Conservation of momentum in multiple inelastic 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/6004984327aa1c00038a12f1

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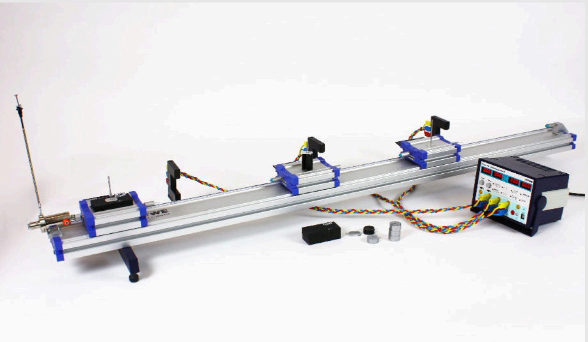
General information

Application



Experiment set-up

In an inelastic impact, kinetic energy is extracted from the system and converted into internal energy, which is no longer available for movement.

The kinetic energy consequently decreases with each impact. The bodies usually undergo a deformation and then continue to move together with an impulse that corresponds to the sum of the individual impulses before the impacts.

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Other information (1/2)

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Prior knowledge

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

Scientific principle

In the case of several successive inelastic shocks, the following applies

$$p_1 + p_2 + p_3 + \ldots \; = p' + p_3 + \ldots \; = p'' + \ldots$$

The energy of the entire system taking into account the deformation energies $\Delta E^{(i)}$ received is as follows:

$$E_{kin} = E'_{kin} + \Delta E' = E''_{kin} + \Delta E_1 + \Delta E'' = \ldots$$

Other information (2/2)

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Learning objective

If two cars collide inelastically, they move together in one direction at the same speed. The momentum of the movement corresponds to the sum of the individual momentums before the collision.

Tasks

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

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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	3
3	Shutter plate for low friction cart, width: 100 mm	11308-00	3
4	Needle with plug	11202-06	3
5	Tube with plug	11202-05	3
6	Plasticine, 10 sticks	03935-03	1
7	Weight for low friction cart, 400 g	11306-10	3
8	Slotted weight, black, 10 g	02205-01	4
9	Slotted weight, black, 50 g	02206-01	3
10	End holder for demonstration track	11305-12	1
11	Starter system for demonstration track	11309-00	1
12	Magnet w.plug f.starter system	11202-14	1
13	Light barrier, compact	11207-20	3
14	Holder for light barrier	11307-00	3
15	PHYWE Timer 4-4	13604-99	1
16	Connecting cord, 32 A, 1000 mm, red	07363-01	3
17	Connecting cord, 32 A, 1000 mm, yellow	07363-02	3
18	Connecting cord, 32 A, 1000 mm, blue	07363-04	3
19	Portable Balance, OHAUS CR2200	48914-00	1
20	Slotted weight, silver bronze, 10 g	02205-02	4
21	Slotted weight, silver bronze, 50 g	02206-02	3
22	Slotted weight, blank, 1 g	03916-00	20

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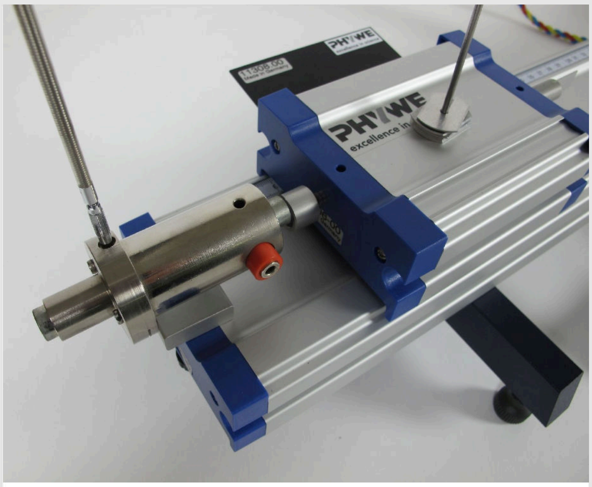
Setup and procedure

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 car 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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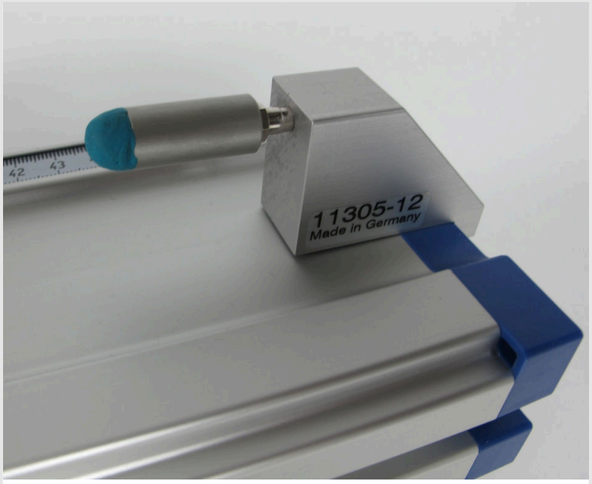

End bracket with plasticine

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 three forked light barriers are mounted with the light barrier holders on the roadway and positioned at the markings for 30 cm, 70 cm and 110 cm.

The light barrier which is closer to the starting device is called light barrier 1, the middle one is called light barrier 2 and the one closest to the end bracket is called light barrier 3.

Set-up (3/4)

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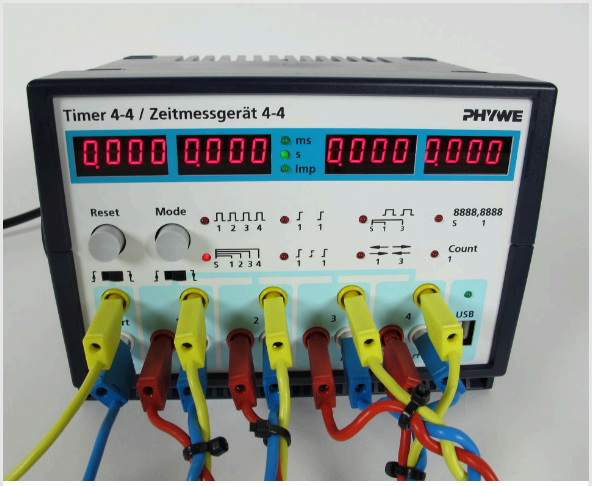

Connecting the light barriers

5. The forked light barriers are connected in sequence from left to right to the sockets in fields "1" to "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 (see illustration).

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 (4/4)

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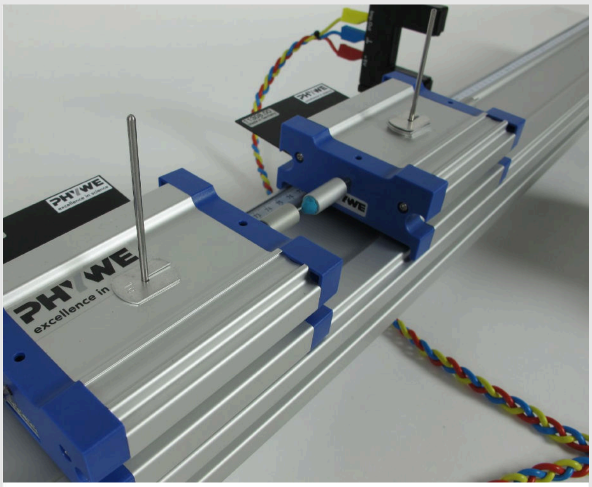

Completed impact in front of light barrier

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

- The left wagon, which is closest to the starting device (hereafter 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 a needle with plug in the direction of travel.
- Into the sides of the middle carriage (carriage 2 with v_2) and of the right wagon (wagon 3), a tube filled with plastiline is inserted in the direction of wagon 1 and a needle with plug in the direction of travel.
- 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 (1/3)

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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 should initially 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 mod 1 2 3 4 ( ). The shadowing times of the forked light barriers are determined, from which the average speed during the corresponding passage is calculated via the aperture length.

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

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Procedure (2/3)

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4.Carriage 1 is placed in the starting device. Carriage 2 is positioned between light barriers 1 and 2 close to light barrier 2. Carriage 3 is positioned behind light barrier 2 just before light barrier 3.

It must be ensured that the respective impact only takes place when the previous light barrier has already been completely passed through by the (front) rolling carriage and that the impact is completed when the impacted carriage moves into the following light barrier.

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

Thereby he gets an initial velocity v_1 and pushes car 2.

Both travel coupled to each other with the common speed v' onwards. Subsequently, they push car 3 and roll together at speed v'' 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.

Procedure (3/3)

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6. The interrupted light barriers only record the shading time of the aperture on the front carriage.

However, since the wagons are coupled together and move at the same speed, this shading time is valid for all wagons.

7. From the three shading times t_i with an orifice length of b = 100 mm, the velocities are always $v_i = b \ / \ t_i$ to determine.

8.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.

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Evaluation (1/11)

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Observations

The cars collide one after the other and move away coupled to each other in the same direction. The speed decreases with each collision.

Evaluation (2/11)

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Measurement example for equal masses

m in kg	t_1 in s	t_2' in s	t_3'' in s
0,4	0,163	0,331	0,508
0,52	0,19	0,39	0,611
0,8	0,243	0,507	0,859

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Evaluation (3/11)

Measurement example for equal masses

v_1 in m/s	v' in m/s	v'' in m/s	p_1 in kg m/s	p' in kg m/s	p'' in kg m/s
0,613	0,303	0,197	0,245	0,242	0,236
0,528	0,257	0,164	0,274	0,267	0,256
0,412	0,197	0,116	0,329	0,316	0,28

Evaluation (4/11)

Measurement example for equal masses

$(p'-p1)/p1$ in %	$(p''-p')/p'$ in %	$(p''-p1)/p1$ in %
−1,4	−2,4	−3,7
−2,7	−4,3	−6,9
−4,0	−11,5	−15,1

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Evaluation (5/11)

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Measurement example for different wagon masses

m_1 in kg	m_2 in kg	m_3 in kg	t_1 in s	t_2' in s	t_3'' in s
0,8	0,6	0,4	0,241	0,435	0,57
0,4	0,6	0,8	0,162	0,413	0,78
0,4	0,55	0,45	0,162	0,394	0,596
0,4	0,45	0,55	0,164	0,354	0,599
0,5	0,8	0,43	0,186	0,499	0,695

Evaluation (6/11)

Measurement example for different wagon masses.

$(p'-p_1)/p_1$ in %	$(p''-p')/p'$ in %	$(p''-p_1)/p_1$ in %
−3,1	−1,9	−5,0
−1,9	−4,7	−6,5
−2,2	−2,7	−4,9
−1,9	−2,6	−4,4
−3,2	−4,5	−7,6

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Evaluation (6/11)

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Measurement example for different wagon masses.

$(p'-p_1)/p_1$ in %	$(p''-p')/p'$ in %	$(p''-p_1)/p_1$ in %
−3,1	−1,9	−5,0
−1,9	−4,7	−6,5
−2,2	−2,7	−4,9
−1,9	−2,6	−4,4
−3,2	−4,5	−7,6

Evaluation (7/11)

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Measurement example for different wagon masses

E_1 in kg m²/s²	E' in kg m²/s²	E'' in kg m²/s²	$\Delta E_g/E_1$ in %	$(E''-E_1)/E_1$ in %
0,0692	0,0371	0,0277	−56	−60
0,0762	0,0293	0,0148	−78	−81
0,0762	0,0307	0,0197	−71	−74
0,0748	0,0339	0,0195	−71	−74
0,0727	0,0262	0,0179	−71	−75

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Evaluation (8/11)

1. For the individual measurements, the impulses are calculated from the wagon masses and the speeds. p_1 before the impact and $p' = (m_1 + m_2) \cdot v'$ after the first, and $p'' = (m_1 + m_2 + m_3) \cdot v''$ after the second impact. Since the cars stay together after the inelastic impact, they can be considered as one car with a larger mass.

2. In the case of central collisions of three masses, the law of conservation of momentum applies before and after each collision:

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

With the initial conditions $v_2 = v_3 = 0$ the law of conservation of momentum simplifies in this experiment as follows:

$$m_1 v_1 = (m_1 + m_2) v' = (m_1 + m_2 + m_3) v''. \quad (2)$$

Evaluation (9/11)

3. A comparison with the measured pulses (see measurement example) confirms the pulse conservation law within the expected error limits.

Due to friction, the impulse of the wagons is reduced as the distance travelled increases. In the measurement example, the total impulse between two light barriers was reduced by approx. 2-4 % in each case. For high total masses, the deviations increase due to the low wagon speeds. This becomes particularly clear in the example of the measurement with three heavy wagons of 800 g each, where the total pulse reduction is over 15 %.

4. The kinetic energies E_1 before the impact and E' and E'' calculated after the corresponding impacts. A comparison of the kinetic energies shows that the kinetic energy has decreased significantly after each impact (see measurement example). The kinetic energy has decreased by a considerable amount after two impacts and is usually less than 50 % of the original kinetic energy (see $(E'' - E_1) / E_1$.

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Evaluation (10/11)

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5. However, in a closed system, the energy must be conserved and cannot be lost. This is because energy is expended in the impacts to deform the wrought rubber. The total deformation energy $\Delta E_g = \Delta E' + \Delta E'' + \ldots$ is composed of the deformation energy of the individual impacts and leads to a reduction of the kinetic energy. The law of conservation of energy is therefore:

$$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 + \frac{1}{2}m_3v_3^2$$

$$= \frac{1}{2}(m_1+m_2)v'^2 + \Delta E' + \frac{1}{2}m_3v_3^2 = \frac{1}{2}(m_1+m_2+m_3)v''^2 + \Delta E' + \Delta E''. \text{ (3)}$$

Evaluation (11/11)

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6. Taking into account the law of conservation of momentum (2), the law of conservation of energy (3) gives the total deformation energy to be expected

$$\Delta E_\text{g} = -\frac{1}{2}m_1v_1^2 \cdot \frac{m_2+m_3}{m_1+m_2+m_3}$$

This is therefore only dependent on the individual masses and the initial speed. A comparison of the theoretical values with the measured values provides a very good agreement.

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Notes (1/2)

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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 carriages do not move completely frictionless, a residual friction remains and the total momentum decreases slightly. This also causes a loss of energy, so that the differences in the kinetic energies before and after the impacts do not fully correspond to the deformation energy ΔE of the wrought masses.

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

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