Free fall with "measure Dynamics" (Item No.: P2130780)

Curricular Relevance

| Area of Expertise: Physics | Education Level: University | Topic: Mechanics | Subtopic: Motion in one Dimension | Experiment: Free fall with "measure Dynamics" |
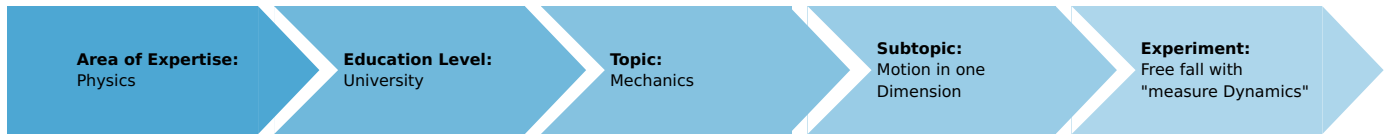
Difficulty	**Preparation Time**	**Execution Time**	**Recommended Group Size**
Easy	10 Minutes	20 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Linear motion due to constant acceleration, law of free fall, gravitational acceleration

Introduction

Overview

The aim of this experiment is to film a high-speed video of a sphere falling from the height of fall h. The "measure Dynamics" software is used for the graphical representation of the distance as a function of time t and also as a function of the square of time t^2 as well as the graphical representation of the velocity v and acceleration a as a function of time t. Then, the measured values are used to determine the gravitational acceleration g.
The velocity and acceleration are then integrated into the video, followed by a discussion of the results.

Figure 1: Experiment set-up

Equipment

Position No.	Material	Order No.	Quantity
1	Release unit	02502-00	1
2	Plate holder	02062-00	1
3	Support base DEMO	02007-55	1
4	Right angle clamp expert	02054-00	1
5	Meter scale, l = 1000 mm	03001-00	1
6	Support rod, stainless steel, 1000 mm	02034-00	1
7	Software "Measure Dynamics", single user	14440-61	1

Additional equipment
High-speed camera, tripod, computer

Tasks

1. Determination of the gravitational acceleration by way of the distance-time law for the free fall.

2. Determination of the gravitational acceleration by way of the velocity-time law for the free fall.

3. Determination of the gravitational acceleration.

4. Integration of the velocity and acceleration into the video.

Set-up and procedure

Set the falling sphere apparatus up as shown in Figure 1. Position the release unit at the selected height. Install the release unit so that the sphere that is held in the release unit faces the camera. In addition, it must be ensured that the sphere cannot fall down onto the support base. It may be necessary to change the position of the release unit or support rod.
Position a scale vertically next to the experiment set-up by way of a support system. The support system consists of a support base, support rod, right-angle clamp, and universal clamp.
In terms of the video that will be recorded, the following must be taken into consideration concerning the setting and positioning of the high-speed camera:

- Since the velocity will change strongly, the camera must be operated with approximately 210 fps in the high-speed mode.

- Select a light-coloured, homogeneous background.

- Provide additional lighting for the experiment.

- The experiment set-up should be in the centre of the video. To ensure this, position the video camera on a tripod centrally in front of the experiment set-up.

- The experiment set-up should fill the vertical video image as completely as possible.

- The optical axis of the camera must be parallel to the experiment set-up.

Then, the video recording process and the experiment can be started by actuating the release unit.
The air drag can be neglected.

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Theory and evaluation

Theory

When an object with the mass m is accelerated from the state of rest in a constant gravitational field (gravitational force $F = m \cdot g$), it performs a linear motion. If the system of coordinates is selected in such a way that the y-axis indicates the direction of motion and if the resulting unidimensional equation of motion is solved, the following results:

$$m \frac{d^2 h(t)}{dt^2} = m \cdot g$$

For the initial conditions

$$h(0) = 0$$

$$\frac{dh(0)}{d(t)} = 0$$

we obtain the coordinate h as a function of time t (see Figure 2):

$$h(t) = \frac{1}{2} g t^2 \tag{1}$$

and for the velocity v:

$$v = g \cdot t \tag{2}$$

Evaluation

Transfer the video that has been recorded to the computer. Then, start "measure Dynamics" and open the video under "File" – "Open video ...". Mark the start of the experiment ("Start selection" and "Time zero") and the end of the experiment ("End selection") in the video for further analysis via the menu line above the video. The experiment starts when the sphere starts to fall and it ends when the sphere hits the floor. Mark the height of fall that is visible in the video under "Video analysis" – "Scaling ..." – "Cali-bration" with the aid of the scale that is included in the experiment. Enter the resulting length into the cor-responding input field. Enter the frame rate that has been set for the experiment (in this case 210) under "Change frame rate", position the origin of the system of coordinates on the start point of the sphere un-der "Origin and direction", and turn it by right-clicking so that the positive y-axis points in the direction of fall of the sphere.

Then, the actual motion analysis can be started under "Video analysis" – "Automatic analysis" or "Man-ual analysis". It is important to select a suitable step size for the analysis, since the sphere will not move sufficiently between two successive individual frames. Here, a step size of approximately "6" should be selected. For the automatic analysis, we recommend selecting "Motion and colour analysis" on the "Analysis" tab. Under "Options", the automatic analysis can be optimised, if necessary, e.g. by changing the sensitivity or by limiting the detection radius. Then, look for a film position in the video where the sphere is perfectly visible. Click the sphere. If the system recognises it, a green rectangle appears and the analysis can be started by clicking "Start".

If the automatic analysis does not lead to any satisfying results, the series of measurements can be cor-rected under "Manual analysis" by manually marking the object that is to be analysed.

Task 1: Determination of the gravitational acceleration by way of the distance-time law for the free fall.

In order to display the curve of the distance covered as a function of time, select "Display" and "Dia-gram", click "Options", delete all of the already existing graphs, and select the graphs t (horizontal axis) – y (vertical axis) (the height of fall m will be named y hereinafter). This leads to:

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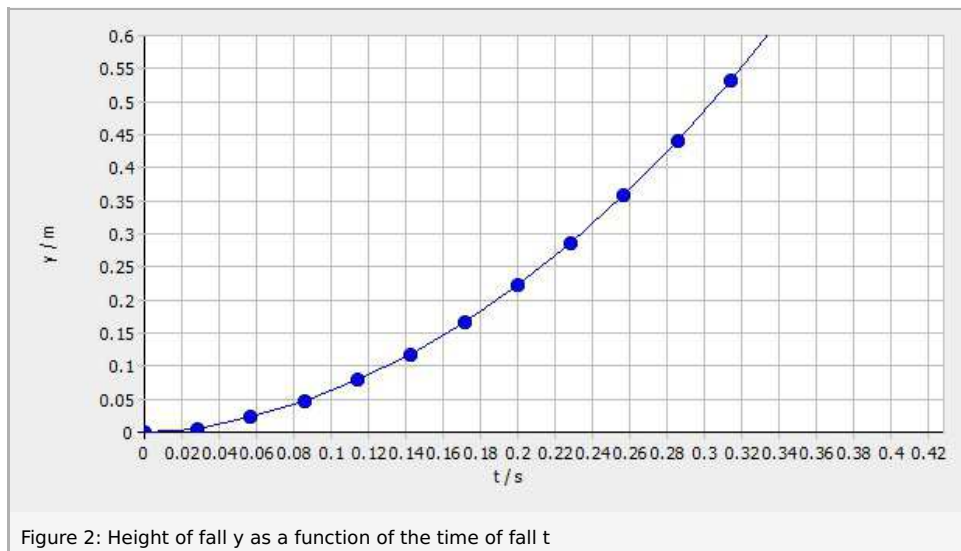Fax: +49 551 604 - 107

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Figure 2: Height of fall y as a function of the time of fall t

As it could have been expected from equation (1), Figure 2 shows a quadratic relationship. In order to examine it in greater detail, it is advisable to consider the dependence of the distance covered on the square of the time. In order to be able to visualise this is graphical form, the worksheet must be extended by clicking "New column" in the table menu line. Then, enter the square of the time "t2" (unit: "s^2"; for-mula: "t^2") into the new column. As a result, the t2-y diagram can be displayed in the same way as the t-y diagram. The following results:
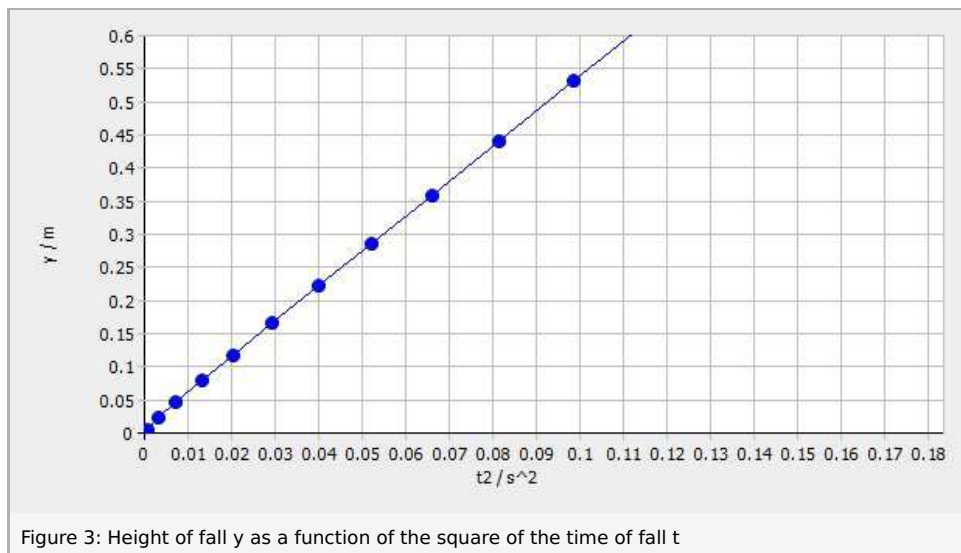

Figure 3: Height of fall y as a function of the square of the time of fall t

As shown in Figure 3, the height of fall is linear with regard to the square of the time of fall. Clicking "Options" in the menu line of the diagram and selecting the tab "Linear regression" will add a regression line to the diagram and the corresponding function will be displayed in the menu window. Since the gradient of the curve (5.32) equals 1/2 g based on the theory (equation 1), the following results:

g = 10.62 m/s². (Literature value: 9.81 m/s²)

This means that the experimental value of the gravitational acceleration is close to the literature value, thereby confirming the theory.

Task 2: Determination of the gravitational acceleration by way of the velocity-time law for the free fall.

In the same manner, it is also possible to visualise the velocity in the y direction as a function of time.
Using the same procedure as for task 1, the function that is shown in Figure 4 leads to a regression line with a gradient of 10.15. According to the theory (equation (2)), this corresponds to the absolute value of the gravitational acceleration with the unit m/s². This means that the experimental value of the gravita-tional acceleration corresponds approximately to the literature value of the gravitational acceleration of 9.81 m/s².

Task 3: Determination of the gravitational acceleration.

In the same manner, it is also possible to visualise the acceleration in the y-direction as a function of time.
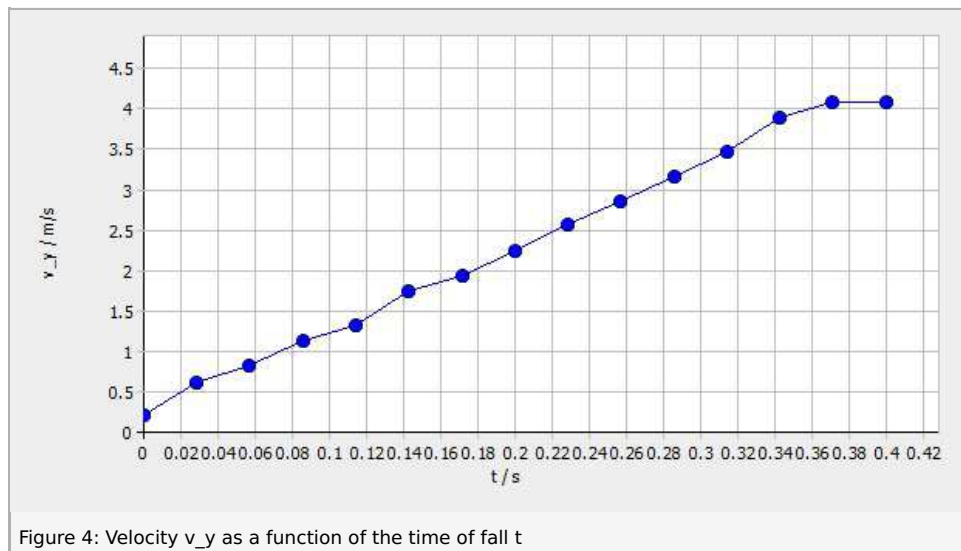
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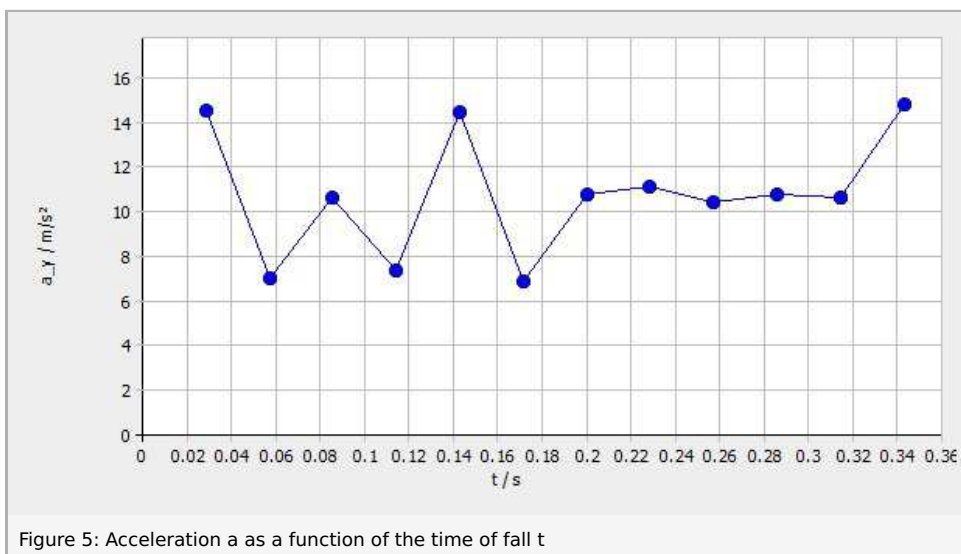Figure 4: Velocity v_y as a function of the time of fall t

Figure 5: Acceleration a as a function of the time of fall t

What would be expected is a horizontal line. Figure 5 shows that the values fluctuate strongly, particularly at the beginning. This is due to the fact that the sphere moves only a little at the beginning and that the sphere cannot be marked in a sufficiently precise manner due to the limited resolution of the highspeed video. On average, however, this error eliminates itself. The mean value of the measuring points is 10.79. This corresponds to the absolute value of the gravitational acceleration that has been determined in this experiment with the unit m/s² and it is close to the literature value (9.81 m/s²).

Task 4: Integration of the velocity and acceleration into the video.

The video becomes even clearer when the velocity and acceleration are integrated. To do so, open "Filters and labels ..." under "Display", click "Add new filter", and select the "Velocity arrow" or the "Acceleration arrow". Under "Filter configuration", select the tab "Limitations" and "Filter visible". Then, select "0" as the "Start selection" and "-1" as the "End selection" under "Cutting (timeline)". On the tab "Icon", select "Arrow with foot" as the icon, since the velocity and acceleration are both vectors. Set the "Trace" length and "Step" to "1". On the "Data source" tab, select the table of the sphere under "Starting point" and "0" as the "Time increment". Select "Fixed value" for the "x- and y-coordinates" and position it so that the vectors are clearly visible. Then, select a suitable "Stretch factor". Select the table of the sphere once again under "End point" and set the "Time increment" to "0". Select "Fixed value" as the "x-coordinate" and set it to "0", and select "v_y" or "a_y" as the "y-coordinate". Then, activate "User-defined scale". The arrows can be labelled under "Display" – "Paint ..." – "Text". "Export" – "Picture series ..." then leads to:

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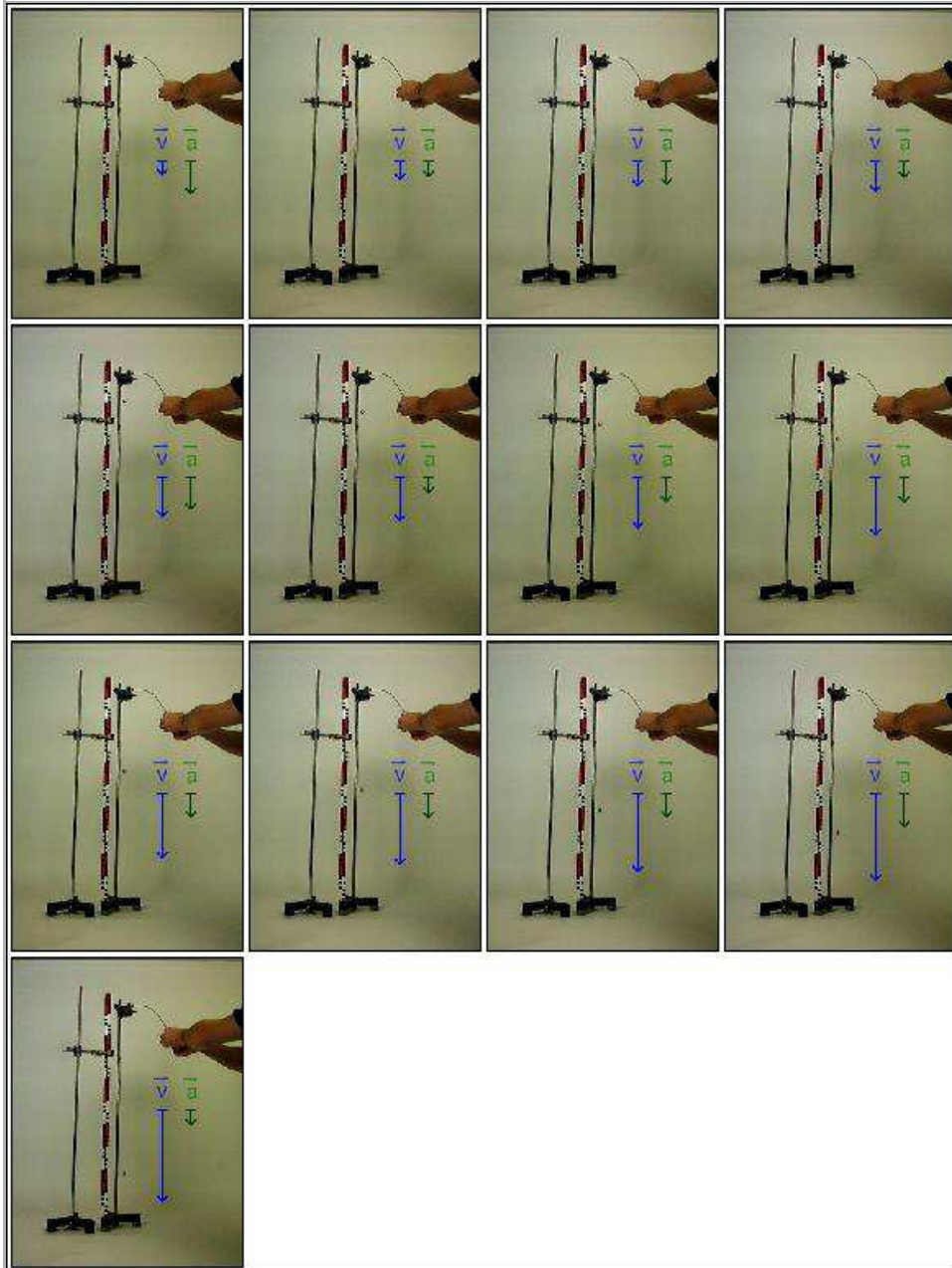Fax: +49 551 604 - 107

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Figure 6: Multiple pictures for integrating the velocity and acceleration into the video

Figure 6 shows the following: While the velocity increases during the fall of the sphere (this is indicated by the increasing length of the velocity arrow), the acceleration arrow remains nearly constant (there is a slight "wobble" of the acceleration arrow due to the low resolution of the high-speed video). This clearly confirms our expectations that were based on the theory.

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