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.

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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 $g = 9{,}81 \dfrac{m}{s^2}$

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:

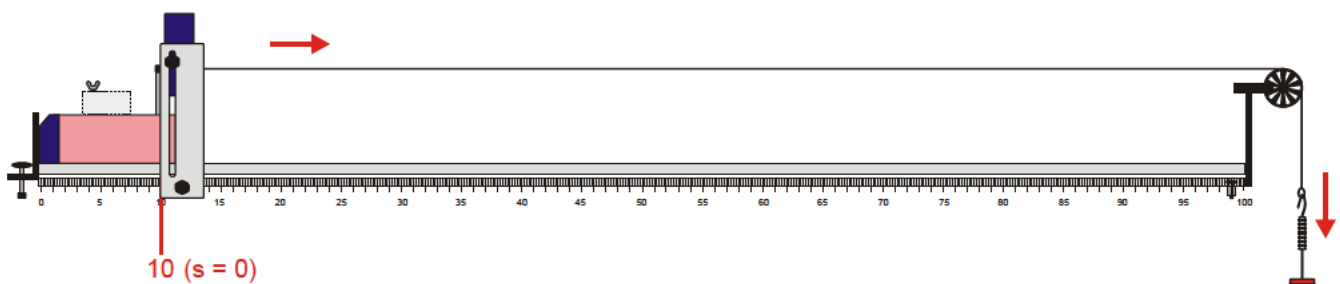$$F_{fr} = \mu \cdot m_2 \cdot g \tag{5}$$

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:

$$F - F_{fr} = m_2 \cdot a \tag{6}$$

or

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

The velocity at any given instant is given by

$$v = \frac{\Delta s}{\Delta t} \tag{8}$$

In order to measure it at a given point, an interrupter flag of known width Δs is attached to the carriage. The flag then breaks the beam of a photo gate (a photoelectric sensor). The time the beam is broken Δt 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.
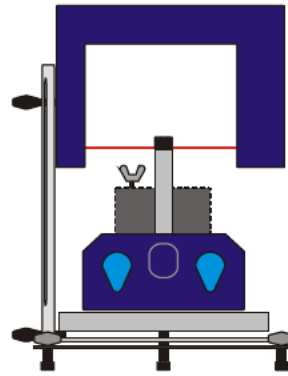

Fig. 2   Alignment of photo gate

- 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 Δt_{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 Δt 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 Δt 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 $v^2 = \left(\dfrac{9\,\text{mm}}{\Delta t}\right)^2$ 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 Δt / ms	m_1 = 20 g Δt / 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 Δt / ms	m_1 = 20 g Δt / ms	m_1 = 30g Δt / ms	m_1 = 40g Δt / 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

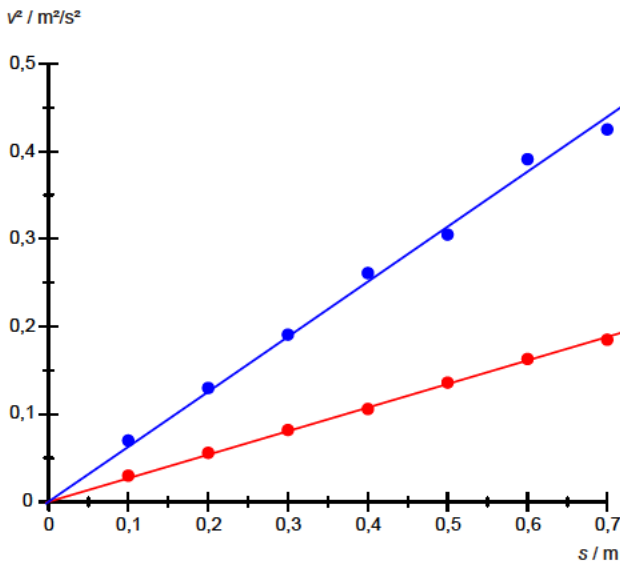| s / cm	m_1 = 10 g v^2 / m²/s²	m_1 = 20 g v^2 / m²/s²	m_1 = 30g v^2 / m²/s²	m_1 = 40g v^2 / m²/s²
10	0.010	0.027	0.050	0.065
20	0.017	0.052	0.094	0.124
30	0.027	0.080	0.136	0.185
40	0.038	0.104	0.180	0.253
50	0.051	0.137	0.242	0.298
60	0.063	0.170	0.294	0.351
70	0.068	0.182	0.316	0.402

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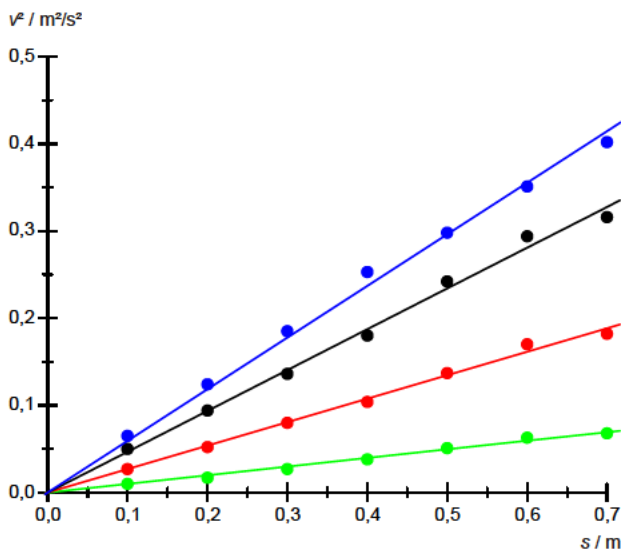

Fig. 4 v^2-s plot for m_2 = 1000 g.
m_1 = 10 g (●), 20 g (●), 30 g (●), 40 g (●)

- 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.

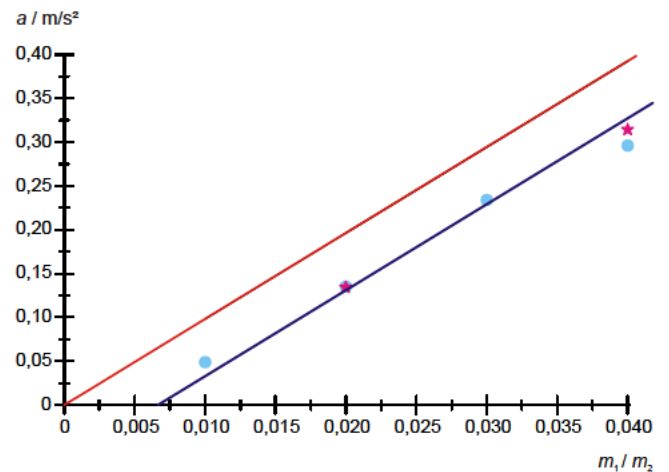| m_1 / g	m_2 / g	m_1/m_2	a / m/s²
10	500	0.02	0.134
20	500	0.04	0.314
10	1000	0.01	0.049
20	1000	0.02	0.135
30	1000	0.03	0.234
40	1000	0.04	0.296

Fig. 5   Acceleration a as a function of the ratio of masses
m_1/m_2. $a = m_1/m_2 \, {}^*g$ (——),
$a = (m_1/m_2 - \mu)^*g$ (——), 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 $\mu = 0.0069$ 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.