

A0. Determination of the density of a solid body

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The aim of the exercise is to become familiar with basic physical instruments and the method of physical measurement, as well as to carry out calculations of the determined physical quantity and the measurement error.

The density of a body (also known as specific mass) is the ratio of the body's mass to its volume.:

$$\rho = \frac{m}{V} \quad (1).$$

When the mass distribution in a given body is not uniform, density is calculated as the derivative of mass with respect to volume: $\rho = dm/dV$. The density of a body is expressed in kg/m^3 .

In this exercise, we determine the unknown density of a body that has a regular cylindrical shape and a uniform mass distribution. Therefore, in this case, we can use formula (1). To do this, we weigh the tested body using a laboratory balance, then – using a caliper – we measure the dimensions of the cylinder, i.e., its height h and base diameter d , in order to calculate the volume of the cylinder using formula: $V = \frac{\pi}{4} d^2 \cdot h$ (2).

By substituting formula (2) into (1), we finally obtain the following expression for the density of the body under examination:

$$\rho = \frac{4m}{\pi d^2 \cdot h} \quad (3)$$

Measuring Protocol

Equipment: caliper, laboratory balance.

Measuring steps:

1. Weigh the tested body using a laboratory balance. Convert the mass value read in grams [g] to kilograms [kg] and record it in the table. Also enter the mass measurement error Δm , which is the reading accuracy of the balance, also expressed in kilograms [kg].
2. Measure the diameter d of the cylinder five times by placing the caliper at different heights of the cylinder. Record the measurement results in the table, expressing them in meters [m].
3. Using the caliper, measure the height h of the cylinder five times. Record the measurement results in the table, expressing them in meters [m].

Data analysis and calculations

1. Calculate the average values of the diameter d_{avg} and height h_{avg} of the cylinder.
2. The errors Δd_{avg} and Δh_{avg} , associated with the average values of d_{avg} and h_{avg} , obtained from $n = 5$ repeated measurements, should be calculated as three times the standard deviation of the mean (SD), i.e:

$$\Delta d_{avg} = 3 \cdot SD = 3 \sqrt{\frac{\sum_{i=1}^n (d_{avg} - d_i)^2}{n(n-1)}} \quad \text{oraz} \quad \Delta h_{avg} = 3 \cdot SD = 3 \sqrt{\frac{\sum_{i=1}^n (h_{avg} - h_i)^2}{n(n-1)}}.$$

After appropriate rounding, present the calculated errors together with the corresponding average values in the following form: $d_{avg} \pm \Delta d_{avg}$ and $h_{avg} \pm \Delta h_{avg}$.

- Calculate the density of the tested body ρ by substituting the mass value m and the rounded average values of d_{avg} and h_{avg} into formula (3).
- The estimation of the measurement error $\Delta\rho$ for the determined density of the tested body is carried out using the logarithmic method, since the function given by formula (3) can be transformed into a product of numbers and powers of its individual variables:

$$\rho = \frac{4m}{\pi d^2 \cdot h} = \frac{4}{\pi} m^1 d^{-2} h^{-1},$$

and in this case, the relative error of the density is expressed by the following formula:

$$\frac{\Delta\rho}{\rho} = \left| \frac{\Delta m}{m} \right| + \left| \frac{-2\Delta d_{avg}}{d_{avg}} \right| + \left| \frac{-\Delta h_{avg}}{h_{avg}} \right|$$

where Δm , Δd_{avg} and Δh_{avg} represent the measurement errors of the mass, and the averaged values of the diameter and height of the cylinder, respectively.

By multiplying the relative error $\frac{\Delta\rho}{\rho}$ by the previously calculated density value ρ , calculate the absolute error $\Delta\rho$.

After appropriately rounding the calculated values, present the result with the absolute error in the following form: $\rho \pm \Delta\rho$. The obtained result is then compared with the tabulated density value of the same substance.

Table*material:**Temperature: T =[°C]*

m [kg]					
Δm [kg]					
d [m]	1 measurement	2 measurement	3 measurement	4 measurement	5 measurement
d_{avg} [m]					
Δd_{avg} [m]					
$(d_{avg} \pm \Delta d_{avg})$ [m]					
h [m]	1 measurement	2 measurement	3 measurement	4 measurement	5 measurement
h_{avg} [m]					
Δh_{avg} [m]					
$(h_{avg} \pm \Delta h_{avg})$ [m]					
ρ [kg/m ³]					
$\Delta\rho$ [kg/m ³]					
$(\rho \pm \Delta\rho)$ [kg/m ³]					