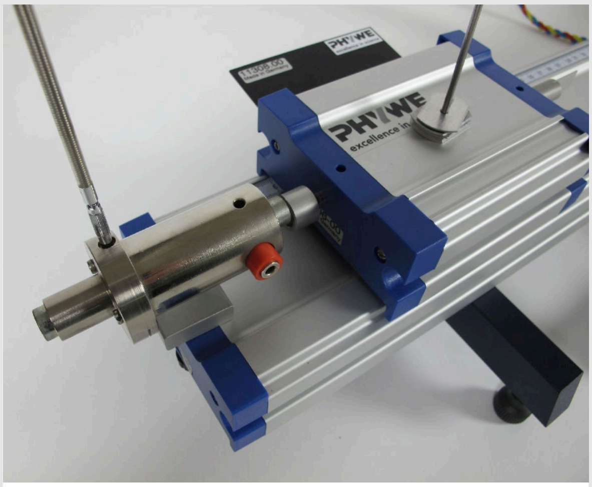
Setup and procedure

Set-up (1/4)



Launching device for shock

1. In order to compensate for minor friction effects, the track must be set at a slight angle using the adjusting screws on the feet, so that a measuring trolley just does not start to roll to the right.

For adjustment you can also let a measuring trolley roll along the track with an initial pulse and compare the shading times of the light barriers.

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 (2/4)

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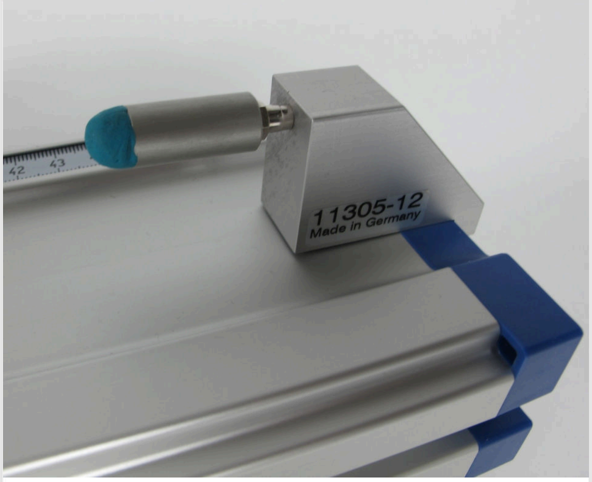

End bracket with plasticine

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 30 cm and 120 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 (3/4)

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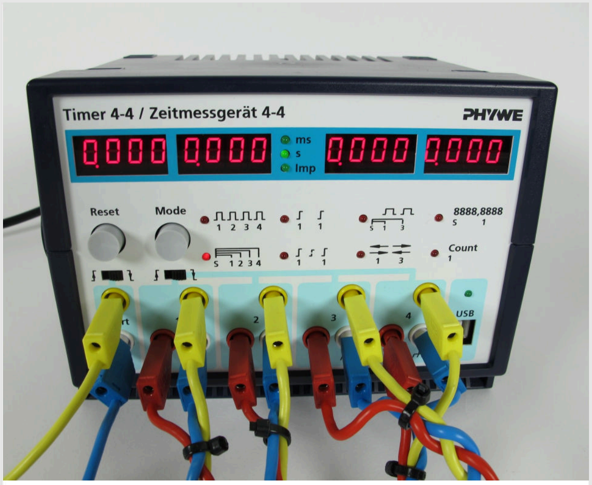

Connecting the light barriers

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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Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
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Set-up (4/4)

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

- The left wagon, which is closest to the starting device (from now on referred to as wagon 1) with speed v_1 is fitted with the holding solenoid with plug in the direction of the starting device and with the plate with plug in the direction of travel.
- A fork with a rubber band is inserted into the sides of the middle carriage (carriage 2) in the direction of carriage 1 and a plate with a plug in the direction of travel.
- In the sides of the right wagon (wagon 3) a fork with rubber band is inserted in the direction of wagon 2 and the pin with plug is inserted facing the end bracket.
- In all wagons, the covers for measuring wagons (b = 100 mm) are latched into the side on which the forked light barriers are to be located.

Procedure (1/4)

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1. At the beginning of the measurement, the masses of the carriages are to be determined by means of the balance. The masses of the wagons may vary slightly due to the different components fitted. In this experiment, however, all three trolley masses must be approximately the same, so small corrections should be made using the 1 g slotted weights.

2. For the execution, the timing device must be switched to operating mode 1 "v(s)" (

). The shadowing times of the forked light barriers are determined from the average speed during the corresponding passage via the aperture length.

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

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37079 Göttingen

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Fax: 0551 604 - 107

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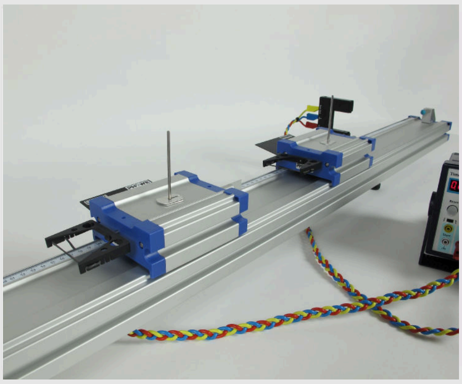
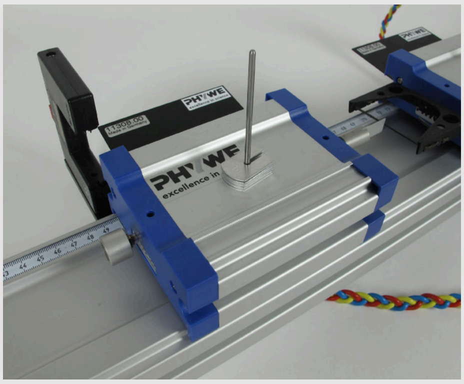
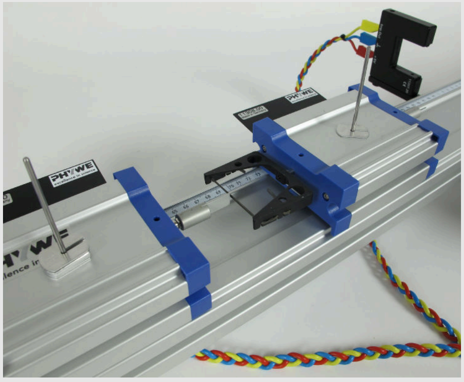
Procedure (2/4)

4. Wagon 1 is placed in the starting device, wagon 2 and wagon 3 are positioned a short distance apart between the two light barriers. Ensure that carriage 1 has completely passed through light barrier 1 when it touches carriage 2. In addition, both impacts must be completely finished before the aperture of trolley 3 reaches light barrier 2.







Procedure (3/4)

5. By triggering the starting device, carriage 1 is accelerated in the direction of carriage 2.

It gets an initial velocity v_1 and pushes wagon 2, which then travels at speed v_2'.

This in turn pushes car 3, which finally runs at speed v_3'' and drives through the rear light barrier.

A single-coated size was measured after the first impact, and a double-coated size was measured after the second impact.

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Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
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Procedure (4/4)

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6. The speeds $v_i = b/t_i$ before and after the shocks, are measured from the two shading periods t_1 and t_3'' along with the aperture length b = 100 mm .

7. The measurement times are to be recorded and averaged for up to five repetitions.

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

Evaluation (1/7)

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Observations

If the masses of the three cars are almost identical, only one car is in motion at a time.

Car 1 with the speed v_1 collides with car 2, which is at rest, and car 1 stops.

Car 2 with the speed v'_2 then collides with car 3, which is at rest, and car 2 also stops.

Car 3 then travels at the speed v''_3, which corresponds approximately to the initial speed of carriage 1, to the end bracket.

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Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

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Evaluation (2/7)

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Measurement example with $m_1 = 0.4kg,\ m_2 = 0.4kg,\ m_3 = 0.399kg$

m in kg	t_1 in s	t_3'' in s	v_1 in m/s	v_3'' in m/s
400	167	173	599	578
800	238	247	420	405
520	195	202	513	495

Evaluation (3/7)

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Measurement example with $m_1 = 0.4kg,\ m_2 = 0.4kg,\ m_3 = 0.399kg$

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 %
240	231	−3.5	0.0717	0.0668	−6.8
336	324	−3.6	0.0706	0.0656	−7.2
267	257	−3.5	0.0684	0.0637	−6.8

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Robert-Bosch-Breite 10
37079 Göttingen

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Fax: 0551 604 - 107

info@phywe.de
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Evaluation (4/7)

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1. The speeds v_1 of car 1 before the collisions and v''_3 of car 3 after the collisions are used to determine the associated moments p_1 and p''_3. In addition, the relative difference of the moments $(p''_3 - p_1)/p_1$ before and after the collisions needs to be included.

2. As 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:

$$m_1 v_1 + m_2 v_2 + m_3 v_3 = m_1 v'_1 + m_2 v'_2 + m_3 v'_3 = m_1 v_1 '' + m_2 v_2 '' + m_3 v_3 '' \quad (1)$$

Evaluation (5/7)

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3. The speeds 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 must be $(E''_3 - E_1)/E_1$ before and after the collisions.

4. In the case of elastic collisions, not only is the total impulse *p* conserved, but the kinetic energy of the whole system as well. The kinetic energy *Ekin* 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:

$$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 + \frac{1}{2} m_3 v_3^2 = \frac{1}{2} m_1 v_1'^2 + \frac{1}{2} m_2 v_2'^2 + \frac{1}{2} m_3 v_3'^2 = \frac{1}{2} m_1 v_1''^2 + \frac{1}{2} m_2 v_2''^2 + \frac{1}{2} m_3 v_3''^2 \quad (2)$$

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Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
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Evaluation (6/7)

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5. The conditions for this experiment have been simplified. Due to the fact that the masses are all the same $(m = m_1 = m_2 = m_3)$ and that there are always two cars 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)

$$mv_1 = mv'_2 = mv''_3 \quad (3)$$

and

$$\frac{1}{2}mv_1^2 \;=\; \frac{1}{2}mv_2'^2 = \frac{1}{2}mv_3''^2 \quad (4)$$

Evaluation (7/7)

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6. The correctness of the law of conservation of momentum in equation (3) is confirmed by the determined moments before and after the collisions during this experiment (see the measurement example in Table 1).

Within the measurement accuracy, the total impulse decreases only slightly by approx. 4 %, which is due to friction.

7. The collisions in this experiment are never completely elastic, so the kinetic energy decreases slightly with each collision.

However, the measurements show that the kinetic energy is almost completely preserved after two collisions according to equation (4) (in the measurement example, the kinetic energy decreases by about 7 %).

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Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Notes

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

3. 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.

4. The cars do not move completely frictionless, there remains a residual friction and the total momentum decreases slightly. This also causes a loss of energy, so that the difference between the kinetic energies before and after the impact does not fully correspond to the deformation energy ΔE of the plasticine.

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de