Theoretical Introduction

Experiment "A R C H I M E D E S"

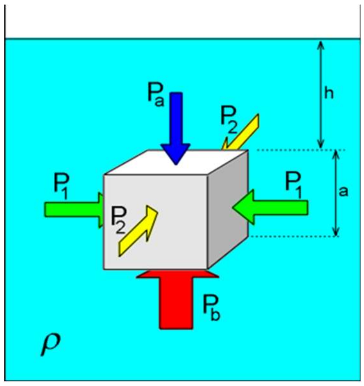
Archimedes discovered that the buoyant force $F_W$acting on a body immersed in a fluid is equal to the weight of the fluid displaced by this body:

$$F_W = m_{displaced\ fluid} \cdot g = \rho_{fluid} \cdot V_{body} \cdot g$$

gdzie:
V_{body} - the volume of the immersed body, or its immersed part, is equal to the volume of the displaced fluid
ρ_{fluid} - (□ - the Greek letter "rho", is the density of the fluid; by definition □ = m/V

Derivation:

We will use a cube with edge length a, immersed in a fluid with density ρ_{fluid}.



Let us consider all six pressure forces acting on the walls of the cube. The sum of the pressure forces acting on the side surfaces is zero. Therefore, the difference between the pressure forces $P_b$and $P_a$constitutes the buoyant force F_W.

$$P_a = \rho_{\text{fluid}} \cdot g \cdot h \cdot a^2$$
$$P_b = \rho_{\text{fluid}} \cdot g \cdot (h + a) \cdot a^2$$
$$F_W = P_b - P_a = \rho_{\text{fluid}} \cdot a^3 \cdot g = \rho_{\text{fluid}} \cdot V_{\text{body}} \cdot g$$

The expression:

$$\rho_{\text{fluid}} \cdot V_{\text{body}} \cdot g$$

represents the weight of the displaced liquid. This expression has a positive value, which means that $P_b > P_a$, so the buoyant force is directed upwards.

Transformation:

The apparent weight $G_{\text{app}}$of a body immersed in a fluid is smaller than the weight of the body in air G_0, and the apparent loss of weight is equal to the buoyant force:

$$F_W = G_0 - G_{\text{app}}$$

According to Archimedes' principle:

$$F_W = \rho_{\text{fluid}} \cdot V_{\text{body}} \cdot g$$

The volume of the immersed body, according to the definition of density, is:

$$V_{\text{body}} = \frac{m_{\text{body}}}{\rho_{\text{body}}}$$

After substitution, we obtain:

$$F_W = \rho_{\text{fluid}} \cdot \left(\frac{m_{\text{body}}}{\rho_{\text{body}}}\right) \cdot g$$

Since $m_{\text{body}} \cdot g$is the weight of the body G_0, we can write:

$$F_W = \frac{\rho_{\text{fluid}}}{\rho_{\text{body}}} \cdot G_0$$

After rearranging the equation, we obtain a form that allows the density of the body to be determined as the slope coefficient:

$$G_0 = \rho_{\text{body}} \cdot \frac{F_W}{\rho_{\text{fluid}}}$$

“A R C H I M E D E S”

Pytania do przygotowania:

1. State Archimedes’ principle and write it as a formula.
2. Give the definition and unit of weight and explain what apparent weight is.
3. Give the definition of density and its SI unit.
4. Give the approximate value of the density of water, steel and air.
5. Explain what buoyant force is and what it depends on.
6. Draw the distribution of forces acting on a body immersed in a liquid.
7. What conditions must be met for a body to float completely immersed in a liquid, for a body to sink in a liquid, and for a body to float partially immersed in a liquid?
8. Give the formula for the buoyant force when the values of the weight of the body in water G_{app} and the weight of the body in air G_0 are known.
9. Explain the difference between weight and mass.
10. What is the relationship between the density of water and temperature?
11. Explain what relative density is.
12. Give the definition of pressure and its SI unit.
13. State Pascal’s law.
14. Explain the difference between hydrostatic pressure and aerostatic pressure.
15. Give methods for determining the density of solids and describe the method used in the exercise.

Instructions for Performing the Measurements

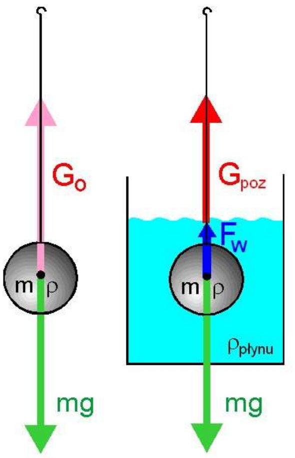
1. Turn on the force meter using the left “ON/OFF” button.
2. Zero the force meter using the right “ZERO” button.
3. Hang the holder on the force meter.
4. Place a weight in the holder. Use weights not smaller than 10 g.
5. Perform the first measurement of the force in air and record it in cell “1” of the G_0 row.
6. Perform the first measurement of the force in water and record it in cell “1” of the G_{app} row.
7. During measurements of masses immersed in water, remember that:
- The holder should be completely immersed in water.
- The weights must not touch the bottom or the walls of the vessel.
- After each measurement in water, dry the holder with the load.
8. Perform the subsequent force measurements in the same way, adding one or two weights each time, until 10 measurement series are obtained. Enter the force values for the total masses in the appropriate cells of the results table.
9. After collecting the results, estimate the measurement uncertainties ΔG_0 and ΔG_{app}.
10. After completing the measurements, turn off the force meter using the left “ON/OFF” button and tidy up the workstation.
11. Calculate the density of the solid body according to the formulas given in the report. In the calculations, remember to use the basic SI units for density.

“A R C H I M E D E S”

Methodological Template

Student 1: Determination of the density of a solid body.
Student 2: Verification of Archimedes’ principle.

Theoretical Basis



Suspending a mass on a force meter allows its weight to be determined:

$$G_0 = m_{\text{body}} \cdot g = \rho_{\text{body}} \cdot V_{\text{body}} \cdot g$$

Complete immersion of this mass in water allows the apparent weight $G_{\text{app}}$to be read.

The buoyant force is the difference:

$$F_W = G_0 - G_{\text{app}}$$

According to Archimedes’ principle, the buoyant force is equal to the weight of the displaced fluid:

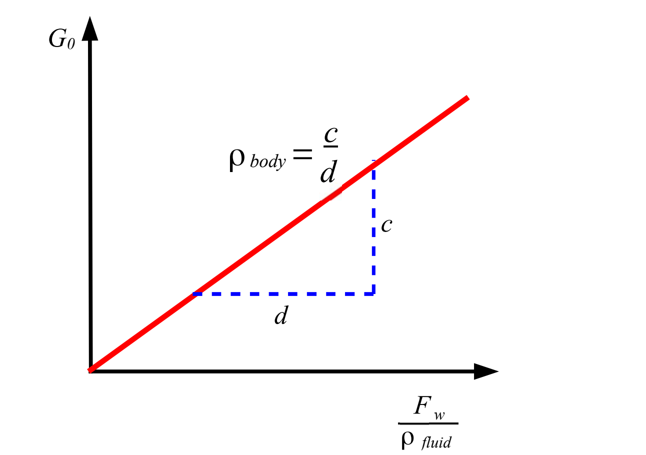
$$F_W = m_{\text{displaced fluid}} \cdot g = \rho_{\text{fluid}} \cdot V_{\text{displaced fluid}} \cdot g$$

Therefore, by equating the volume of the immersed body with the volume of the displaced fluid, the following proportion can be written:

$$\frac{G_0}{\rho_{\text{body}}} = \frac{F_W}{\rho_{\text{fluid}}}$$

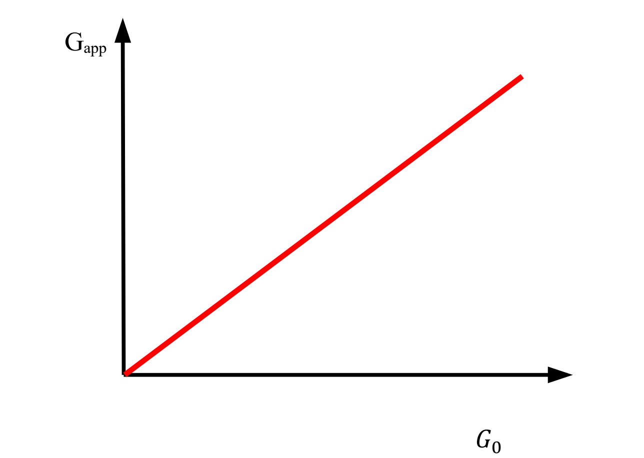
which can be transformed into the form:

$$G_0 = \rho_{\text{body}} \cdot \frac{F_W}{\rho_{\text{fluid}}}$$



Therefore, in order to determine the density of a solid body, one should:

- perform measurements of the dependence of the apparent weight $G_{\text{app}}$of a body immersed in water on its actual weight G_0,
- prepare a graph of the actual weight G_0as a function of the buoyant force divided by the density of water: G_0 as a function of $\frac{F_W}{\rho_{\text{fluid}}}$
- read from the graph the value of the density of the immersed solid body.



Therefore, in order to verify Archimedes’ principle, one should:

- perform measurements of the dependence of the apparent weight $G_{\text{app}}$of a body immersed in water on its actual weight G_0,
- prepare a graph of the dependence: G_{app} as a function of G_0
- analyse its linearity.

W doświadczeniu można użyć wody, która w temperaturze pokojowej ma gęstość: $\rho_{\text{płynu}}$ = 998 kg/m^3.

“A R C H I M E D E S”

Report Guidelines – Determination

Student 1: Determination of the density of a solid body.

I. Methodology (conceptual plan of the exercise)

II. Course of the exercise

II.1. Course of activities

II.2. Sketch of the measurement setup

II.1. Results

II.2. Measurement results

		1	2	3	4	5	6	7	8	9	10
G_0	[N]										
G_{app}	[N]										

$\Delta G_0 = \ldots$ $\Delta\, G_{app} = \ldots$

III.2. Calculations (example calculations – referring, for example, to measurement no. 3)

$$\frac{F_w}{\rho_{fluid}} = \frac{G_0 - G_{app}}{\rho_{fluid}} =$$

$$\Delta\frac{F_w}{\rho_{fluid}} = \frac{\Delta G_0 + \Delta G_{app}}{\rho_{fluid}} =$$

III.3. Calculation results

		1	2	3	4	5	6	7	8	9	10
G_0	[N]										
ΔG_0	[N]										
$\frac{F_w}{\rho_{fluid}}$	[…]										
$\Delta\frac{F_w}{\rho_{fluid}}$	[…]										

IV.4. Graph

- calculation of density r, the slope of the “best-fit” straight line
- calculation of r', the slope of the deviated straight line
- calculation of: $\Delta r = | r - r' |$

IV.5. Summary

The determined value of … is …

Accuracy of the method: …

Additional conclusion, observations, causes of measurement uncertainties…

“A R C H I M E D E S”

Report Guidelines – Verification

Student 2: Verification of Archimedes’ principle.

I. Methodology (conceptual plan of the exercise)

II. Course of exsercise

II.1. Course of activities

II.2. Sketch of the measurement setup

III. Results

III.1. Measurement results

		1	2	3	4	5	6	7	8	9	10
G_0	[N]										
G_{app}	[N]										

$\Delta G_0 = \ldots$ $\Delta G_{app} = \ldots$

III.2. Calculations

This report does not include example calculations..

III.3. Calculation Results

This report does not include example calculations..

III.4. Graph

IV. Summary

Since on the graph … it is possible to draw a straight line passing through all measurement uncertainty rectangles, there are no grounds to conclude a deviation from …

Alternatively:

The deviation from linearity in the range … may result from …

Additional conclusions, observations, causes of measurement uncertainties.