Mechanics

Aero- and hydrodynamics
Buoyancy

Measuring the buoyancy as a function of the immersion depth

Objects of the experiments

- Measuring the force F acting on a cylinder immersed in a liquid and determining the buoyancy force.
- Confirming the proportionality between the buoyancy force F_G and the immersion depth h.
- Determining the densities ρ of three different liquids.

Principles

According to Archimedes' principle, a body immersed in a liquid is acted upon by a buoyancy force F_G, the magnitude of which is equal to the weight of the displaced liquid

$$G = \rho \cdot V \cdot g \qquad \text{(I).}$$

ρ: density, V: volume, g: acceleration of free fall

If, for example, the immersed body is a cylinder with cross section A,

$$G = \rho \cdot g \cdot A \cdot h \qquad \text{(II)}$$

as long as the immersion depth h is smaller than the height H of the cylinder (see Fig. 1). At greater immersion depths, the buoyancy force has the constant value

$$G_H = \rho \cdot g \cdot A \cdot H \qquad \text{(III).}$$

If the cylinder is suspended from a dynamometer, the dynamometer measures the weight F_0 of the cylinder as long as the cylinder is not immersed in the liquid, and the force

$$F = F_0 - G \qquad \text{(IV)}$$

if the cylinder is immersed.

In the experiment, the force F is measured as a function of the immersion depth in three different liquids. Since the buoyancy force F_G is equal to the weight G, Eq. (IV) leads to

$$F_G = F_0 - F \qquad \text{(V).}$$

Evaluation of the measuring results will confirm Eq. (II).

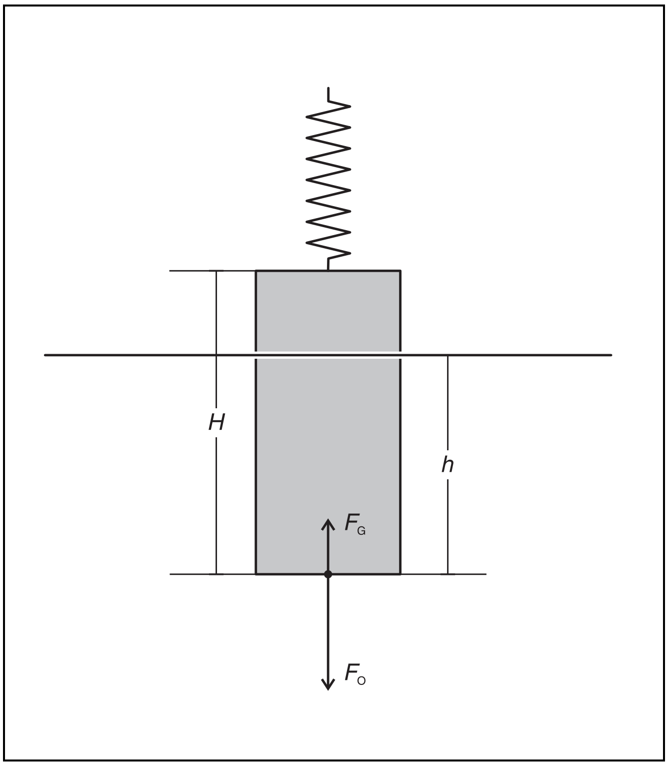

Fig. 1 Diagram for calculating the buoyancy force F_G on a body immersed in a liquid

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Apparatus

1 Archimedes cylinder 362 01

1 precision dynamometer 314 141
1 steel tape measure 311 77

1 beaker, 250 ml, ts, hard glass 664 113

glycerine, 99 %, 250 ml 672 121
ethanol, denatured, 1 l 671 972

in addition:

distilled water, 250 ml

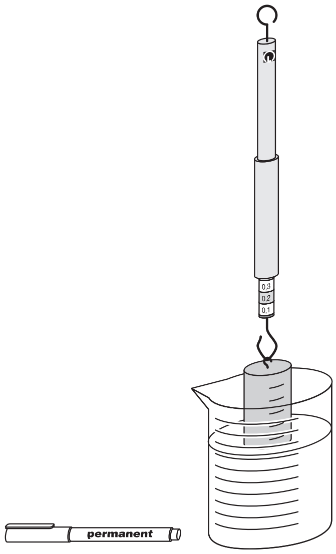

Fig. 2 Experimental setup for measuring the buoyancy force as a function of the immersion depth

Setup and execution of the experiment

The experimental setup is illustrated in Fig. 2.

– Determine the dimensions of the solid cylinder (from 362 01).
– Hold the dynamometer suspended vertically and adjust the zero position.
– Suspend the solid cylinder from the dynamometer and determine its weight F_0.
– To make determination of the immersion depth easier, make equidistant marks on the solid cylinder with a water and ethanol proof pen.
– Fill about 200 ml of distilled water into the beaker.
– Immerse the solid cylinder up to the first mark and measure the force *F*.
– Immerse the solid cylinder further and measure the force *F* as a function of the immersion depth *h*.
– Pour out the distilled water and dry the beaker and the solid cylinder using, for example, absorbent tissue.
– Repeat the experiment with ethanol and then with glycerine.

Measuring example

Data of the solid cylinder:

diameter d = 38 mm, height H = 65 mm

weight F_2 = 1.00 N

Table 1: The force *F* acting on the solid cylinder as a function of the immersion depth *h*

$\frac{h}{\text{mm}}$		$\frac{F}{\text{N}}$	
	Water	Ethanol	Glycerine
0	1.00	1.00	1.00
11	0.89	0.91	0.86
22	0.78	0.83	0.71
33	0.67	0.74	0.56
44	0.54	0.65	0.41
55	0.42	0.55	0.26
65*	0.30	0.46	0.10
70*	0.29	0.45	0.09
80	0.29	0.45	0.09

*) When the cylinder is slowly lowered, the force shown by the dynamometer reaches its lowest value at an immersion depth between 65 mm and about 68 mm. At this point, an additional force which stems from the surface tension of the liquid, can be detected.

Evaluation and results

In Fig. 3, the buoyancy force F_G calculated from the data of Table 1 is plotted as a function of the immersion depth h. The slopes (cf. Eq. (II))

$a = \rho \cdot g \cdot A$

of the straight lines drawn through the origin and the corresponding densities ρ of the liquids are compiled in Table 2. The deviation from the values quoted in the literature, which are also given in Table 2, is due to an admixture of air during the process of filling the liquids into the beaker.

Tab. 2: The slopes of the straight lines (see Fig. 3) and the densities ρ of the liquids calculated from them

Liquid	$\frac{a}{\text{Nmm}^{-1}}$	$\frac{\rho}{\text{gcm}^{-3}}$	$\frac{\rho}{\text{gcm}^{-3}}$ literature
Ethanol	0.0081	0.73	0.79
Water	0.0105	0.94	1.00
Glycerine	0.0136	1.22	1.26

In Fig. 4, the buoyancy force F_G acting on the solid cylinder when it is completely immersed is shown as a function of the density ρ of the liquid.

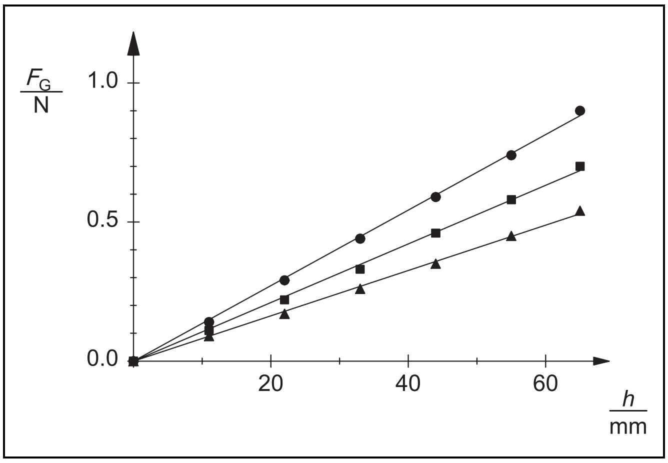

Fig. 3 The buoyancy force F_G acting on a solid cylinder as a function of the immersion depth h
circles: glycerine, boxes:water, triangles: ethanol

Fig. 4 The buoyancy force F_G acting on the solid cylinder when it is completely immersed as a function of the density ρ of