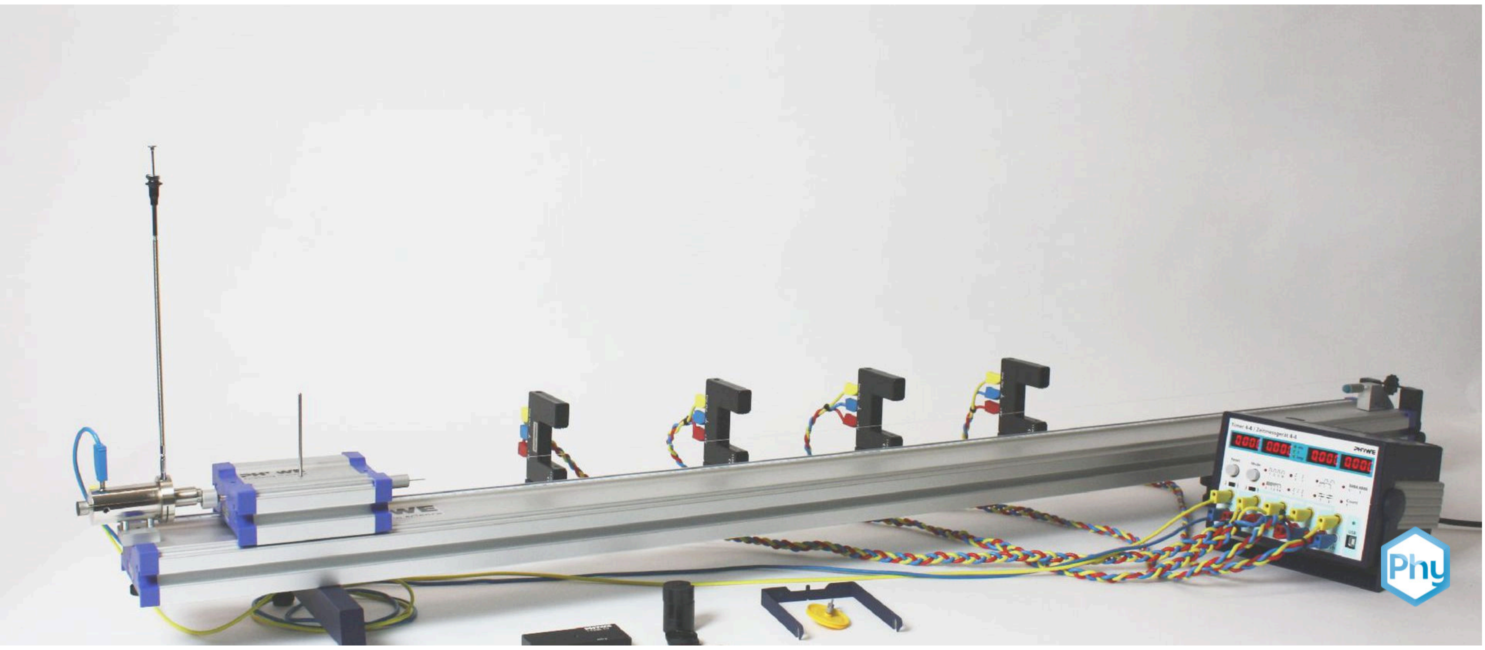
# Equivalence of inertial mass and gravitational mass with thedemonstration track and the timer 4-4



Physics | Mechanics | Energy conservation & impulse

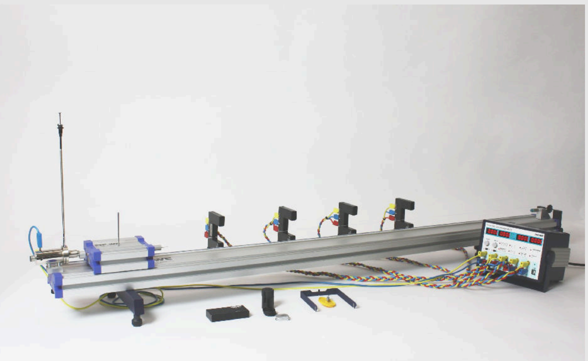
| Difficulty level | Group size | Preparation time | Execution time |
|---|---|---|---|
| medium | 2 | 20 minutes | 10 minutes |

This content can also be found online at:

http://localhost:1337/c/600497c427aa1c00038a12df

# General information

## Application



Experiment set-up

The mass of a body can be determined in different ways; by weighing the heavy mass or by measuring the acceleration at a known constant accelerating force, resulting in the inertial mass. It is assumed that heavy mass and inertial mass are equivalent.

In this experiment, a car with different heavy masses is accelerated on the roller track, its inertial mass is determined and the relationship between heavy and inertial mass is derived.



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**

Students should have a good understanding of the classical equations of motion and Newton's axioms.

**Scientific principle**

Up til now, the term mass has always been used in connection with the weight of a body and its movement.

In principle, these are two different properties, the heavy mass and the inertial mass.

In general, they are not distinguished because of their equivalence, but it should be noted that they are basically independent properties.

## Other information (2/2)

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**Learning objective**

It should be possible to distinguish between the two physical properties of weight and mass of a body.

**Tasks**

1. Determination of the total heavy mass and the driving mass by weighing.
2. Determination of the acceleration of the trolley and from this the inertial mass of the system.
3. Comparison of heavy and inertial mass.



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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

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



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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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# 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 | Starter system for demonstration track | 11309-00 | 1 |
| 9 | Magnet w.plug f.starter system | 11202-14 | 1 |
| 10 | Pulley for demonstration track | 11305-10 | 1 |
| 11 | Holder for pulley | 11305-11 | 1 |
| 12 | Weight for low friction cart, 400 g | 11306-10 | 1 |
| 13 | Slotted weight, black, 50 g | 02206-01 | 3 |
| 14 | Slotted weight, black, 10 g | 02205-01 | 4 |
| 15 | Weight holder, silver bronze, 1 g | 02407-00 | 1 |
| 16 | Slotted weight, blank, 1 g | 03916-00 | 20 |
| 17 | Silk thread, l = 200 m | 02412-00 | 1 |
| 18 | Light barrier, compact | 11207-20 | 4 |
| 19 | Holder for light barrier | 11307-00 | 4 |
| 20 | PHYWE Timer 4-4 | 13604-99 | 1 |
| 21 | Connecting cord, 32 A, 1000 mm, red | 07363-01 | 4 |
| 22 | Connecting cord, 32 A, 1000 mm, yellow | 07363-02 | 5 |
| 23 | Connecting cord, 32 A, 1000 mm, blue | 07363-04 | 5 |
| 24 | Portable Balance, OHAUS CR2200 | 48914-00 | 1 |



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Robert-Bosch-Breite 10
37079 Göttingen

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Fax: 0551 604 - 107

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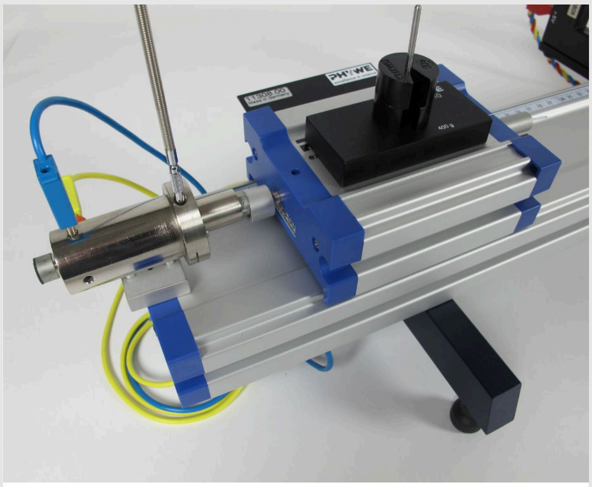
# Set-up and Procedure

## Set-up (1/6)




Launching device without 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.

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

Note; to start the trolley with initial pulse, the starting device must be mounted so that the punch moves away from the measuring trolley when triggered.



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

## Set-up (2/6)

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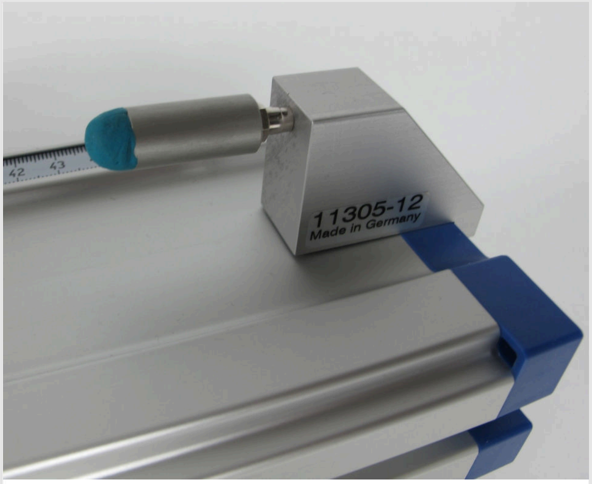


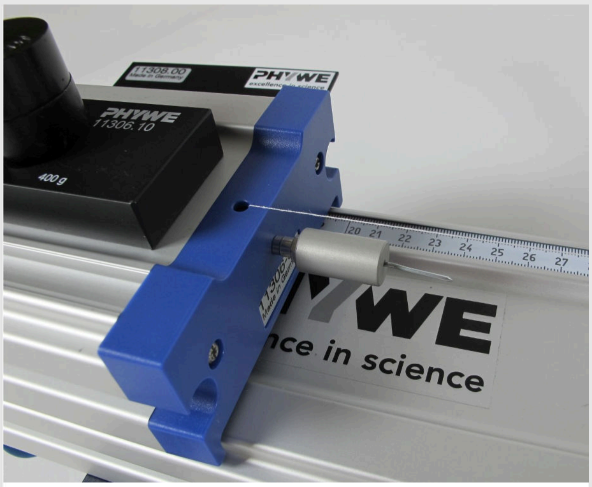

End bracket with plasticine

**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 deflection roller is attached to the right end of the track with the bracket for deflection roller and the incremental wheel is inserted.

## Set-up (3/6)

PHYWE




Fastening the thread to the trolley

**5.** The measuring trolley is equipped with the holding magnet with plug as well as the cover for measuring trolley (b = 100 mm).

**6.** The beginning of the thread is inserted from above into the vertical hole of the carriage end cap and fixed by inserting the needle with plug from the front.



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Robert-Bosch-Breite 10
37079 Göttingen

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

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## Set-up (4/6)

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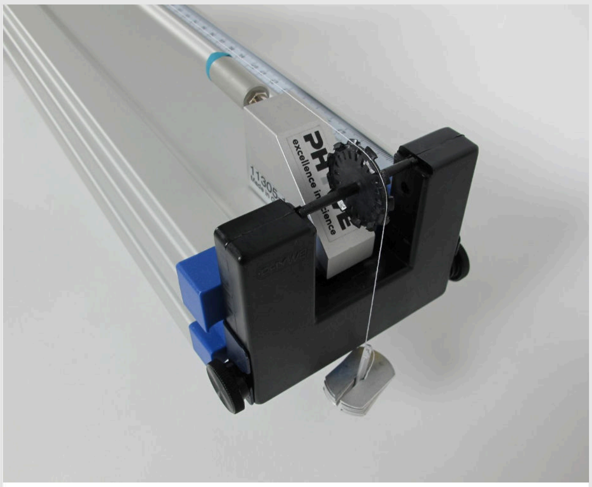

Positioning of the weight plate

**7.** The thread is placed over the incremental wheel of the deflection pulley and knotted at the end to the weight plate so that it hangs freely directly below the wheel, as shown in the illustration. The weight plate together with the 5-20 slotted weights (1g each) lying on it serve as a constant accelerating force. The thread must run parallel to the track.

**8.** The mass of the car can be varied by means of the black painted weights.

## Set-up (5/6)

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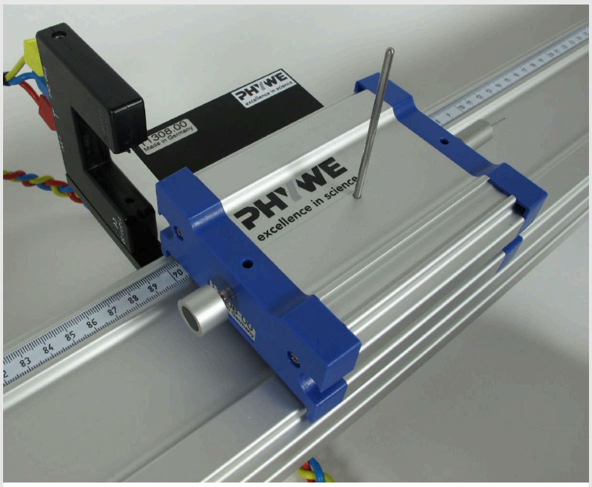


Release of the light barriers after aperture passage

**9.** The four forked photoelectric sensors are mounted on the roadway with the photoelectric sensor holders and distributed evenly over the measurement section.

When rolling the trolley, make sure that all light barriers can be passed through by the rear part of the screen before the weight plate touches the ground.

**10.** The forked light barriers are connected from left to right in sequence to the sockets in fields "1" to "4" 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.



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

## Set-up (6/6)

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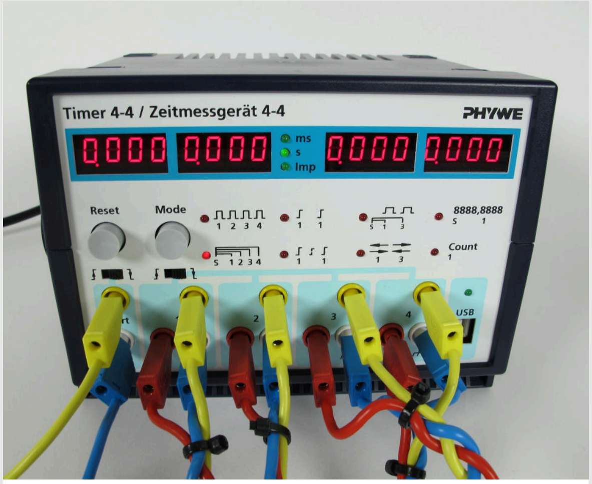

Connecting the light barriers and the starting device

**11.** 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.

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

## Procedure (1/2)

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**1.** The measuring carriage is released by the starter and experiences constant acceleration until the weight plate touches the ground. It then continues to roll at a constant speed.

**2.** First the times $t_1 ... t_4$ are measured in mode 2 ( S 1 2 3 4), which are the times required from the start until the respective light barriers are reached. Subsequently, a measurement is made in mode 1 ( 1 2 3 4 ) to determine the corresponding speeds.

When performing this measurement, the shading times are $\Delta t_1 ... \Delta t_4$ of the four forked light barriers; from these in turn, the average speed during the corresponding passage is later calculated via the aperture length (100 mm).



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Robert-Bosch-Breite 10
37079 Göttingen

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

info@phywe.de
www.phywe.de

# Procedure (2/2)

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**3.** The measuring times are recorded up to five times for different trolley masses with constant mass of the weight plate. Before each measurement, press the "Reset" key to reset the displays. Before starting a new series of measurements, the total heavy mass is measured with a balance. $m_s = m_W + m_A$ (car mass and accelerating mass of the driving body).

**4.** The heavy mass of a body is proportional to the weight force $F_g$ acting on it. The drive body ($m_A$, weight plate with weights) can be determined with a balance.

# Evaluation (1/8)

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**Measurement example for light barrier 1**

| $F_g$ in N | $m_s$ in kg | $t_{1m}$ in s | $\Delta t_{1m}$ in s | $v_1$ in m/s | $a_1$ in m/s² |
|---|---|---|---|---|---|
| 0,0981 | 0,41 | 1,235 | 0,293 | 0,341 | 0,276 |
| 0,0981 | 0,55 | 1,436 | 0,344 | 0,291 | 0,202 |
| 0,0981 | 0,81 | 1,781 | 0,43 | 0,233 | 0,131 |

**Measurement example for light barrier 2**

| $F_g$ in N | $m_s$ in kg | $t_{2m}$ in s | $\Delta t_{2m}$ in s | $v_2$ in m/s | $a_2$ in m/s² |
|---|---|---|---|---|---|
| 0,0981 | 0,41 | 1,776 | 0,22 | 0,454 | 0,256 |
| 0,0981 | 0,55 | 2,067 | 0,258 | 0,387 | 0,187 |
| 0,0981 | 0,81 | 2,573 | 0,323 | 0,309 | 0,12 |



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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 (2/8)

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**Measurement example for light barrier 3**

| $F_g$ in N | $m_s$ in kg | $t_{3m}$ in s | $\Delta t_{3m}$ in s | $v_3$ in m/s | $a_3$ in m/s² |
|---|---|---|---|---|---|
| 0,0981 | 0,41 | 2,202 | 0,185 | 0,541 | 0,245 |
| 0,0981 | 0,55 | 2,566 | 0,217 | 0,46 | 0,179 |
| 0,0981 | 0,81 | 3,2 | 0,273 | 0,367 | 0,115 |

**Measurement example for light barrier 4**

| $F_g$ in N | $m_s$ in kg | $t_{3m}$ in s | $\Delta t_{3m}$ in s | $v_3$ in m/s | $a_3$ in m/s² |
|---|---|---|---|---|---|
| 0,0981 | 0,41 | 2,555 | 0,163 | 0,613 | 0,24 |
| 0,0981 | 0,55 | 2,98 | 0,192 | 0,52 | 0,175 |
| 0,0981 | 0,81 | 3,722 | 0,243 | 0,412 | 0,111 |

## Evaluation (3/8)

PHYWE

**Mean values of the measurement examples**

| $F_g$ in N | $m_s$ in kg | $a_m$ in m/s² | $1/a$ in s²/m |
|---|---|---|---|
| 0,0981 | 0,41 | 0,254 | 3,94 |
| 0,0981 | 0,55 | 0,186 | 5,38 |
| 0,0981 | 0,81 | 0,119 | 8,4 |



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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 (4/8)

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1. From the five measurements each of $t_1 ... t_4$ and $\Delta t_1 ... \Delta t_4$, the mean values $t_{1m} ... t_{4m}$ and $\Delta t_{1m} ... \Delta t_{4m}$ can be determined.
2. Calculate the velocities from the shading times $v_{im}(t_{im}) = b/\Delta t_{im}$ and the accelerations $a_i = v_{im}(t_{im})/t_{im}$ with the aperture length $b$ = 0.1 m.
3. The four accelerations belonging to a series of measurements $a_i$ are averaged. From the resulting values $a_m$ the reciprocal values of the acceleration $1/a_m$ is determined (see measurement example 1).

## Evaluation (5/8)

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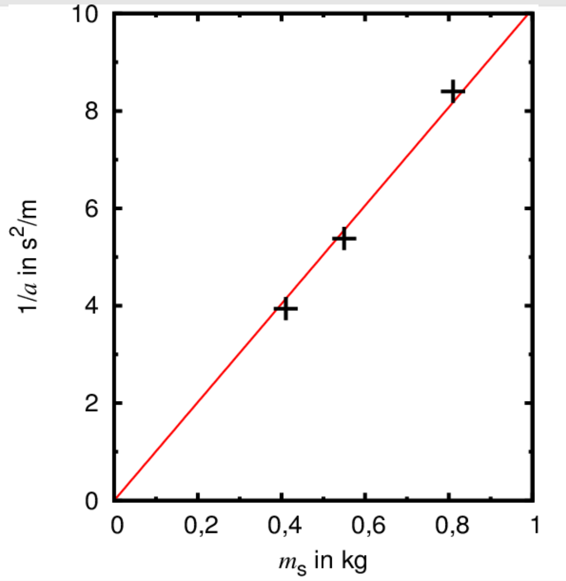
**4.** Finally, one carries the reciprocal accelerations $1/a_m$ against the total heavy mass $m_s$ from the trolley and drive mass in a coordinate system and determines the gradient of the straight line through these points.

For comparison, the values of the measurement example are shown in the figure.



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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 (6/8)

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**5.** Every body has the property of gravity. Due to the earth's gravity, it experiences an accelerating force, the weight force $F_g$ which is proportional to its heavy mass $m_s$ (Newton's law of gravity).

In this experiment, the heavy mass consists of $m_s = m_W + m_A$ from the mass of the car and the mass of the driving body.

**6.** If no force acts on a body, it remains in its state of motion (Newton's 1st axiom). When an external force acts on the body, it opposes the change of its state of motion with a resistance, the property of inertia.

The greater its inertial mass $m_t$ the more force must be applied to accelerate the body to a certain value (Newton's 2nd axiom).

## Evaluation (7/8)

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**7.** From the values of the (1/a, ms) coordinate system shown in Fig. 8, a straight line through the origin is obtained. At constant accelerating force, the heavy mass of the system is inversely proportional to the acceleration of the carriage:

$$m : s \propto \frac{1}{a} \text{ for } F_g = \text{const.}$$

With larger heavy mass $M_s$ the acceleration decreases $a$.

**8.** According to Newton's second axiom $F_g = m_t \cdot a$, the mass $m_t$ of a body is inversely proportional to its acceleration a.

If both heavy and inertial mass are inversely proportional to acceleration, then heavy and inertial mass must be proportional to each other:

$$m_s = k \cdot m_t.$$



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

## Evaluation (8/8)

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**9.** The determination of the proportionality factor $k$ is done via a gradient triangle on the graph from slide 20.

The gradient gives a value of 10.1 s²/(kg-m), the reciprocal of which is 0.0990 kg-m/s² of the weight force

$F_g$ = 0.0981 kg-m/s² (cf. measurement example 1). Heavy and inertial mass must therefore be identical:

$$m_s = m_t.$$

## Notes

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**1.** To reduce the distance between the weight adjuster and the incremental wheel, the thread length can be shortened by turning the needle with plug several times on the carriage, thus winding up the thread.

**2.** The from $\Delta t_i$ calculated speeds $v_i$ are, strictly speaking, not instantaneous velocities, since acceleration continues to act on the carriage as it passes through the light barrier.

The velocities thus arise from a secant slope, but not from a tangent slope, of the graph of s(t). Using $\Delta s$= 0.1 m, a systematic error of about 2 % must be expected.



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Robert-Bosch-Breite 10
37079 Göttingen

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info@phywe.de
www.phywe.de