Free fall: Time measurement with forked light barrier and the digital counter

Objects of the experiment

- Measuring the times of fall of a ball between the holding magnet and the forked light barrier and the obscuration times at the forked light barrier for recording the path-time-diagram and the velocity-time-diagram point by point.
- Determining the acceleration of gravity.
- Comparing the times of fall and the obscuration times when the measurement is made with two forked light barriers at different distances from the holding magnet.

Principles

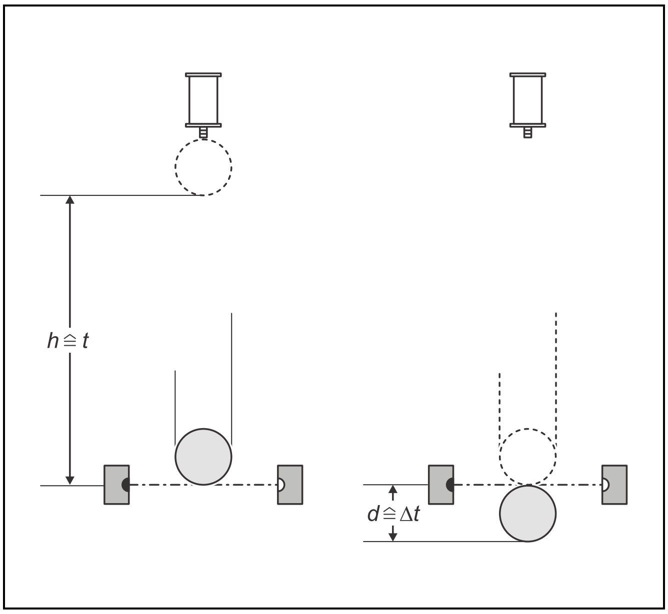
If a body falls in the earth's gravitational field from the height h to the ground, it experiences a constant acceleration g, as long as the distance of fall is short and friction can be neglected. This motion is called free fall. That means free fall is a uniformly accelerated motion.

If the body starts at the time $t = 0$ with the initial velocity $v_0 = 0$, its instantaneous velocity is

$$v(t) = g \cdot t \qquad \text{(I)},$$

and after the time t the body has passed the distance

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



In this experiment, a steel ball is suspended from and electromagnet for studying free fall. As soon as the electromagnet is switched off, the ball, being uniformly accelerated by its gravitational force

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

m: mass of the ball

falls downwards. Electronic measurement starts as soon as the ball is released by interrupting the magnetizing current. The time of fall is measured by one or two light barriers which the ball passes during the fall. The measuring results for different distances of fall are entered as pairs of data into a path-time-diagram. As the ball is at rest when the time measurement starts, the acceleration of gravity g can be determined via Eq. (II).

Apart from the time of fall t, the obscuration time Δt of the forked light barrier is measured. If the diameter d of the ball is known, the instantaneous velocity

$$v = \frac{d}{\Delta t} \qquad \text{(IV)}$$

of the ball can be determined so that a velocity-time-diagram $v(t)$ can be plotted. Thus Eq. (I) can be used as well for determining g.

Fig. 1 Diagram for a measurement of the time of fall t and the obscuration time Δt of a falling ball with a light barrier

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Apparatus

1 steel ball, 16 mm dia.	200 67 288
1 holding magnet with clamp	336 21
1 STE Si-diode N 4007	578 51
1 or 2 forked light barriers	337 46
1 or 2 multicore cables, 6-pole, 1.5 m long	501 16
1 digital counter	575 48
1 stand base, V-shape, 28 cm	300 01
1 stand rod, 150 cm	300 46
1 stand rod, 25 cm	300 41
1 Leybold multiclamp	301 01
1 vertical scale, 1 m long	311 22
1 saddle base	300 11
1 cord, 10 m	309 48
1 set of 6 weights, 50 g each	340 85
Connection leads	

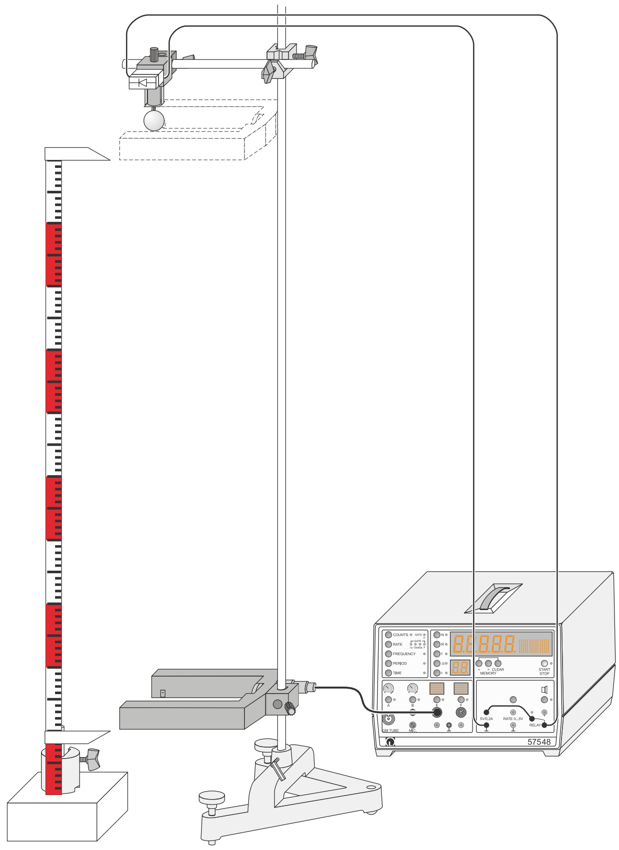


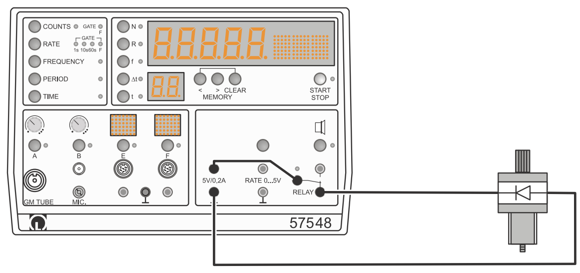
Fig. 2 Experimental setup for measuring the time of fall between the holding magnet and a forked light barrier.

Setup

The experimental setup is illustrated in Fig. 2, the connection of the holding magnet in Fig. 3.

– Align the long stand rod perpendicularly with the adjusting screws of the stand base.
– Attach the forked light barrier(s) with the red LED(s) pointing upwards and connect it (them) to input E (and F) of the digital counter via a 6-pole multicore cable.
– Mount the short stand rod with the Leybold multiclamp and attach the holding magnet so that it points downwards.
– Connect the positive pole of the 5-V output via the relay of the digital counter to one socket of the holding magnet and the ground connection to the other socket. Put the STE Si-diode on the input of the holding magnet (see Fig. 3).
– Switch the digital counter on and press the key TIME (for time of fall in s).
– Press the key E (and the key F) several times until the display ↓⊓ appears in each case.
– Suspend the steel ball from the holding magnet.
– Align the (upper) light barrier and the holding magnet with the steel ball exactly so that the light barrier is interrupted by the lower edge of the steel ball (observe the red LED).
– Set up the vertical scale with pointers and align the upper pointer with the lower edge of the (upper) light barrier as zero of the path.

Fig. 3 Connection of the holding magnet and the digital counter.



Carrying out the experiment

a) Measurement with one forked light barrier:

– For the distance of fall of 90 cm shift the forked light barrier downwards by 90 cm.
– Unscrew the knurled screw of the holding magnet, put the cord through the hole and suspend a weight from it.
– Adjust the arrangement so that the light barrier is interrupted by the cord.
– Remove the cord and screw the knurled screw in again.
– Suspend the steel ball from the holding magnet, and screw the knurled screw back until the steel ball just adheres (mark the knurled screw in order to be able to reproduce the adjustment).
– Suspend the steel ball, and start the measurement with the key START STOP.
– As soon as the ball has fallen down, press the key START STOP once more.
– Read the time of fall *t* in s, and take it down.
– Press the key Δt two times, read the obscuration time Δ*t* in ms, and take it down.

– For the distance of fall of 80 cm slide the forked light barrier upwards by 10 cm, and, if necessary, check the adjustment with the cord.
– Repeat the measurement of the time of fall and of the obscuration time.

– Repeat the measurement for other distances of fall.

b) Measurement with two forked light barriers:

– Fix the upper forked light barrier at a distance of fall of 10 cm and the lower forked light barrier at a distance of fall of 40 cm.
– Unscrew the knurled screw of the holding magnet, put the cord through the hole and suspend a weight from it.
– Adjust the arrangement so that both light barriers are interrupted by the cord.
– Remove the cord and screw the knurled screw in again.
– Suspend the steel ball from the holding magnet, and screw the knurled screw back until the steel ball just adheres (mark the knurled screw in order to be able to reproduce the adjustment).
– Suspend the steel ball, and start the measurement with the key START STOP.
– As soon as the ball has fallen down, press the key START STOP once more.
– Read the time of fall *t* in s, and take it down.
– Press the key Δt two times, read the obscuration time Δ*t* in ms, and take it down.
– Press the call-memory key “<”, read the second pair of data *t* and Δ*t*, and take it down.

– Slide the lower forked light barrier to the distance of fall of 90 cm, and, if necessary, check the adjustment with the cord.
– Repeat the measurement of the time of fall and of the obscuration time.

– Repeat the measurement for the distances of fall of 20 and 80 cm.

Measuring example

a) Measurement with one forked light barrier:

Tab. 1: time of fall *t* and obscuration time Δ*t* for different distances of fall *h*, measured with one forked light barrier

$\frac{h}{\text{m}}$	$\frac{t}{\text{s}}$	$\frac{\Delta t}{\text{ms}}$
0.1	0.160	10.925
0.2	0.216	7.923
0.3	0.259	6.528
0.4	0.297	5.676
0.5	0.330	5.097
0.6	0.360	4.614
0.7	0.388	4.317
0.8	0.414	3.919
0.9	0.438	3.695

b) Measurement with two forked light barriers:

Tab. 2: time of fall *t* and obscuration time Δ*t* for different distances of fall *h*, measured with two forked light barriers

$\frac{h_1}{\text{m}}$	$\frac{t_1}{\text{s}}$	$\frac{\Delta t_1}{\text{ms}}$	$\frac{h_2}{\text{m}}$	$\frac{t_2}{\text{s}}$	$\frac{\Delta t_2}{\text{ms}}$
0.1	0.160	10.823	0.4	0.297	5.295
0.1	0.161	10.920	0.9	0.440	3.746
0.2	0.214	7.925	0.8	0.412	3.883

Evaluation

a) Measurement with one forked light barrier:

Tab. 3: distance of fall *h*, instantaneous velocity *v* (determined according to Eq. (IV) from the diameter *d* and the obscuration time Δ*t*), times of fall *t* and squares of the times of fall

$\frac{h}{\text{m}}$	$\frac{v}{\text{ms}^{-1}}$	$\frac{t}{\text{s}}$	$\frac{t^2}{\text{s}^2}$
0.1	1.47	0.160	0.0256
0.2	2.02	0.216	0.0467
0.3	2.45	0.259	0.0671
0.4	2.82	0.297	0.0882
0.5	3.14	0.330	0.1089
0.6	3.47	0.360	0.1296
0.7	3.71	0.388	0.1505
0.8	4.08	0.414	0.1714
0.9	4.33	0.438	0.1918

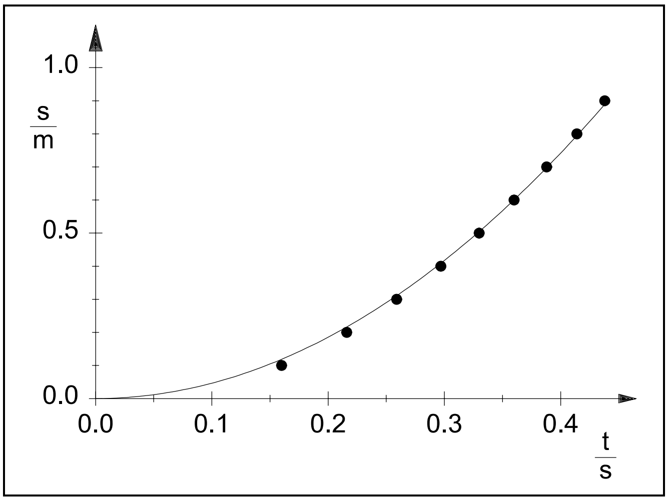


Fig. 4 Path-time-diagram of free fall.

Fig. 4 shows the path-time-diagram of the ball based on the data from Table 3. The ball experiences a uniform acceleration by its gravitational force. Therefore the distance *h* passed in the fall is not a linear function of the time *t*, as is confirmed by fitting to a parabola.

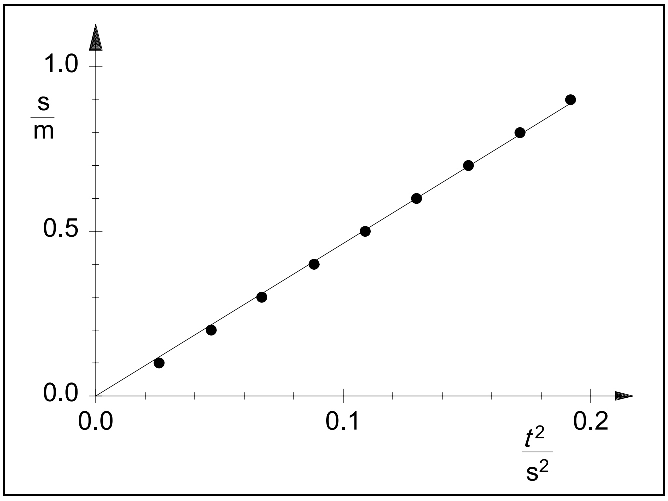


Fig. 5 The distance of fall as a function of the square of the time of fall

The linarisation in Fig. 5 is obtained by plotting the distance of fall against the square of the time of fall. The agreement of the fitted straight line through the origin with the measured values confirms Eq. (II). From the slope of the straight line *A*

$$g = 2 \cdot A = 9.27\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

is obtained.

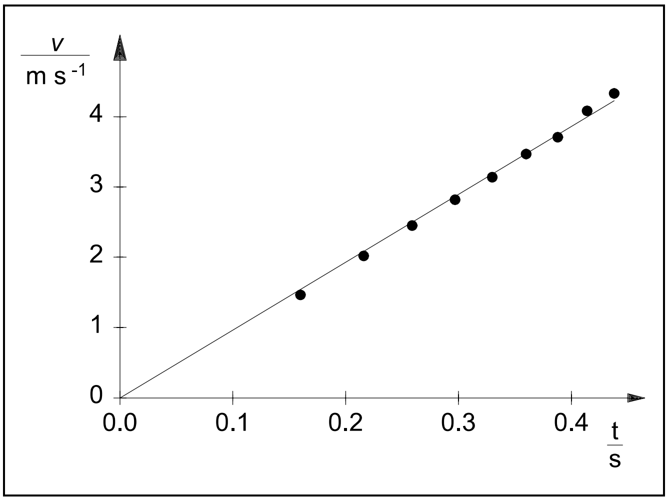


Fig. 6 Velocity-time-diagram of free fall.

Fig. 6 shows the velocity-time-diagram of the ball based on the data from Table 3. In agreement with Eq. (I) the velocity *v* is proportional to the time t, as is confirmed by a fit of a straight line though the origin to the measured values. From the slope *A* of the straight line

$$g = A = 9.65\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

is obtained.

Value of the acceleration of gravity quoted in the literature (for Europe):

$$g = 9.81\ \frac{m}{s^2}$$

b) Measurement with two forked light barriers:

Tab. 4: Distance of fall *h*, instantaneous velocity *v* (determined according to Eq. (IV) from the diameter *d* and the obscuration time Δt), times of fall *t* and squares of the times of fall

$\frac{t_1}{\mathrm{s}}$	$\frac{h_1}{\mathrm{m}}$	$\frac{v_1}{\mathrm{ms^{-1}}}$	$\frac{t_2}{\mathrm{s}}$	$\frac{h_2}{\mathrm{m}}$	$\frac{v_2}{\mathrm{ms^{-1}}}$	$\frac{t_2}{t_1}$	$\frac{h_2}{h_1}$	$\frac{v_2}{v_1}$
0.16	0.1	1.5	0.30	0.4	3.0	1.9	4	2.0
0.16	0.1	1.5	0.44	0.9	4.3	2.8	9	2.9
0.21	0.2	2.0	0.41	0.8	4.1	2.0	4	2.1

Table 4 shows a compilation of the values measured in pairs for the uniformly accelerated motion of the ball. The ratio of the distances of fall is equal to the square of the velocities and the times of fall, respectively.

For determining the acceleration of gravity, the measuring results can be evaluated graphically as in part a.

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