Free fall

Recording and evaluating with VideoCom

Objects of the experiments

- Recording the path-time diagram of free fall with VideoCom.
- Determining the gravitational acceleration *g*.

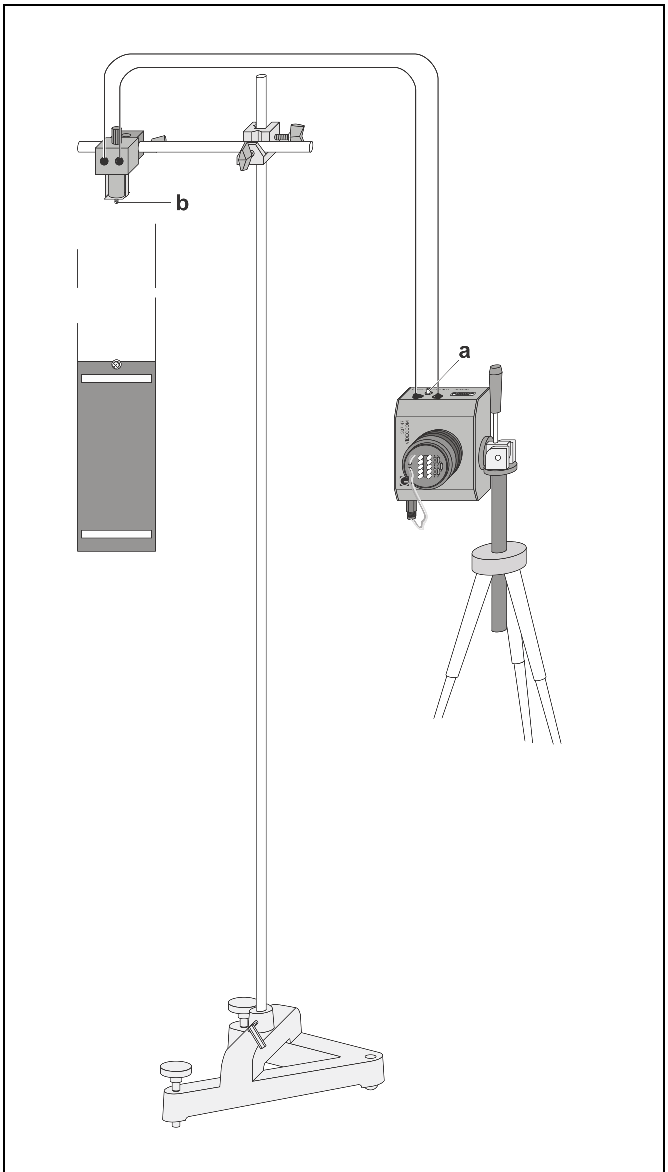

Fig. 1 Experimental setup for recording free fall with VideoCom.

Principles

If a body falls in the gravitational field of the earth to the ground from a height *h*, it is subject to a constant acceleration *g* as long as the distance of fall is small and friction can be neglected. This motion is called free fall. Thus free fall is an example of a uniformly accelerated motion.

If the initial velocity of the body at time $t = 0$ is $v_0 = 0$, the instantaneous velocity is

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

and after the time *t* the body has covered the distance

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

In the experiment, the falling of a body is recorded with the single-line CCD camera VideoCom. The camera illuminates a retroreflecting foil attached to the falling body with LED flashes and images the reflected flashes with a camera lens to a CCD line with 2048 pixels (CCD: charge-coupled device). The current position of the falling body is transferred to a computer via a serial interface up to 80 times per second. A computer program enclosed with VideoCom displays the entire motion of the falling body as a path-time diagram and enables further evaluation of the measured data. In particular the velocity

$$v(t) = \frac{s(t + \Delta t) - s(t - \Delta t)}{2 \cdot \Delta t} \quad \text{(III)}$$

and the acceleration

$$a(t) = \frac{v(t + \Delta t) - v(t - \Delta t)}{2 \cdot \Delta t} \quad \text{(IV)}$$

can be activated with a mouse click, whereby several time intervals Δt can be selected.

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Apparatus

1 VideoCom	337 47
1 plug-in unit 230 V / 12 V∼/ 20 W	562 791
1 camera tripod	300 59
1 falling body for VideoCom	337 472
1 holding magnet	336 21
1 stand base, V-shape, 28 cm	300 01
1 stand rod, 25 cm	300 41
1 stand rod, 150 cm	300 46
1 Leybold multiclamp	301 01
4 connecting leads, 200 cm	501 38

additionally required:

1 PC with Windows 95/NT or higher version

Setup and carrying out the experiment

The experimental setup is illustrated in Fig. 1.

Setting up the arrangement for the free fall:

– Mount the holding magnet to the stand material as shown in Fig. 1, direct it downwards, and connect it to VideoCom with connecting leads (see instruction sheet for VideoCom).

Setting up VideoCom:

– Screw VideoCom onto the camera tripod so that it is aligned vertically, and set it up at a distance of approx. 3 m from the arrangement for the free fall.
– Align VideoCom at half the distance of fall as parallel as possible to the path of fall. See to it that the level is aligned perpendicularly.
– Supply VideoCom with voltage via the plug-in unit, and connect it to the PC with a serial input (e. g. COM1).
– If necessary, install the VideoCom software, call the program “VideoCom Motions”, and select the desired language and the serial interface (see instruction sheet for VideoCom).

Aligning VideoCom:

– Suspend the falling body for VideoCom from the holding magnet, setting the voltage of the holding magnet as low as possible with the adjusting pin **(a)** at the VideoCom housing so that the falling body just adheres to the magnet.
– Turn the iron core of holding magnet back with the knurled screw **(b)** until the falling body is suspended vertically.
– Click “Intensity Test” in the program “VideoCom Motions”.
– Slightly darken the room to reduce the background.
– Align VideoCom so that on the LC display on the camera housing or on the screen two peaks are seen at the right end; check the perpendicular alignment.
– Remove interfering light or reflections so that no other peaks are seen.
– Improve the alignment further until the ratio of the intensities of the peaks and the background is greater than 5 to 1.

Calibrating VideoCom and recording the path-time diagram:

– Call the menu “Settings/Path Calibration” with the button or the key F5.
– Enter the values 0.2 m for the first position and 0 m for the second position of the two retroreflecting foils in the register “Path Calibration”.
– Click the button “Read Pixels from Display” and activate “Apply Calibration”.
– Call the menu “Settings/Path Calibration” once more, and select the following settings in the register “Measuring Parameters”.

Δt	12.5 ms (80 fps)
Flash	Auto
Smoothing	Maximum (8*dt)
Measurement Stop	At End of Path s = 1 m

– Start the measurement with the button or the key F9 and record the falling.
– Next click the button “Suggest Linearization” in the register “Linearization” of the menu “Settings/Path Calibration”.
– If an angle $\alpha > 1°$ is indicated, t the alignment of VideoCom is not yet sufficiently perpendicular (see Fig. 2):
– Reject the linearization with the button “Cancel”.
– Improve the perpendicular alignment of VideoCom.
– Delete the old measured values with the button or the key F4, record the falling of the falling body once more, and determine the angle α anew.
– Repeat the procedure until $\alpha < 1°$ is displayed; then activate “Apply Linerization” and accept the indicated distortion δ.
– Store the measured values with or F2 using a telling filename.

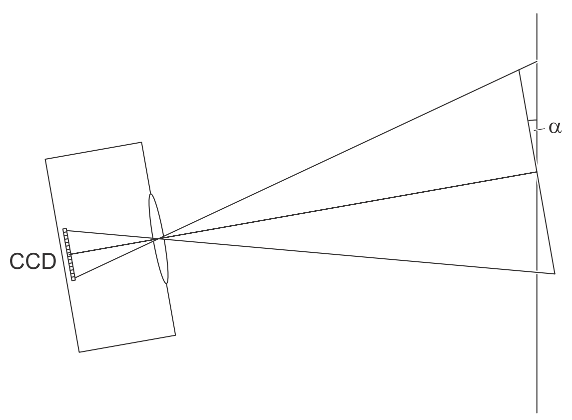

Fig. 2 Diagram defining the angle α between VideoCom and the path of fall.

– Repeat the path calibration, click the button “Read Pixels from Table” in the register “Path Calibration”, activate “Apply Calibration”, and confirm with “OK”.
– Click the measured values column “s1/m” with the right mouse button, and choose “Delete Column” from the menu that appears.
– Store the measured values with or F2 using a telling filename.

Measuring example and evaluation

Fig. 3 shows the recorded path-time diagram of the falling body. The covered path *s* does not depend on the time *t* linearly. The time dependence corresponds to a parabola (cf. (I)).

By fitting a parabola A*x^2+B*x+C the gravitational acceleration is obtained. It is

$$g = 2 \cdot A = 9.82\ \frac{\text{m}}{\text{s}^2}$$

The instantaneous velocity *v*, which is calculated from the measured values by clicking the register “Velocity”, is a linear function of time (see Fig. 4 and cf. (II)). From the slope of the fitted line A*x+B the gravitational acceleration is obtained:

$$g = A = 9.82\ \frac{\text{m}}{\text{s}^2}$$

If the instantaneous acceleration *a* is calculated as a function of time by clicking the register “Acceleration”, constant values are obtained within the accuracy of measurement (see Fig. 5). Their mean value is

$$g = 9.82\ \frac{\text{m}}{\text{s}^2}$$

Value of the gravitational acceleration in Europe quoted in the literature:

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

Supplementary information

The fitting result $B = -0.1\ \text{m s}^{-1}$ in Fig. 4 and Fig. 5 corresponds to a (physically meaningless) negative initial velocity of the falling body. Actually the recording of the measured values was started somewhat earlier than the motion of the falling body because the holding magnet released the falling body with a slight delay.

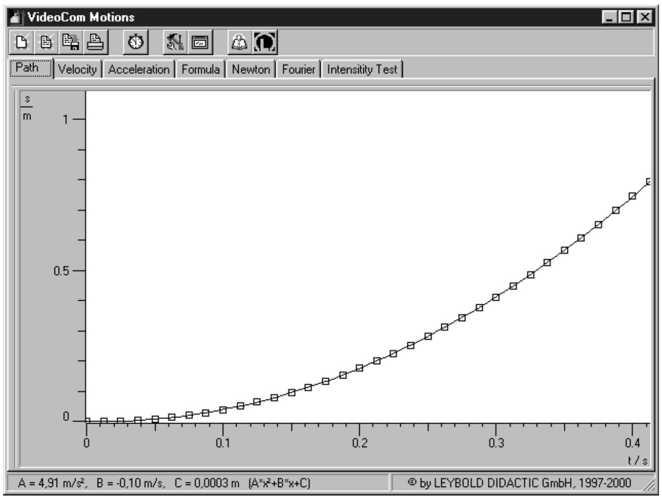

Fig. 3 Path-time diagram of the falling body.

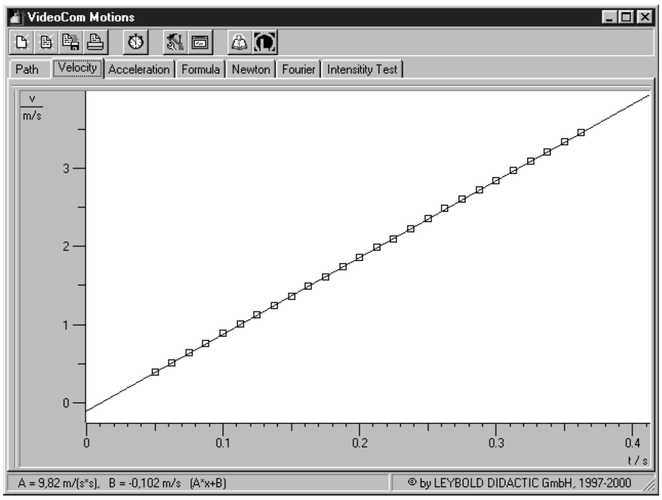

Fig. 4 Velocity-time diagram of the falling body.

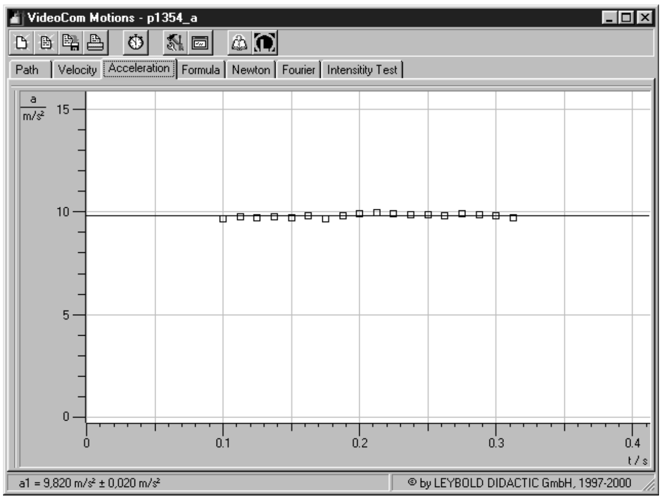

Fig. 5 Acceleration-time diagram of the falling body.