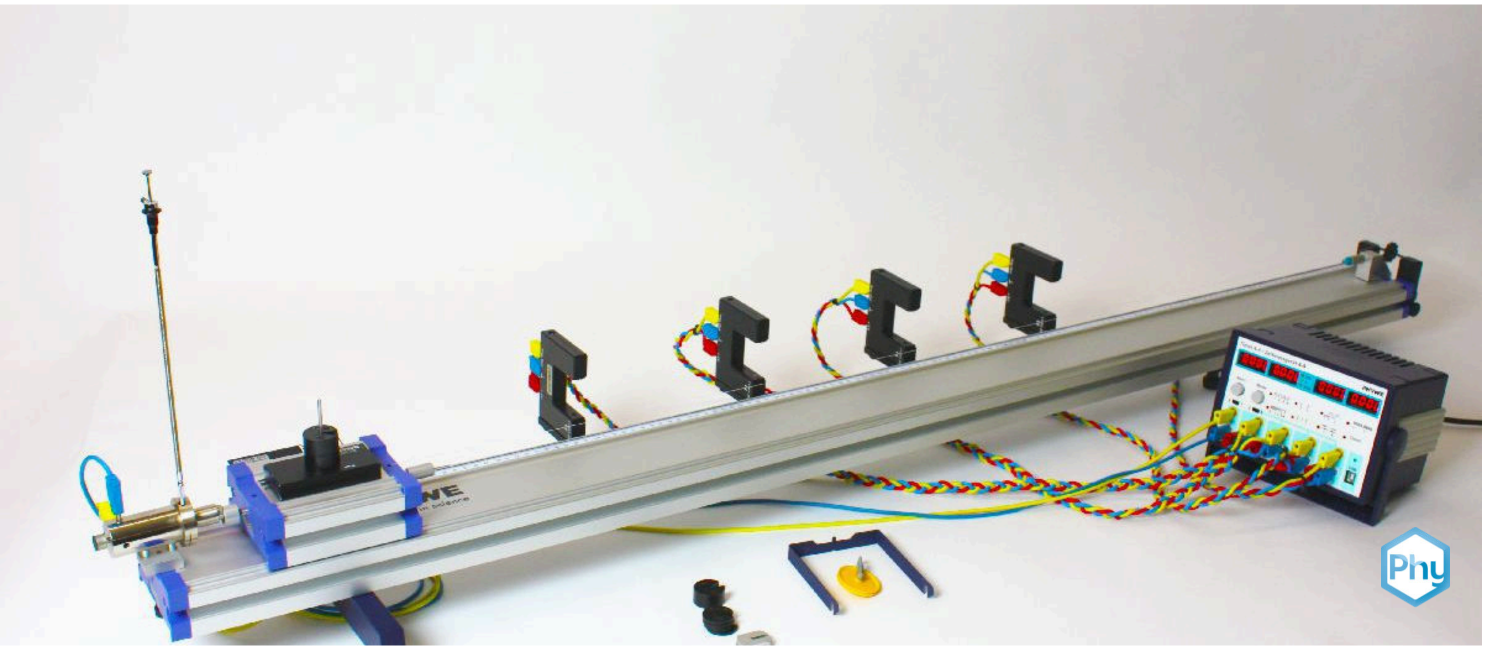
# The uniformly delayed movement with the roller track and timing device 4-4



Physics | Mechanics | Dynamics & Motion

| Difficulty level | Group size | Preparation time | Execution time |
|---|---|---|---|
| medium | 1 | 20 minutes | 10 minutes |

This content can also be found online at:

http://localhost:1337/c/60043b6ff3052e0003c4a2c5

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# General information

## Application

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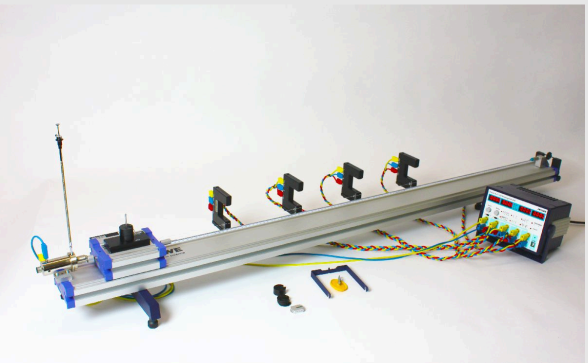

Experiment set-up

A body experiences a constant acceleration parallel to the plane on an inclined plane due to the component of gravity acting on it.

If this counteracts the initial velocity of the body, it slows down its motion and eventually reverses its direction.

Here, the laws of motion for uniformly decelerated motion are to be confirmed by travel time measurements of a car on the inclined roller track.



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## Other information (1/2)

**Prior knowledge**

Students should be familiar with the basic concept and terminology of classical equations of motion.

**Scientific principle**

If an object moves along an inclined plane, it experiences a constant acceleration due to the gravitational field of the earth.

If the direction of action is opposite to the direction of movement, the object is slowed down as a result.

## Other information (2/2)

**Learning objective**

If a body is accelerated uniformly in the opposite direction to its direction of motion, its motion is decelerated.

**Tasks**

1. Determination of the path-time dependence from several time measurements after different distances covered.
2. Determination of the velocity-time dependence from the shadowing time measurement of the light barriers at different positions.
3. Determination of the decelerating acceleration from the inclination angle of the path.



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## Safety instructions

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

## Theory

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The distance covered follows a parabolic course according to the distance-time law and the speed is linear according to the speed-time law:

$$s(t) = \frac{1}{2} \cdot a \cdot t^2 + v_0 \cdot t, v(t) = a \cdot t + v_0$$

It should be noted that $a$ and $v(0)$ have different signs.

Depending on the angle of inclination of the track, the force of gravity acting on the carriage results in a uniformly accelerated movement proportional to the acceleration due to gravity:

$$a = g \cdot sin(\alpha)$$



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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 | 1 |
| 3 | Shutter plate for low friction cart, width: 100 mm | 11308-00 | 1 |
| 4 | Needle with plug | 11202-06 | 1 |
| 5 | Tube with plug | 11202-05 | 1 |
| 6 | Plasticine, 10 sticks | 03935-03 | 1 |
| 7 | End holder for demonstration track | 11305-12 | 1 |
| 8 | Weight for low friction cart, 400 g | 11306-10 | 1 |
| 9 | Slotted weight, black, 50 g | 02206-01 | 2 |
| 10 | Slotted weight, black, 10 g | 02205-01 | 4 |
| 11 | Light barrier, compact | 11207-20 | 4 |
| 12 | Holder for light barrier | 11307-00 | 4 |
| 13 | Starter system for demonstration track | 11309-00 | 1 |
| 14 | Magnet w.plug f.starter system | 11202-14 | 1 |
| 15 | Supporting blocks,set of 4 | 02070-00 | 1 |
| 16 | PHYWE Timer 4-4 | 13604-99 | 1 |
| 17 | Connecting cord, 32 A, 1000 mm, red | 07363-01 | 4 |
| 18 | Connecting cord, 32 A, 1000 mm, yellow | 07363-02 | 5 |
| 19 | Connecting cord, 32 A, 1000 mm, blue | 07363-04 | 5 |
| 20 | Measuring tape, l = 2 m | 09936-00 | 1 |
| 21 | Portable Balance, OHAUS CR2200 | 48914-00 | 1 |



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# Set-up and Procedure

## Set-up (1/6)


Launching device for the 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 the measuring carriage just does not start to roll to the right.

Then place an object (optionally blocks, books, stacks of paper, etc.) under the double-legged stand of the track to raise it by approx. 1-5 cm.



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## Set-up (2/6)

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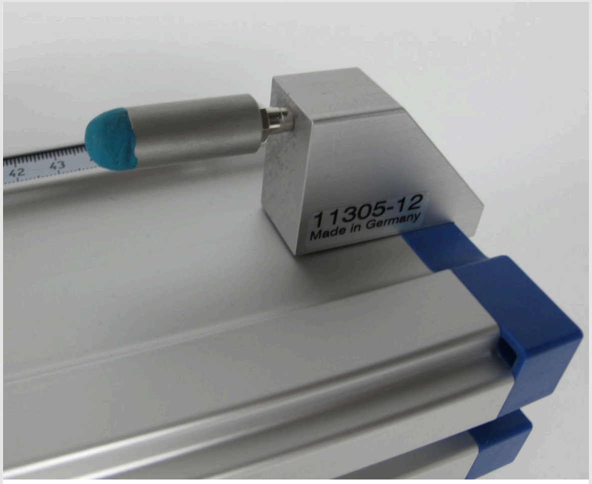


End bracket with plasticine

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

Note that to start the trolley without an initial pulse, the starting device must be mounted so that the plunger moves away from the measuring trolley when triggered.

**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.

## Set-up (3/6)

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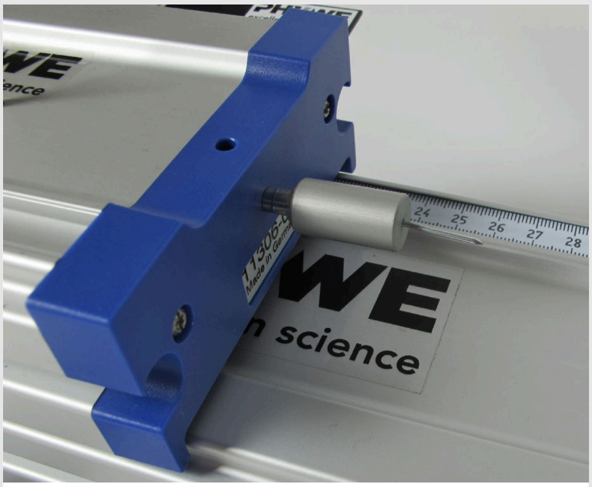

The front of the measuring carriage

**4.** The measuring carriage is equipped with the holding magnet with plug, a needle with plug as well as the cover for measuring carriage (b = 100 mm).

**5.** The mass of the trolley should be adjusted by means of the weights so that it reaches the end holder at most with a minimum residual speed.



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## Set-up (4/6)

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Mounting of the light barriers

**6.** The four forked light barriers are mounted on the roadway with the light barrier holders. Position the forked light barriers so that the measuring section is divided into segments of approximately equal size.

## Set-up (5/6)

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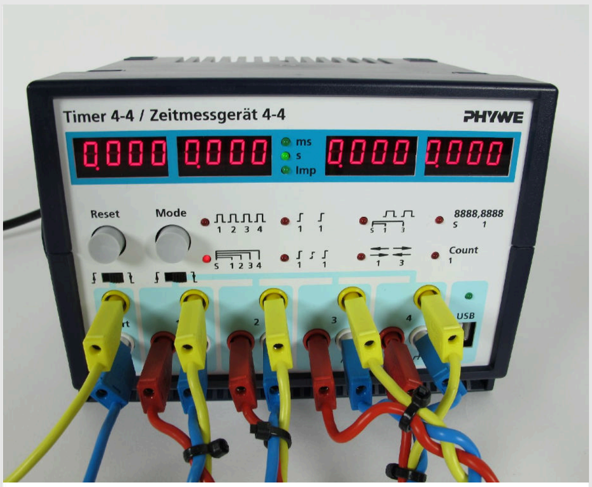


Connecting to the timing device

**7.** The four forked light barriers are connected in sequence from left to right to the sockets in fields "1" to "4" of the timing device as shown in the illustration.

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.



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## Set-up (6/6)

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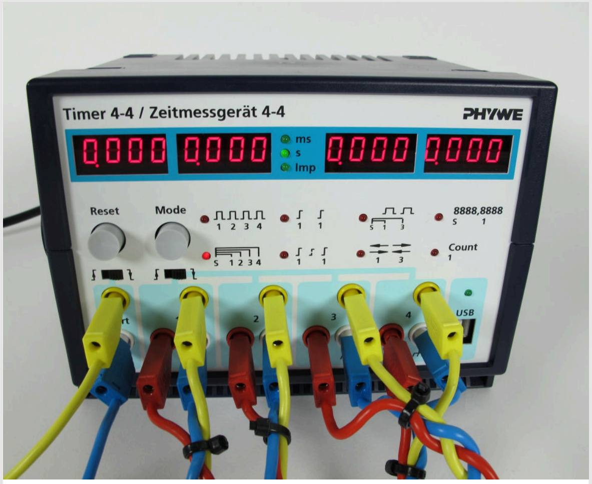


Verify settings

**8.** The starting device must be connected to the two "Start" connection sockets of the timing device.

Make sure that the polarity is correct.

The red socket of the starting device is connected to the yellow socket of the timing device.

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

## Procedure (1/4)

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**1.** The distances $s_1 ... s_4$ of the light barriers to the start position of the trolley are measured.

It should be noted that the light barriers are only interrupted by the front edge of the panel mounted on the trolley.

For an exact determination of the distances, the following procedure can be followed:

- Move the carriage to the start position and set the value ($x_0$) on the measuring tape at the right end of the carriage.
- Move the carriage to a position where the right end of the diaphragm just interrupts the light beam of the forked light barrier i and the value ($x_i$) on the measuring tape at the right end of the carriage.
- $s_i = x_i - x_0$ is the distance the car has travelled from the start to the corresponding light barrier.



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## Procedure (2/4)

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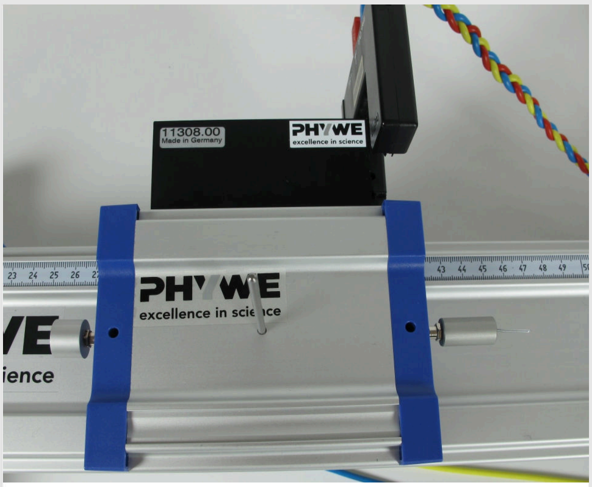


Interruption of the light barrier

**2.** The measuring carriage is given an initial velocity by the force impact of the launcher $v(0)$ and experiences a constant acceleration opposite to its velocity due to the gravitational component acting on it.

## Procedure (3/4)

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**3.** The times $t_1 ... t_4$ which are used to cover the distances $s_1 ... s_4$ from the start position to the respective light barrier are determined in mode 2 ( ). Subsequently, a measurement is performed in mode 1 ( ) to determine the corresponding velocities. The average speed during the corresponding passage is later calculated via the aperture length (100 mm) and the shadowing times $\Delta t_1 ... \Delta t_4$ of the four forked light barriers.

**4.** The measuring times are recorded for up to five repetitions. Before each execution, press the "Reset" button to reset the displays.

**5.** In order to obtain a larger number of measuring points, it is now possible to reposition the light barriers and carry out another series of measurements as described above.

**6.** The mass of the trolley shall be determined by means of a balance.



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## Procedure (4/4)

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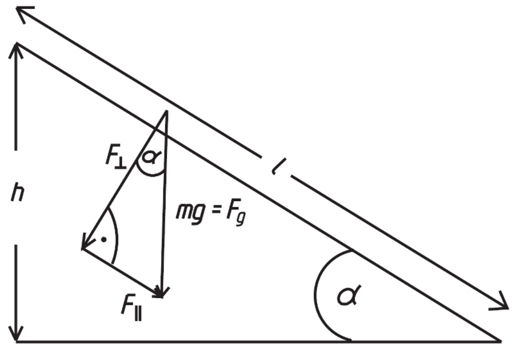
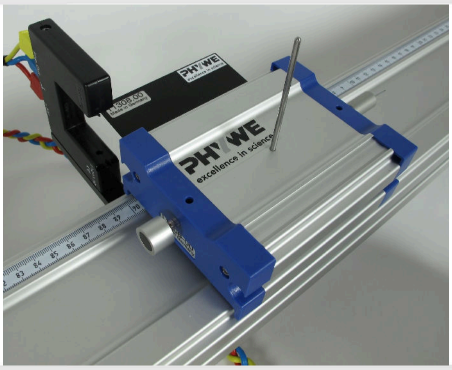
**7.** For the determination of the angle of inclination $\alpha$ of the track, measure the distance between the track stands $l$ and the height $h$ of the object placed under the path. Compare with the figure on the left. Make sure that the trolley passes the barrier completely (right figure).



## Evaluation (1/8)

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### Observation

If approximately equal distances between the light barriers were selected, it can be observed that the differences in the transit times $t_i$ and the shading times $\Delta t_i$ of the carriage due to the opposing acceleration becomes greater and greater as the distance increases. When the carriage reaches the apex, it reverses its direction of motion and performs a uniformly accelerated movement back to the starting point.



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## Evaluation (2/8)

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**Measured values**

| $s$ in m | $t_m$ in s | $\Delta t_m$ in s | $s / t_m$ in m/s | $v = b/\Delta t_m$ in m/s |
|---|---|---|---|---|
| 0,128 | 0,2 | 0,18 | 0,64 | 0,56 |
| 0,428 | 0,764 | 0,214 | 0,56 | 0,47 |
| 0,728 | 1,455 | 0,277 | 0,5 | 0,36 |
| 1,028 | 2,456 | 0,551 | 0,42 | 0,18 |
| 0,228 | 0,373 | 0,189 | 0,61 | 0,53 |
| 0,53 | 0,97 | 0,23 | 0,55 | 0,43 |
| 0,83 | 1,718 | 0,32 | 0,48 | 0,31 |
| 1,078 | 2,527 | 0,818 | 0,43 | 0,12 |

## Evaluation (3/8)

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**a) The distance-time and the velocity-time law**

1. From the five measurements of both $t_1 ... t_8$ and $\Delta t_1 ... \Delta t_8$, determine the mean values $t_{1m} ... t_{8m}$ and $\Delta t_{1m} ... \Delta t_{8m}$.
2. Calculate the velocities from the shading times $v_i(t_{im}) = b/\Delta t_{im}$ with the aperture length $b$ = 0.1 m.
3. In addition to the previous formulations of the displacement and velocity-time laws, it must now be taken into account that the car already has an initial velocity v(0) at the starting time t = 0.



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## Evaluation (4/8)

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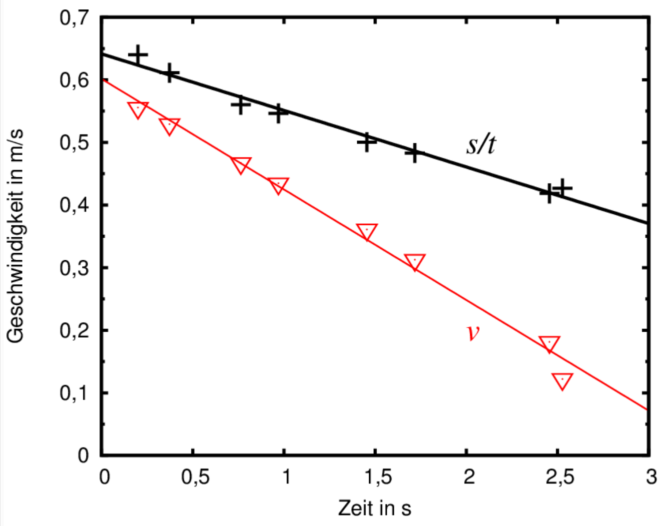
- In a (v, t) coordinate system, the determined instantaneous velocities are $v_i$ against the clock $t_{im}$ and determine the slope of the straight line and its intercept graphically or by linear regression (see figure).
- The average speeds are represented in a (s/t, t) coordinate system. For this purpose, the measured values of the distance per unit of time $s_i(t_{im})/t_{im}$ against the clock $t_{im}$ and the slope of the straight line and its intercept are also determined graphically or by linear regression (see figure).




## Evaluation (5/8)

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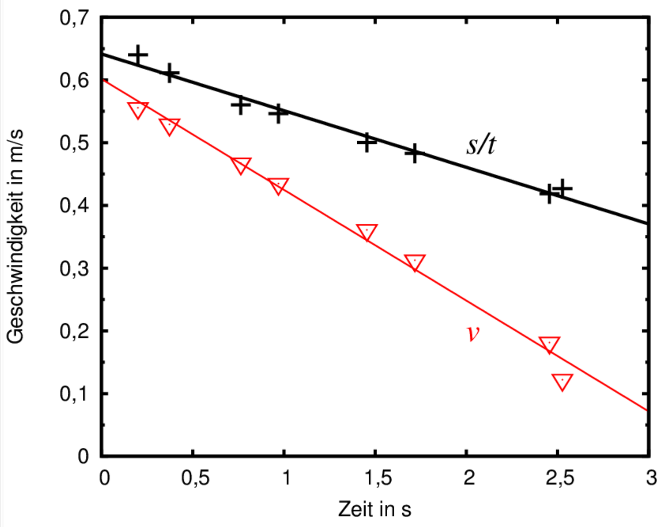
- For the measurement example
- $(v,t)$-Diagram: $a$ = -0.180 m/s,$v(0)$ = 0.61 m/s,
- $(s/t,t)$-Diagram: $a$ = -0.178 m/s,$v(0)$ = 0.64 m/s.



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## Evaluation (6/8)

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**4.** In the first graph, the velocity-time law can be used to determine

$$v(t) = a \cdot t + v(0)$$

the slope of the straight line as the acceleration a. The intercept corresponds to the initial velocity $v(0)$ of the wagon at the time $t = 0$. The opposite directions of initial velocity and acceleration are expressed by their different signs, they can be understood as vectorial quantities.

If currently $t_S =- v(0)/a$ the speed $v(t_S)$ is zero, all the kinetic energy must have converted into potential energy.

## Evaluation (7/8)

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**5.** From the second graph we get the linear relationship

$$\frac{s(t)}{t} = k_1 \cdot t + k_2$$

A comparison of the obtained coefficients: $k_2 \approx v(0)$ and $k_1 \approx a/2$. When applied, this results in the displacement-time law for uniformly decelerated motion:

$$s(t) = \frac{1}{2}a \cdot t^2 + v(0) \cdot t$$

Here, too, the opposite directions of initial velocity and acceleration have the effect of reversed signs. With negative $a$ the graph $s(t)$ is a downward-open parabola, the vertex of which is at $t_s$ represents the reversal point of the movement.



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## Evaluation (8/8)

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**6.** The acceleration acting on the car $a$ can also be calculated exclusively from the angle of inclination, as shown in the figure on slide 18. $\alpha$ of the path by the decomposition of the weight force $F_g$ in the components $F_{||}$ and $F_{\perp}$ substantiate

$$a = g \cdot sin(\alpha)$$

## Notes

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1. The calculated speeds $v_i$ from $\Delta t_i$ are, strictly speaking, not instantaneous velocities, since an acceleration continues to act on the carriage as it passes through the light barrier. The velocities thus result from a secant slope, but do not from a secant slope of the graph of $s(t)$. The slower the movement of the trolley, the greater the systematic error.
2. The car mass has no influence on the acceleration of the car. Nevertheless, it does have an effect on its range. This is due to the start impulse $p = m \cdot v$ which is transferred from the starter to the carriage. Consequently, with a larger car mass, the initial speed must be reduced in inverse proportion.



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