Free fall: time measurement with the contact plate and the counter S

Objects of the experiment

- Measuring the falling times of a ball between the holding magnet and the contact plate for recording the path-time diagram point by point.
- Confirming the proportionality between the falling distance and the square of the falling time.
- Determining the acceleration of gravity.

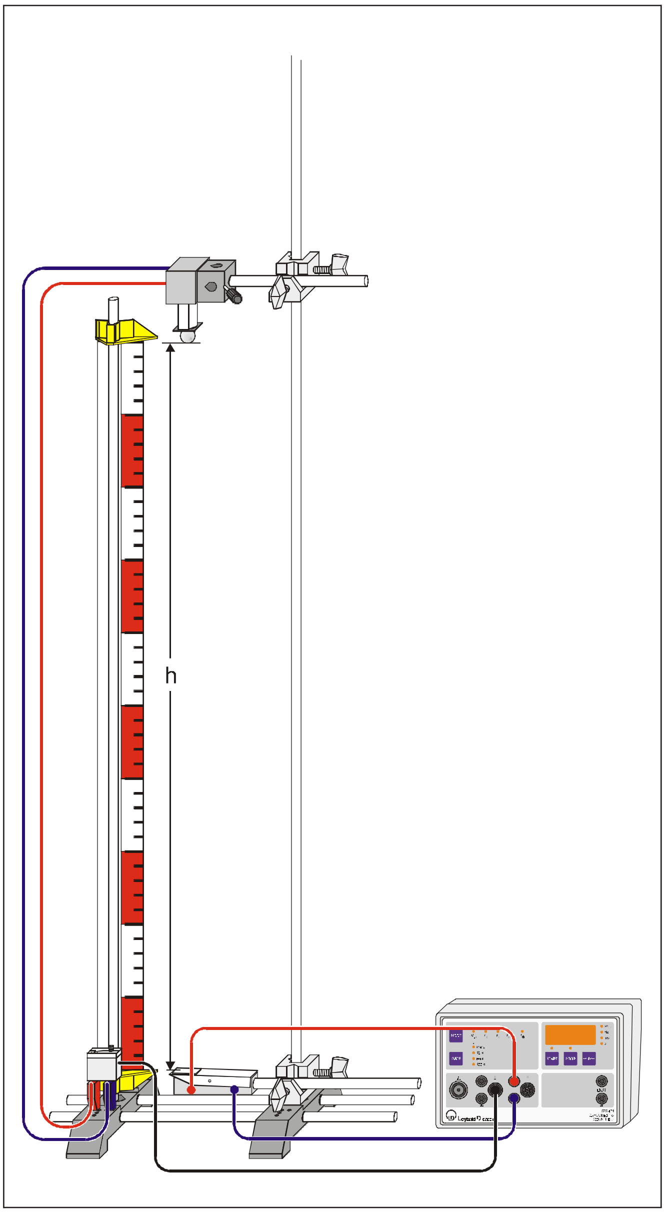

Fig. 1 Experimental setup for determining the acceleration of gravity with the contact plate and the counter S

Principles

When a body falls in the gravitational field of the earth from a height h to the ground, it experiences a constant acceleration g as long as the falling distance is small and friction can be neglected. This motion is called free fall.

If the body starts at the time $t_0 = 0$ with the initial velocity $v_0 = 0$, the distance it cover in the time t is

$$h = \frac{1}{2} \cdot g \cdot t^2 \qquad \text{(I).}$$

Thus the free fall is an example of a uniformly accelerated motion.

In the experiment, the free fall is investigated on a steel ball which is suspended from an electromagnet (see Fig. 1). Due to its gravitational force

$$F = m \cdot g \qquad \text{(II)}$$

m: mass of the ball

it falls downward in a uniformly accelerated motion as soon as the electromagnet is switched off. In this moment the electronic time measurement is started. Having covered the falling distance h, the ball hits a contact plate and stops the measurement at the falling time t. The measuring results for various falling distances are entered in a path-time diagram as pairs of values. As the ball is at rest at the beginning of the time measurement, Eq. (I) can be used to determine the acceleration of gravity g.

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Apparatus

1 large contact plate, incl. steel ball	336 23
1 holding magnet with multiclamp	336 21
1 holding magnet adapter with a release mechanism	336 25
1 counter S	575 471
2 stand bases MF	301 21
3 stand rods, ∅ 10 mm, 25 cm	301 26
1 stand rod, ∅ 12 mm, 150 cm	300 46
2 Leybold multiclamps	301 01
1scale with pointers	311 23
connecting leads	

Setup

The experimental setup is illustrated in Fig. 1.

– Set the two stand bases MF up so that the bores are in front and establish a rigid connection between then stand bases using two short stand rods.

– Clamp the scale in the left stand base MF and the long stand rod in the right one. The scale and the stand rod should not touch the ground.

– Mount the contact plate at the lower end of the stand rod and the holding magnet at the upper end of the stand rod.

– If necessary press the contact plate into the zero position (horizontally aligned, i.e. the switch is closed).

– Align the scale and the contact plate so that the height of the black impact surface is exactly 0 cm.

– Connect the connecting leads to the holding magnet and plug the free ends in the bores of the left stand base MF.

– Connect the holding magnet adapter with release mechanism to the free ends of the connecting leads and, on the other side, to the input E of the counter S.

– Using connecting leads, connect the two 4 mm sockets of the contact plate to the two 4 mm sockets of the input F of the counter S (right socket to ground).

– Connect the counter to the mains by means of the plug-in power supply.

– Arrange soft material around the contact plate as a cushion for the ball when it bounces from the contact plate.

– Suspend the ball from the holding magnet, and align the holding magnet so that the falling ball hits exactly the black impact surface.

– Suspend the ball from the holding magnet anew, and turn the knurled screw back until the ball just adheres to the magnet.

– Adjust the distance h = 100 cm between the lower edge of the ball and the contact plate.

Carrying out the experiment

– Set the operating mode of the counter to $t_{E \rightarrow F}$ by pressing the MODE key several times.

– If necessary, press the contact plate back into the zero position.

– Press the START key so that the associated status LED shines.

– Press the key of the holding magnet adapter quickly to start the free fall of the ball.

– When the ball has hit the contact plate, read the falling time and take it down.

– Reduce the falling distance h by 5 cm by lowering the holding magnet, press the contact plate into its zero position, and reset the counter S to zero by pressing the Start key.

– Suspend the ball anew, and repeat the measurement.

– Reduce the falling distance in steps of 5 cm, each time repeating the measurement.

Measuring example

Table 1: falling times t measured for various falling distances h

$\frac{h}{\text{cm}}$	$\frac{t}{\text{ms}}$	$\frac{h}{\text{cm}}$	$\frac{t}{\text{ms}}$
100	458	50	328
95	448	45	311
90	437	40	292
85	424	35	273
80	411	30	256
75	398	25	233
70	384	20	209
65	374	15	184
60	357	10	149
55	343	5	106

Evaluation

a) Falling distances *h* = 10 cm, 40 cm and 90 cm:

With the values from Table 1 we obtain:

$$\frac{t(40\ \text{cm})}{t(10\ \text{cm})} = \frac{0{,}292\ \text{s}}{0{,}149\ \text{s}} = 1{,}96 \approx 2$$

$$\frac{t(90\ \text{cm})}{t(10\ \text{cm})} = \frac{0{,}437\ \text{s}}{0{,}149\ \text{s}} = 2{,}93 \approx 3$$

For falling distances with the ratio 9 : 4 : 1, the ratio of the falling times is 3 : 2 : 1.

That means, the falling distance is proportional to the square of the falling time.

b) complete evaluation:

Fig. 2 shows the path-time diagram of the ball based on the values from Table 1. The ball experiences a uniform acceleration due to its gravitational force. Therefore the falling distance *h* covered is not a linear function of the time *t*. This is confirmed by a fit of the measured values to a parabola.

A linearization in obtained in Fig. 3 by plotting the falling distance against the square of the falling time (compare Table 2). Eq. (I) is confirmed by the agreement of the fitted straight line through the origin with the measured values. The slope *A* of the straight line gives

$$g = 2 \cdot A = 9{,}43 \frac{\text{m}}{\text{s}^2}$$

Literature value of the acceleration of gravity for Europe:

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

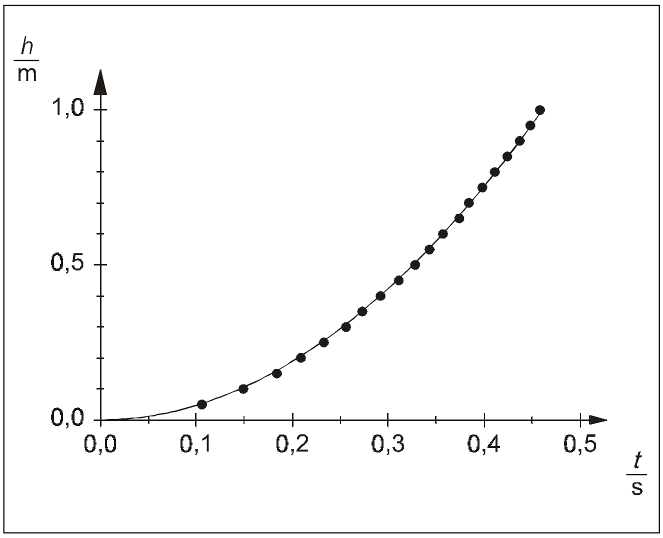

Fig. 2 Path-time diagram of the free fall of the ball

Table 2: Values of t^2 calculated for various falling distances *h*

$\frac{h}{\text{cm}}$	$\frac{t^2}{\text{s}^2}$	$\frac{h}{\text{cm}}$	$\frac{t^2}{\text{s}^2}$
100	0.210	50	0.108
95	0.201	45	0.097
90	0.191	40	0.085
85	0.180	35	0.075
80	0.169	30	0.066
75	0.158	25	0.054
70	0.147	20	0.044
65	0.140	15	0.034
60	0.127	10	0.022
55	0.118	5	0.011

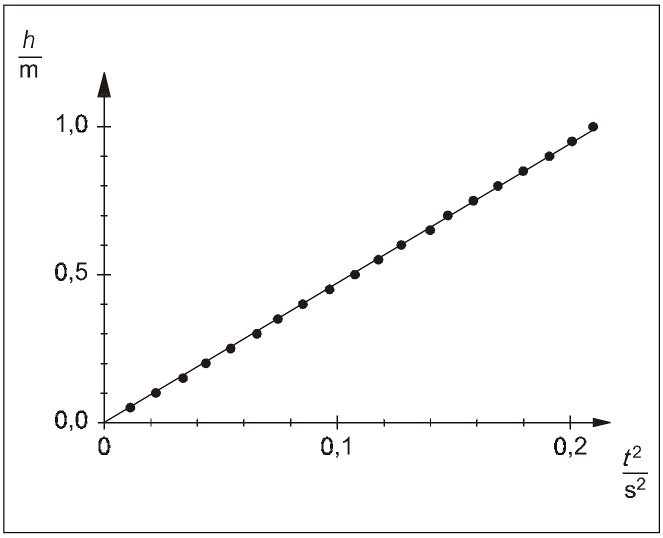

Fig. 3 Falling distance as a function of the square of the falling time

Result

In a free fall, the falling distance *h* is proportional to the falling time *t*. From the factor of proportionality the acceleration of gravity *g* can be calculated.

Supplementary information

In the evaluation, the fact that the ball falls with a delay of a few milliseconds after pressing the Start key was not taken into account. This effect is the greater, the lower the knurled screw of the holding magnet has been turned.

Moreover, the contact plate stops the time measurement after the ball has hit it with a certain delay.

If, for example a time delay of 7.5 ms is taken into account in the present measuring data, the overall agreement of the measured value with the literature value of the acceleration of gravity is even better.

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