# Mechanics

Translational motion

PHYSICS EXPERIMENT

# Uniformly accelerated motion

## MEASUREMENT OF INSTANTANEOUS VELOCITY AS A FUNCTION OF THE DISTANCE COVERED

- Investigate uniformly accelerated motion as a function of the accelerated mass.
- Investigate uniformly accelerated motion as a function of the accelerated mass.

UE1030250

10/16 MEC

## GENERAL PRINCIPLES

**In the case of uniform acceleration, the velocity *v* and the distance covered *s* increase over the course of time *t*. Thus the velocity increases as the distance becomes greater.**

The instantaneous velocity after a period of time $t$ is as follows:

$$v(t) = a \cdot t \tag{1}$$

The distance covered is given by

$$s(t) = \frac{1}{2} \cdot a \cdot t^2 \tag{2}$$

This leads to the following conclusions:

$$v(s) = \sqrt{2 \cdot a \cdot s} \tag{3a}$$

and

$$v^2(s) = 2 \cdot a \cdot s \tag{3b}$$

This relationship is used in the experiment to determine the constant acceleration $a$ of a carriage on a roller track. The carriage has a mass $m_2$ and is uniformly accelerated due to a falling weight attached to it by a cord running over a pulley. The force exerted by the falling weight is as follows:

$$F = m_1 \cdot g \tag{4}$$

where $g = 9{,}81 \frac{\text{m}}{\text{s}^2}$

However, it is also necessary to take into account the friction between the carriage and the roller track. The friction is proportional to the weight of the carriage and is constant to a good approximation:

$$F_{\text{fr}} = \mu \cdot m_2 \cdot g \tag{5}$$

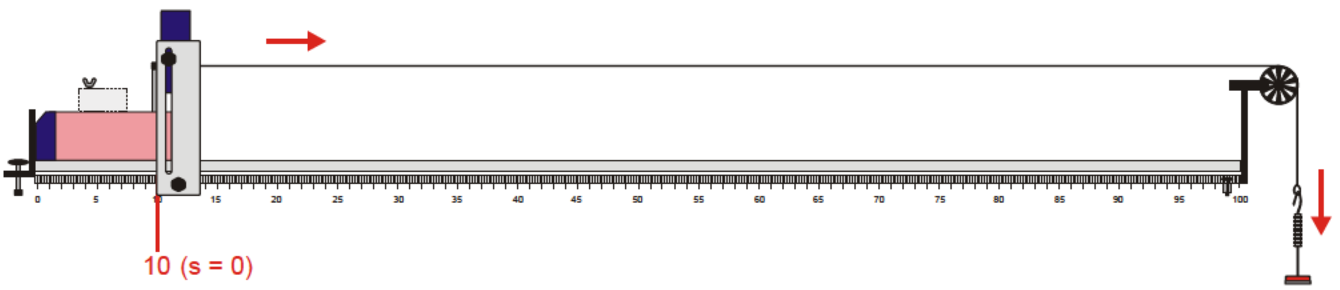


Fig. 1: Start position of carriage on track

Strictly speaking, the mass $m_1$ is also being accelerated. However, since it is small in comparison to $m_2$, it can be disregarded. The relationship therefore becomes:

$$F - F_{fr} = m_2 \cdot a \quad (6)$$

or

$$a = \left( \frac{m_1}{m_2} - \mu \right) \cdot g \quad (7)$$

The velocity at any given instant is given by

$$v = \frac{\Delta s}{\Delta t} \quad (8)$$

In order to measure it at a given point, an interrupter flag of known width $\Delta s$ is attached to the carriage. The flag then breaks the beam of a photo gate (a photoelectric sensor). The time the beam is broken $\Delta t$ is measured by means of a digital counter.

## LIST OF EQUIPMENT

| | |
|---|---|
| 1 Roller track | 1003318 (U35000) |
| 1 Set of slotted weights | 1003227 (U30031) |
| 1 Cord for experiments | 1001055 (U8724980) |
| 1 Photo gate | 1000563 (U11365) |
| 1 Digital counter (230 V) | 1001033 (U8533341-230) |
| or | |
| 1 Digital counter (115 V) | 1001032 (U8533341-115) |
| 1 Pair of safety experiment leads | 1002849 (U13812) |

## SET-UP

- Set up the experiment as in Fig. 1.
- Lay out the roller track horizontally and attach the spoked wheel at the right-hand end in order to use it as a pulley.
- Use the carriage without magnets but with 4 magnet holders.
- Attach the long flag with a diameter $\Delta s$ = 9 mm to the carriage and park the carriage at the start of the track.

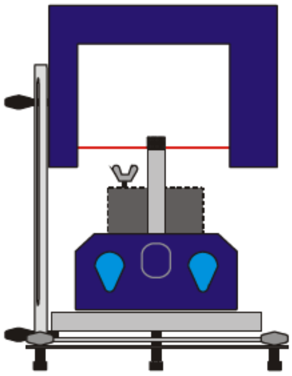

Fig. 2 Alignment of photo gate

- The photoelectric sensor (photo gate) should be attached at the 10-cm mark on the track scale and adjusted in height such that the beam is only broken by the flag and not by the wing nut holding the added weight when the carriage starts moving, see Fig. 2.
- Connect the photo gate to the socket "A" of the digital counter.
- Connect sockets "OUT START" (yellow) and "IN STOP" (red) on the digital counter by means of experiment leads.
- Set the selector switch to $\Delta t_{AB}$ (0.0 ms).
- Position the flag on the carriage in such a way that it is right next to breaking the beam, without actually doing so.
- Put the additional mass in front of the carriage so that it cannot move.
- Cut off about 130 cm of the cord for experiments and attach one end to the flag. Run the cord over the pulley and suspend the weight holder for slotted weights from it.
- Make sure the cord is horizontal between the pulley and the carriage.

## PROCEDURE

- Move the photo gate to the 20-cm mark ($s$ = 10 cm).
- Release the carriage and let it break the photoelectric beam.
- Read off the time the beam is interrupted $\Delta t$ and enter it into Table 1.
- Move the photo gate to the 30-cm mark ($s$ = 20 cm).
- Allow the carriage to move down the track and read off the time $\Delta t$ when it breaks the beam.
- Keep lengthening the distance $s$ in 10-cm steps by moving the photo gate and repeat the measurement each time.

- Always make sure that the weight accelerating the carriage does not hit the floor before the carriage has broken the beam.

**Changing the mass of the accelerating weight $m_1$:**

**Changing the mass of the accelerated carriage $m_2$:**

- Attach an additional weight of 500 g to the carriage $m_2$ = 1000 g.
- Repeat the whole set of measurements, increasing $m_1$ up to 40 g and enter the results into Table 2.

- Add a 10-g slotted weight to the weight holder to increase the mass of the accelerating weight to $m_1$ = 20 g.
- Repeat the whole set of measurements and enter the values obtained into Table 1.

## EVALUATION

- Calculate $v^2 = \left(\frac{9\,\text{mm}}{\Delta t}\right)^2$ in each case, enter the results into tables 3 and 4 and plot them in a graph of $v^2$ against $s$.

## SAMPLE MEASUREMENT

Table 1: $m_2$ = 500 g

| $s$ / cm | $m_1$ = 10 g $\Delta t$ / ms | $m_1$ = 20 g $\Delta t$ / ms |
|---|---|---|
| 10 | 52.4 | 34.0 |
| 20 | 38.1 | 25.0 |
| 30 | 31.4 | 20.6 |
| 40 | 27.6 | 17.6 |
| 50 | 24.4 | 16.3 |
| 60 | 22.3 | 14.4 |
| 70 | 20.9 | 13.8 |

Table 2: $m_2$ = 1000 g

| $s$ / cm | $m_1$ = 10 g $\Delta t$ / ms | $m_1$ = 20 g $\Delta t$ / ms | $m_1$ = 30g $\Delta t$ / ms | $m_1$ = 40g $\Delta t$ / ms |
|---|---|---|---|---|
| 10 | 89.8 | 54.5 | 40.4 | 35.4 |
| 20 | 68.9 | 39.5 | 29.3 | 25.6 |
| 30 | 55.1 | 31.9 | 24.4 | 20.9 |
| 40 | 46.4 | 27.9 | 21.2 | 17.9 |
| 50 | 40.0 | 24.3 | 18.3 | 16.5 |
| 60 | 35.9 | 21.8 | 16.6 | 15.2 |
| 70 | 34.6 | 21.1 | 16.0 | 14.2 |

Table 3: $m_2$ = 500 g

| $s$ / cm | $m_1$ = 10 g $v^2$ / m²/s² | $m_1$ = 20 g $v^2$ / m²/s² |
|---|---|---|
| 10 | 0.030 | 0.070 |
| 20 | 0.056 | 0.130 |
| 30 | 0.082 | 0.191 |
| 40 | 0.106 | 0.261 |
| 50 | 0.136 | 0.305 |
| 60 | 0.163 | 0.391 |
| 70 | 0.185 | 0.425 |

Table 4: $m_2$ = 1000 g

| $s$ / cm | $m_1$ = 10 g $v^2$ / m²/s² | $m_1$ = 20 g $v^2$ / m²/s² | $m_1$ = 30g $v^2$ / m²/s² | $m_1$ = 40g $v^2$ / m²/s² |
|---|---|---|---|---|
| 10 | 0.010 | 0.027 | 0.050 | 0.065 |
| 20 | 0.017 | 0.052 | 0.094 | 0.124 |
| 30 | 0.027 | 0.080 | 0.136 | 0.185 |
| 40 | 0.038 | 0.104 | 0.180 | 0.253 |
| 50 | 0.051 | 0.137 | 0.242 | 0.298 |
| 60 | 0.063 | 0.170 | 0.294 | 0.351 |
| 70 | 0.068 | 0.182 | 0.316 | 0.402 |

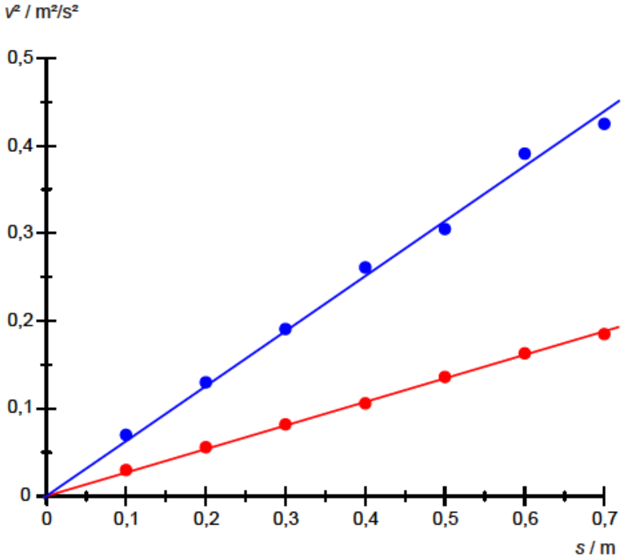


Fig. 3 $v^2$-$s$ plot for $m_2$ = 500 g. $m_1$ = 10 g (●), 20 g (●)

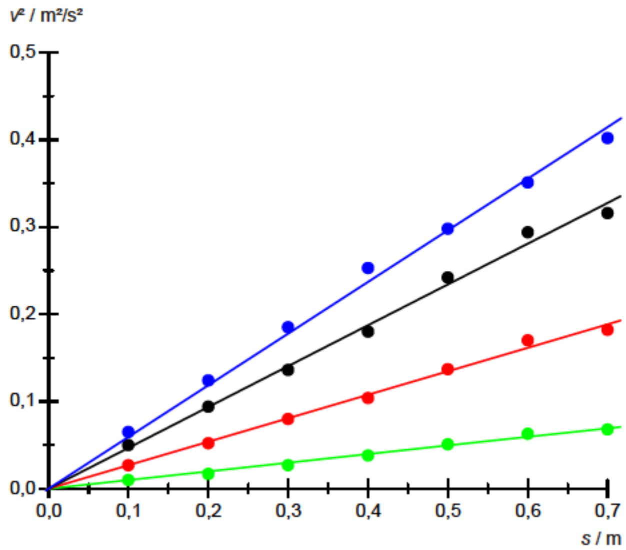


Fig. 4 $v^2$-$s$ plot for $m_2$ = 1000 g.
$m_1$ = 10 g (●), 20 g (●), 30 g (●), 40 g (●)

- Draw straight lines through the points and the origin as in both Figs. 3 and 4.
- Calculate the acceleration $a$ from the gradients of the lines and enter the values into Table 5.
- Also plot these values on a graph and fit straight lines to it which match Equation (7).

Table 5: Values for acceleration $a$ calculated from the gradients in Figs. 3 and 4.

| $m_1$ / g | $m_2$ / g | $m_1/m_2$ | $a$ / m/s² |
|---|---|---|---|
| 10 | 500 | 0.02 | 0.134 |
| 20 | 500 | 0.04 | 0.314 |
| 10 | 1000 | 0.01 | 0.049 |
| 20 | 1000 | 0.02 | 0.135 |
| 30 | 1000 | 0.03 | 0.234 |
| 40 | 1000 | 0.04 | 0.296 |

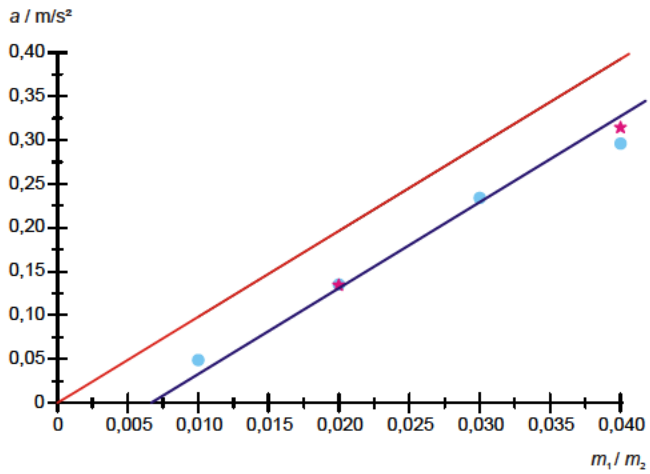


Fig. 5 Acceleration $a$ as a function of the ratio of masses $m_1/m_2$. $a = m_1/m_2 \cdot g$ (▬▬), $a = (m_1/m_2 - \mu) \cdot g$ (▬▬), $m_2$ = 500g (★), 1000 g (●)

Fig. 5 shows how the acceleration depends on the ratio of the two masses $m_1/m_2$. To a fairly good approximation, the values lie on a straight line, whereby μ = 0.0069 as per Equation (7).

## RESULT

Under constant acceleration the square of the instantaneous velocity increases in proportion to the distance covered. For a quantitative assessment it is necessary to take friction into account. This remains constant to a good approximation at low velocities and is proportional to the weight of the carriage.



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