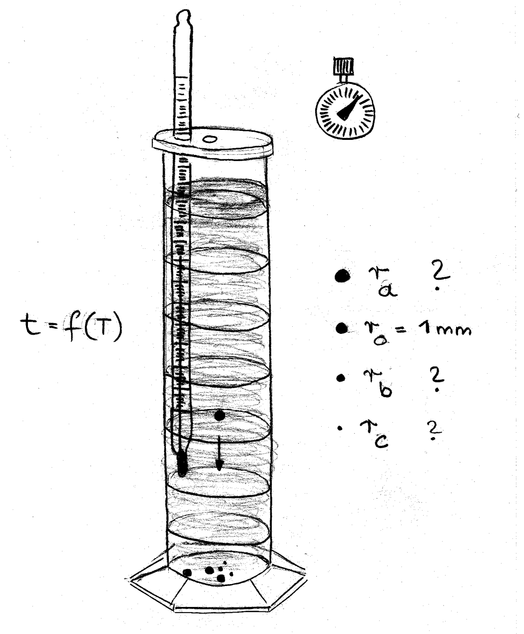
FALLING BALL VISCOSIMETER GPI



Key Words

Laminar Flow.

Internal friction, Viscosity; Drag, *Stoke's*- and *Hagen-Poiseuille Law*.

Turbulent flow and *Reynolds number*.

Aim of the Experiment

Investigating the drag, internal friction, viscosity and laminar flow around a ball falling in a liquid; *Stoke's Law*. Temperature dependence of the viscosity.

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Literature

[1]: Chapter 3.3

[2]: Chapter 16.2 and 18.1

Exercises

1. Measuring the velocity of steel balls, with known and unknown radii, falling through a liquid as a function of the temperature of the liquid.
2. Investigating the dependence of the viscosity of glycerol as a function of temperature. Determining the viscosity of the glycerol at 20 °C and comparing the result with the literature value.
3. Determining the unknown radii of steel balls from the measurements and comparing the results with direct measurements made with a micrometer.
4. Setting up and solving the equation of motion with the boundary conditions v(t=0) = v_0 = 0 and v(t→ ∞) = v_∞ and estimating the time and distance respectively where the ball sinks with almost constant velocity.

Physical Principles

Liquids (continuous media) have the property of *laminar* or *turbulent* flow. The frictional forces arising in laminar flow are determined by the viscosity η (coefficient of internal friction). *Stoke's Law* applies for the frictional force R when a ball moves in a viscous fluid:

$$R = -6\,\pi\,\eta\,r\,v \tag{1}$$

where r is the radius and v the velocity of the ball.

If a ball drops under the influence of gravity in a liquid, then the force of gravity G, diminished by the amount of the buoyancy force A, works against the drag (frictional) force R. After a certain time and independent of the initial velocity and because of the velocity dependence of the drag, a state of balance is reached in which the sum of all forces vanishes:

$$G + A + R = 0 \tag{2}$$

The ball then falls with constant velocity from which one can calculate the viscosity.

Temperature Dependence

In liquids, the internal friction originates from the action of intermolecular forces and decreases with increasing temperature. In many cases, the temperature dependence follows a functional progression given by:

$$\eta(T) = A\,\mathrm{e}^{\frac{B}{T}} \tag{3}$$

Presentation of the Physical Principles

(As preparation for a part of the report): Aside from the method of measurement (measurement equations), a short presentation should be given on the themes internal friction and laminar flow and the definition of viscosity.

Equipment

Stand cylinder with ring markings and thermometer; filled with glycerol (see figure on the title page). Refrigerator. Steel balls of various sizes. Tweezers. Paper and 2-Propanol to clean the balls Stopwatch. Metal rule. Micrometer.

Experiment and Evaluation

The measurement of the temperature dependence of the viscosity throws up a number of problems: The temperature, as a state variable, presupposes thermodynamic equilibrium, which is very difficult to achieve in practice. The following experimental procedure is thus prescribed as a compromise between effort and result:

The stand cylinders are stored in a refrigerator. At the start of the experiment they are taken out and exposed to room temperature so that the temperature of the oil takes on changing values. This warming up is a dynamic process without thermodynamic equilibrium. However, one can, as an approximation, presume that the systematic errors in the values are about the same for all measurements so that the temperature dependence of viscosity can be reasonably well observed.

The experimental procedure is as follows: The cylinders are taken out of the refrigerator and during a certain time interval (about 1 hour), and thus over a certain temperature range (about 6 to 10 K) repeated measurements are made of the falling times of the different balls $t(r_0)$, $t(r_a)$, $t(r_b)$, $t(r_c)$ one after the other and the corresponding temperatures. All other parameters must remain unchanged (falling distance of the balls, position of the thermometer, etc). Observe and take into account the accelerating phase of the balls when determining the falling distance. It is recommended to protocol the initial- and final temperatures for each falling time and to take the average for the subsequent evaluation. One then gets a table of values for the falling time as a function of temperature and ball radius.

<u>Any attempt to achieve a uniform temperature (e.g. by stirring the oil) is pointless and brings about conditions making further experimental work impossible (e.g. air bubbles in the oil)</u>.

Stoke's Law applies rigorously only for the movement of a ball in an infinitely extended medium. In a narrow cylindrical tube, the resistance is increased due to boundary interference. For this reason, the balls should fall, as close as possible, in the middle of the cylinder. Furthermore, the measurement must be stopped an ample distance from the bottom of the cylinder.

Before beginning the experiment, the balls must be cleaned from any remaining traces of old oil (why?). At the end of the experiment, the balls are removed from the bottom of cylinder using a magnet.

The experiment is evaluated by plotting the falling time as a function of temperature on single log paper. As a check, it is recommended to plot the results during the course of the experiment. Later, a second axis can be drawn along the ordinate with the actual viscosity values derived from the falling time of the known balls.

The radii of the unknown balls are found by determining the ratio of the falling times to that of r_0, provided one assumes that all other conditions remain unchanged. For viscosity, this may not be taken for granted since temperature changes can not be influenced. However, comparative data can be obtained from the plot by interpolation with the aid of best fit lines.

Supplementary Questions

The transition from laminar- to turbulent flow is described by the *Reynolds number* R_E:

$$R_E = \frac{\rho\, r\, v}{\eta} \tag{4}$$

where ρ is the density of liquid. In which range are the *Reynolds numbers* in this experiment? Does this prove that we are dealing with laminar flow?