Name:

Study group No.: 2

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# Experiment No.: 2

# Free fall study and acceleration due to gravity measurement

## 2.1 Purpose of experiment

1. Measure the free fall time of two steel balls of various diameters.
2. Create a graph with the dependence of the height on the free fall height.
3. Calculate the acceleration due to gravity g and its uncertainty. Compare the result with the accepted value for Prague.

## 2.2 List of apparatus

1. Variant of Atwood's machine, basic resolution: 1 [cm]
2. Timer, basic resolution: 1 [ms]
3. Micrometer, basic resolution: 0.01 [mm]
4. Laboratory weight, basic resolution, 0.1 [g]

## 2.3 Data

Steel ball1: $m_1$ = 16.8 [g], $d_1$ = 15.99 [mm]

Steel ball2 $m_2$ = 18.9 [g], $d_2$ = 16.67 [mm]

Steel ball1:

| h[m] | t1[s] |
|---|---|
| 0,1 | 0,142 |
| 0,2 | 0,201 |
| 0,3 | 0,247 |
| 0,4 | 0,285 |
| 0,5 | 0,319 |
| 0,6 | 0,349 |
| 0,7 | 0,377 |
| 0,8 | 0,403 |
| 0,9 | 0,428 |
| 0,95 | 0,44 |
| 5,45 | 3,191 |
| 0,545 | 0,3191 |

Steel ball2:

| h[m] | t2[s] |
|---|---|
| 0,1 | 0,143 |
| 0,2 | 0,202 |
| 0,3 | 0,247 |
| 0,4 | 0,285 |
| 0,5 | 0,318 |
| 0,6 | 0,35 |
| 0,7 | 0,377 |
| 0,8 | 0,403 |
| 0,9 | 0,428 |
| 0,95 | 0,44 |
| 5,45 | 3,193 |
| 0,545 | 0,3193 |

## 2.4 Computation outline

We measured free fall time from various heights ten times for each ball. We created one graph for each ball (graph 1 and graph 2), where x-axis represents time and y-axis represents height.

Then we found dependence:

$$h = f(t)$$

with the method of least squares where function f is second order polynomial:

$$h = a_2 t^2 + a_1 t + a_0$$

where coefficient $a_0$ is difference between real height of the free fall and measured value set on the centimeter scale, coefficient $a_1$ is initial velocity which in our case can be considered almost zero thanks to the releasing mechanism and coefficient $a_2$represents the free fall acceleration.

Because the real height depends on the ball diameter, it is hard to measure the real height on the centimeter scale. This difference affects the coefficient $a_0$.

To find coefficients and uncertainty we use tool on this page: http://herodes.feld.cvut.cz/mereni/grafy-new/grafy.php.

The first ball coefficients we obtained are:

$$a_2 = 4.880\, m \cdot s^{-2}$$

$$a_1 = 0.017\, m \cdot s^{-1}$$

$$a_0 = -0.001\, m$$

The second ball coefficients we obtained are:

$$a_2 = 4.840\, m \cdot s^{-2}$$

$$a_1 = 0.045\, m \cdot s^{-1}$$

$$a_0 = -0.006\, m$$

While we were using the tool for the method of the least squares we were said to fill in form with values and uncertainty. We estimated the uncertainty with the uncertainty of apparatus. But$\frac{\chi^2}{\nu}$was not close to one, therefore our estimation of uncertainty is overestimated.

Because of that we filled the space for the uncertainty with number one and let the tool calculate the result. The result contained the uncertainty $\sqrt{\frac{\chi^2}{\nu}}$that is the uncertainty of each measurement. We filled fields for measured values once again and this time we filled in the uncertainty we gained before.

The acceleration uncertainty of the first ball is:

$$\sigma_{a_2} = 0.041\, m \cdot s^{-2}$$

And the acceleration uncertainty of the second ball is:

$$\sigma_{a_2} = 0.041\, m \cdot s^{-2}$$

We know that the height of free fall may be calculated by the formula:

$$h = \frac{1}{2} g t^2 + v_0 t + h_0$$

where $g$ is gravity $v_0$ is initial velocity and $h_0$ is difference between measured height and real height of the free fall.

We compared formula for calculation of the height of the free fall with second order polynomial of height dependence on time we obtained these formulas for gravity $g$ and its uncertainty $\sigma_g$:

$$g_i = 2a_2$$

$$\sigma_{g_i} = 2\sigma_{a_2}$$

We calculated the gravity and its uncertainty for each ball:

$$g_1 = (9.760 \ \pm 0.082)\, m \cdot s^{-2}$$

$$g_2 = (9.69 \ \pm 0.12)\, m \cdot s^{-2}$$

We obtained the resulting gravity by calculating this formula:

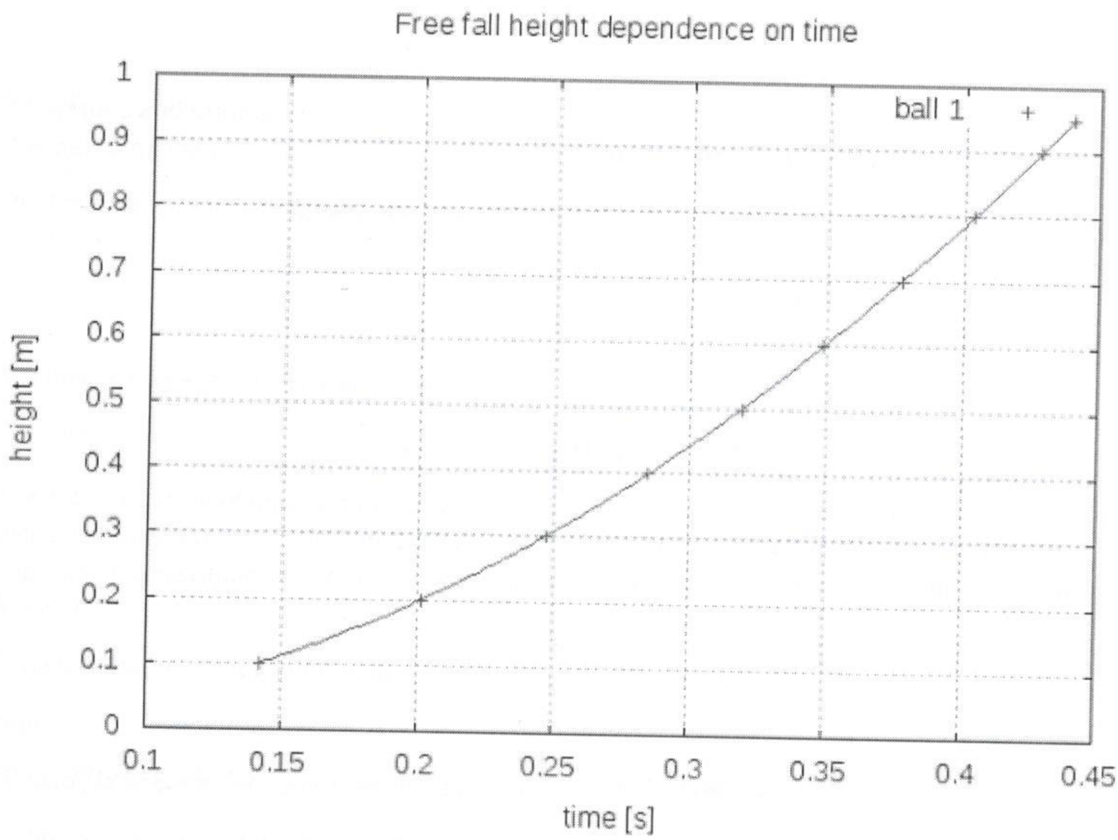
$$g = \bar{g} \pm \sigma_g$$

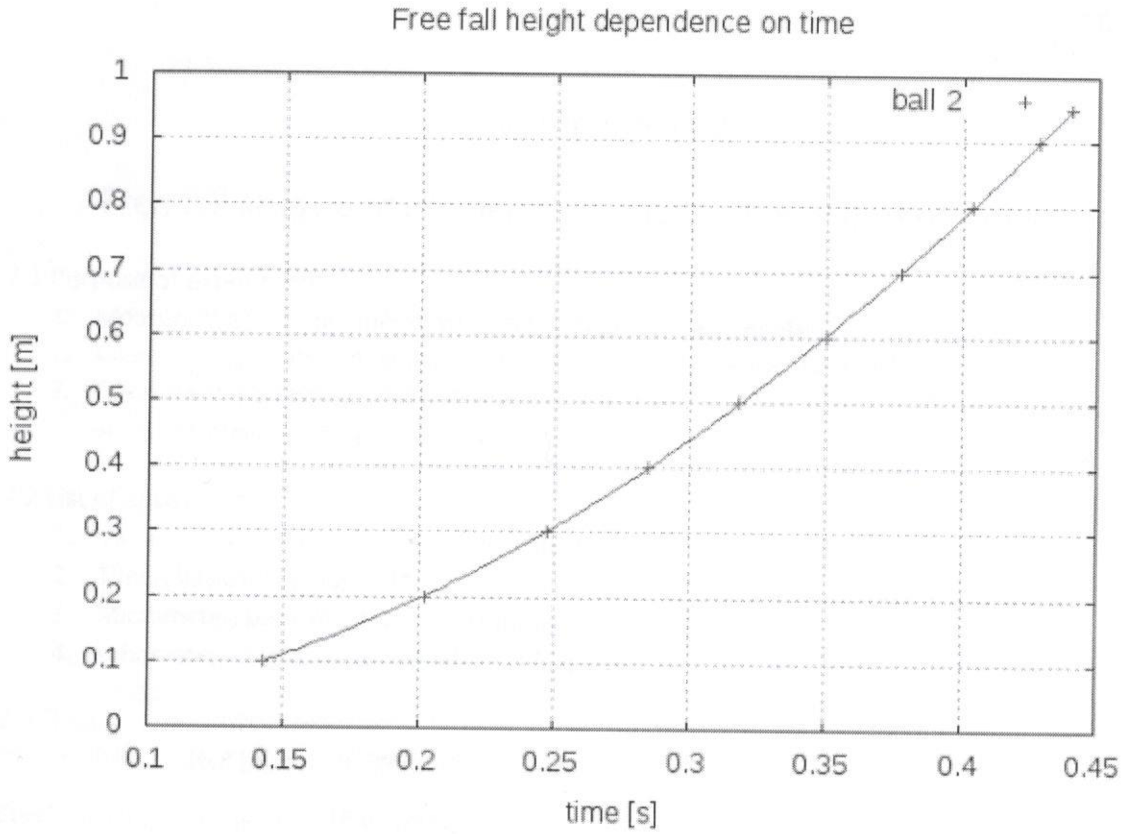
Where $\bar{g}$ is average of $g_1$ and $g_2$ and $\sigma_g$ is combined uncertainty

$$\sigma_g = \sqrt{u_A^2(\bar{g}) + \sigma_{g_1}^2 + \sigma_{g_2}^2}$$

$$\sigma_g = \sqrt{0.0008 + 0.006724 + 0.0144}\, m \cdot s^{-2} = 0.148\, m \cdot s^{-2}$$

2.5 Graphs






## 2.6 Results and outlines

We measured the free fall time of two steel balls of various diameters.

Our task was to calculate gravity and this is the results we obtained:

$$g_1 = (9.760 \pm 0.082)\ m \cdot s^{-2}$$

$$g_2 = (9.69 \pm 0.12)\ m \cdot s^{-2}$$

The final average gravity we calculated is:

$$g = (9.72 \pm 0.15)\ m \cdot s^{-2}$$

The accepted value of gravity for Prague is $g = 9.81373\ m \cdot s^{-2}$. Because this value is in range of our result we can say that we calculated the gravity right. Sources of uncertainty may be that we neglected the resistance of air or the inaccuracy of human eye while we were setting the height of free fall.

We also observed that various weights of ball have no effect on result.

Source:

[1] http://aldebaran.feld.cvut.cz/vyuka/physics_I_oi/Labs/2_Free_fall_study.pdf

[2] http://aldebaran.feld.cvut.cz/vyuka/physics_I_oi/Least_squares.pdf

[3] https://cs.wikipedia.org/wiki/T%C3%ADhov%C3%A9_zrychlen%C3%AD