Experiment 5
Newton's 2nd Law

Related Topics

Velocity, acceleration, force, acceleration of gravity.

Principle

The distance-time law, the velocity-time law, and the relationship between mass, acceleration and force are determined with the aid of the air track rail for uniformly accelerated motion in a straight line.

Equipment

1	Air track rail	11202.17
1	Blower	13770.97
1	Pressure tube, l = 1.5 m	11205.01
1	Glider f. air track	11202.02
1	Screen with plug, l = 100 mm	11202.03
8	Slotted weight, 10 g, black	02205.01
4	Slotted weight, 50 g, black	02206.01
1	Weight holder 1 g	02407.00
1	Timer 4-4	13605.99
4	Connecting cord, l = 1000 mm, red	07363.01
4	Connecting cord, l = 1000 mm, yellow	07363.02
4	Connecting cord, l = 1000 mm, blue	07363.04
1	Connecting cord, l = 2000 mm, yellow	07365.02

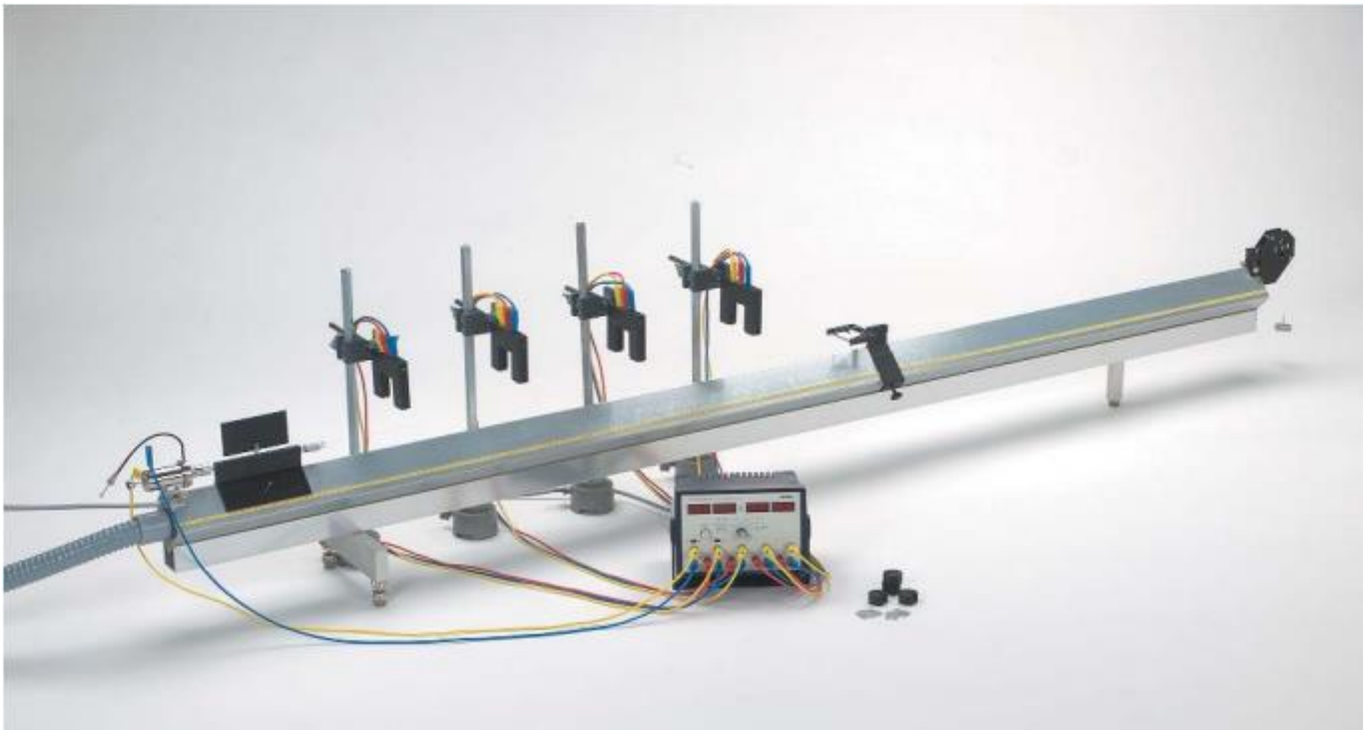

Fig. 1: Experimental set-up for investigation of uniformly accelerated motion.

Experiment 5
Newton's 2nd Law

Tasks

Determination of:

1. Distance travelled as a function of time
2. Velocity as a function of time
3. Acceleration as a function of the accelerated mass
4. Acceleration as a function of force

Set-up and procedure

The experimental set-up is shown in Fig. 1.

The starting device is mounted in such a manner that the triggering unit releases the glider without giving it an initial impulse when triggered. It is connected with the two "Start" jacks on the timer; when connecting it, ensure that the polarity is correct. The red jack on the starting device is connected with the yellow jack of the timer. The four light barriers are connected in sequence from left to right with the control input jacks "1" to "4" on the timer. Connect jacks having the same colour when doing so.

The mass of the glider can be altered by adding slotted weights. Always place weights having the same mass on the glider's weight-bearing pins, as optimum gliding properties are provided only with symmetrically loading. The accelerating force acting on the glider can be varied by changing the number of weights (on the weight holder) acting via the silk thread and the precision pulley. Determine the mass of the glider without the supplementary slotted weights by weighing it. Position the four light barriers in a manner such that they divide the measuring distance into approximately equal segments. Place the last light barrier such that the glider with screen passes through it before the accelerating weight touches the floor. Position the adjustable stop with the fork and plug on the track in such a manner that the glider is gently braked by the rubber band just before the accelerating weight touches the floor. Measure the distances travelled $s_1 \ldots s_4$ between the front edge of the screen from the starting position to the respective light barriers exactly for the evaluation. Perform all subsequent measurements without changing the light barriers' positions.

After measuring the times $t_1 \ldots t_4$ required for the four distances travelled $s_1 \ldots s_4$ with the timer in the "s(t)" operating mode (see operating instructions), determine the corresponding velocities with the "v(t)" operating mode. While doing so, the shading times $\Delta t_1 \ldots \Delta t_4$ of the four light barriers are measured; from them the mean values of the velocity for the corresponding distance travelled are determined with reference to the screen's length. These mean velocities correspond to the instantaneous velocities represented by the times $t'_1 \ldots t'_4$ in accordance with the following:

$$t'_n = t_n + \frac{\Delta t_n}{2}$$

To determine the acceleration as a function of the mass, increase the mass of the glider progressively by 20 g increments (10 g on each side), and measure the instantaneous velocity at a predetermined position.

In determining the acceleration as a function of force, the total mass remains constant. Successively transfer 2 g (1 g from each side) from the glider to the weight holder and measure the instantaneous velocity at a fixed position. The accelerated mass must not exceed 20 g.

Before beginning with the measurements, it is advisable to check the track's adjustment.

Theory and evaluation

Newton's equation of motion for a mass point of mass m to which a force is applied is given by the following:

$$m \cdot \vec{a} = \vec{F} \ ,$$

where

$$\vec{a} = \frac{d^2 \vec{r}}{dt^2}$$

is the acceleration.

The velocity v obtained by application of a constant force is given as a function of the time t by the expression

$$\vec{v}(t) = \frac{\vec{F}}{m} t$$

for

$$\vec{v}(0) = 0.$$

Assuming that

$$\vec{v}(0) = 0; \ \vec{r}(0) = 0$$

the position of $\vec{F}$ of the mass point is

$$\vec{r}(t) = \frac{1}{2} \frac{\vec{F}}{m} \cdot t^2 . \qquad (0)$$

In the present case the motion is one dimensional and the force produce by a weight of m_1 is

$$|\vec{F}| = m_1 \cdot |\vec{g}| = m_1 \cdot g$$

where g is the acceleration of gravity. If the total mass of the glider is m_2 the equation of motion is given by

$$(m_2 + m_1) \cdot |\vec{a}| = m_1 \cdot g; \qquad (1)$$

The velocity is

$$|\vec{v}(t)| = v = \frac{m_1 \cdot g}{m_1 + m_2} \cdot t \qquad (2)$$

And the position is

$$|\vec{r}(t)| = s(t) = \frac{1}{2} \frac{m_1 \cdot g}{m_1 + m_2} \cdot t^2 . \qquad (3)$$

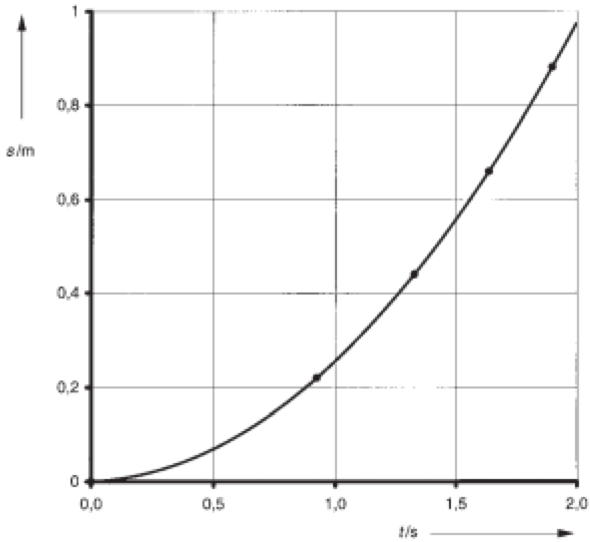

Fig.2: The distance travelled s plotted as a function of the time t; m_1 = 10 g, m_2 = 201 g.

The evaluation is now illustrated by the following sample measurements. For all the measurements the distances of the four light barriers from the starting point were 22 cm, 44 cm, 66 cm and 88 cm, respectively. The mass of the glider including the screen, hooks and support magnet was 201 g.

Fig. 2 shows the distance travelled s as a function of the time t (m_1 = 10 g, m_2 = 201 g). In Fig. 3 the distance travelled is illustrated as a function of t^2 for the same measured values. A linear correlation results, as was expected from the theory. The slope is 0.246 m/s^2 and the following is thus obtained from Equation (0):

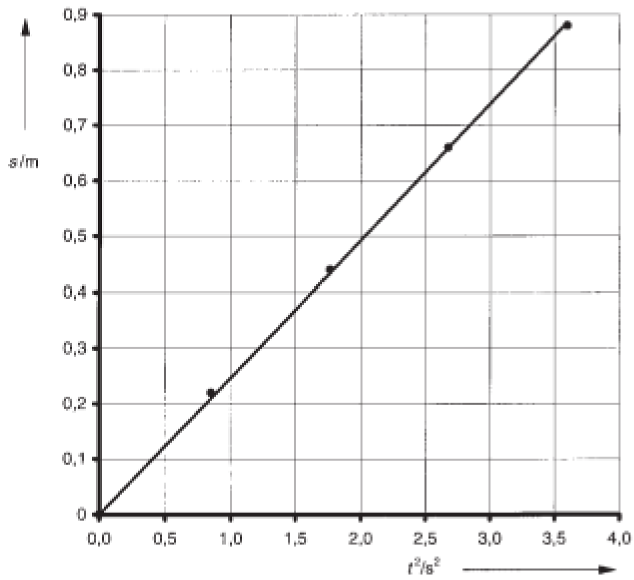

Fig.3: The same measurement as in Fig. 2 plotted against t^2.

$$F = 2 \cdot (m_1 + m_2) \cdot 0.246 \text{ ms}^{-2} = 0.104 \text{ N}.$$

As a good approximation, this corresponds to the weight force of the mass m1 (0.010 kg); F = m_1g = 0.0981 N.

Under the same experimental conditions, the correlation v(t) presented in Fig. 4 is obtained by measuring the shading time of the four light barriers due to the screen, which has a length of 10 cm. The slope of the compensation line drawn through the origin correspond to the acceleration a in this case. For the presented sample measurement a = 0.473 ms^{-2}. We expect a to be equal to

$$a = \frac{m_1 g}{m_1 + m_2} = 0.465\ \frac{m}{s^2}$$

This value agrees with the acceleration determined using Fig. 4 very well.

In the same manner as shown in the example in Fig. 4, the accelerations are measured in two measuring series as a function of the inert mass $m_1 + m_2$ (F = constant) and as a function of the force ($m_1 + m_2$ = constant). In the process, one can make the evaluation work much easier by using a computer with a spreadsheet program (e.g. Microsoft Excel®).

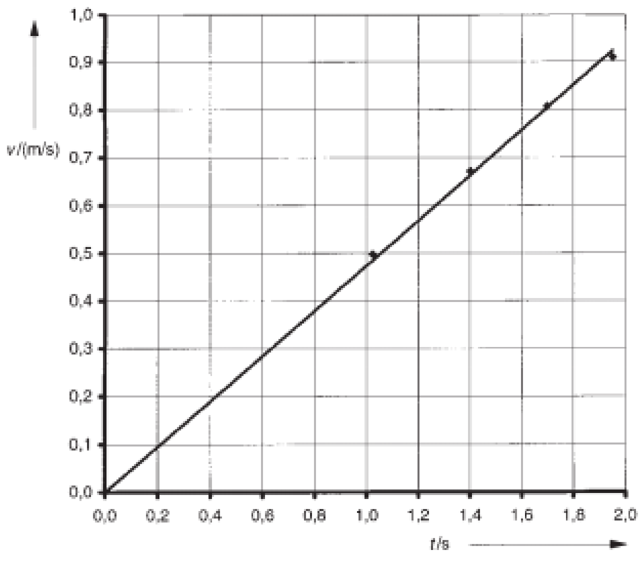

Fig.4: The velocity v plotted as a function of the time t; m_1 = 10 g, m_2 = 201 g.

Fig. 5 shows the acceleration due to the mass m_1 = 10 g as a function of the inert mass. If the acceleration is plotted against the reciprocal of the inert mass using the same measured values, a linear correlation results, as expected (Fig. 6). The slope of the straight lines should be equal to the accelerating force,

m_1g = 0.981 N. The evaluation of the present example in Fig. 6. results in a slope of 0.999 kg·m·s^2 = 0.999 N.

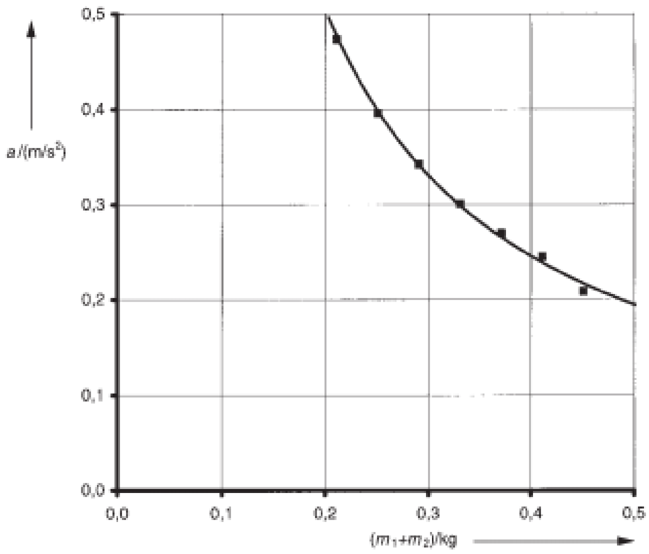

Fig.5: The acceleration a as a function of the inert mass $m_1 + m_2$ measured at a constant accelerating (weight) force due to the mass m_1 = 10 g.

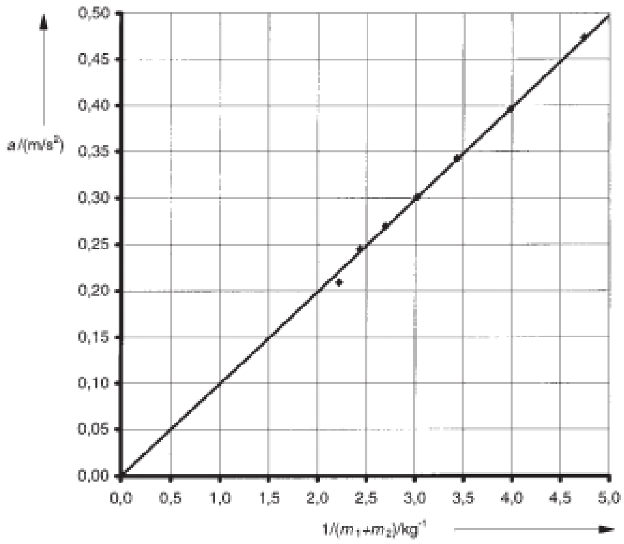

Fig.6: The same measurement as in Fig. 5 plotted against the reciprocal inert mass.

In conclusion, Fig. 7 shows the dependence of the acceleration on the accelerating force F. One sees the linear proportionality between the two parameters. The reciprocal slope is 0.213 kg and corresponds well to the inert mass $m_1 + m_2 = 0.217$ kg.

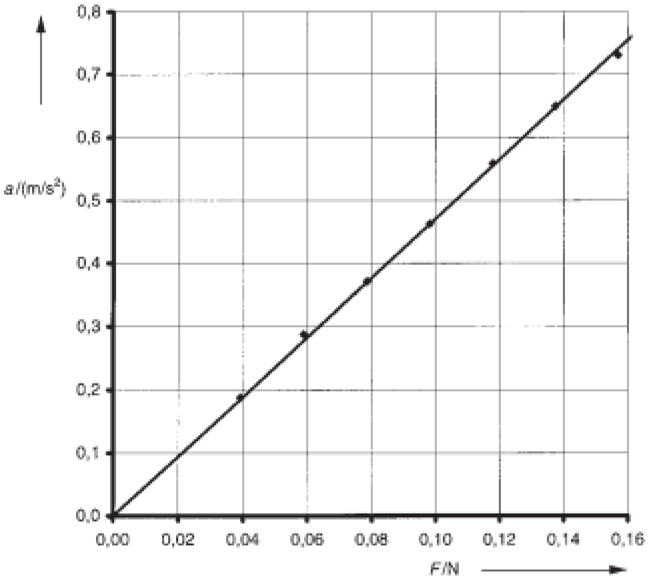

Fig.7 The acceleration a as a function of the force F for constant inert mass $m_1 + m_2 = 217$ g.

Table 1 Kinematic equations for motion in a straight line under constant acceleration

Equation	Information Given by Equation
$v_{xf} = v_{xi} + a_x t$	Velocity as a function of time
$x_f - x_i = \frac{1}{2}(v_{xi} + v_{xf})t$	Displacement as a function of velocity and time
$x_f - x_i = v_{xi}t + \frac{1}{2}a_x t^2$	Displacement as a function of time
${v_{xf}}^2 = {v_{xi}}^2 + 2a_x(x_f - x_i)$	Velocity as a function of displacement

Experiment 5
Newton's 2nd Law

1) Put m_1 on the weight holder (Remember that weight holder's mass is 1g). Measure the distance travelled $s_{1,...,}s_4$ between the front edge of the screen from the starting position to the respective light barriers exactly for the evaluation. Perform all subsequent measurements without changing the light barriers' positions. Record them on table 2. (m_1 is the mass on the weight holder and m_2 is the total mass of the glider)

Table 2.

m_1(g)	m_2(g)	t_1(s)	t_2(s)	t_3(s)	t_4(s)	s_1(m)	s_2(m)	s_3(m)	s_4(m)
	Avg.								

2) Calculate velocities(V_1 ,V_2 ,V_3 ,V_4) **by using Table 1** and record them on Table 3.

....

....

....

....

....

....

....

....

....

....

Table 3.

V_1 (m/s)	V_2 (m/s)	V_3 (m/s)	V_4 (m/s)

3) Draw s-t, $s\text{-}t^2$ and v-t plots. (Remarks: see Fig.2, Fig.3 and Fig.4)

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

4) The mass of the glider (m_2) can be altered by adding slotted weights. Fill the table given below with different value of gliders' mass. For the weights on Table 4, calculate accelerations (a_1, a_2, a_3) using formula given below. **Plot a (m/s^s) – (m_1+m_2) (g)**. (Remarks: see Fig. 5)

$$a = \frac{m_1}{m_1 + m_2} g$$

……

……

……

……

……

……

……

……

……

……

……

……

……

……

……

Table 4.

m_1 (g)	m_2 (g)	a (m/s^2)

5) Repeat the experiment for different masses on the weight holder (m_1) and fill the table given below. Use necessary formulations from Table 1. For the weights on Table 5, calculate accelerations (a_1, a_2, a_3, a_4). **Plot a (m/s^s) – F (N)**. (Remarks: see Fig. 7).

....

....

....

....

....

....

....

....

....

....

....

....

....

m_1 (g)	$F=m_1g$ (N)	V_4 (m/s)	t_4 (s)	a (m/s^2)

6) Results and Discussion: *Discuss the results*

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………