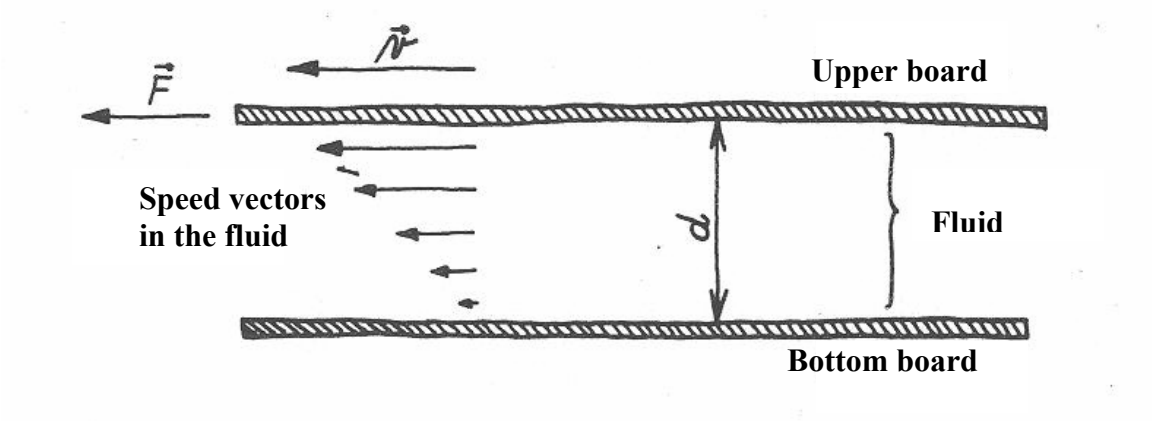
Laboratory exercise No. 5 – Dynamic viscosity of fluid + Working with microscope

Measurement of dynamic viscosity coefficient of fluid

The best way to explain v*iscosity* is using the relative motion of two parallel boards with a fluid between them, see Fig.1.



A layer of fluid which adjoins to an upper board moves together with upper board, while bottom board and the adjoining liquid do not move. In a distance *d* the speed of fluid is changing from 0 to *v*. If we have a *Newtonian fluid*, the change of speed in dependence on the distance *d* is uniform, see Fig. 1.

If we want the upper board to be in a uniform motion with respect to the bottom board, we must apply a force *F* on the upper board which is proportional to the surface of the pulled board. Hence, it is more convenient to introduce the strain τ which does not depend on the surface of the used board,

$$\tau = \frac{F}{S}. \qquad (1)$$

Experiments show that for the Newtonian fluids the strain is proportional to the ratio *v*/*d*,

$$\tau = \frac{v}{d} \qquad (2)$$

The constant of proportionality is called the *dynamic viscosity* c*oefficient of a fluid*, η (N.s.m^{-2}) or, usually, (Pa.s). A *Newton law* is thus valid – the tangential stress is proportional to the speed gradient

$$\tau_{xy} = -\eta \frac{dv_x}{dy}, \tag{3}$$

where τ_{xy} is the tangential strain ($N.m^{-2}$) which represents x-axis components of the moment in the y-axis direction and $\frac{dv_x}{dy}$ is the gradient of speed.

The ratio of the dynamic viscosity to the density is called the *kinematic viscosity* ν ($m^2.s^{-1}$),

$$\nu = \frac{\eta}{\rho}. \tag{4}$$

The viscosity of fluids depends on the pressure as well as the temperature. The viscosity increases with the pressure, and decreases with the temperature. The Newtonian formula is satisfied for most of the fluids. The exceptions are anomalous fluids which contain a cluster of several molecules for which the viscosity depends on the speed gradient (the so-called *non-Newtonian fluids*).

The next example may be the motion of body through a fluid. Here the fluid also acts on, for example, a ball, with the magnitude of the force action depending on the viscosity of a fluid.

If a body moves (for example, a ball) in a fluid with a low speed v, the fluid acts on it by the force

$$F_S = 6\pi \eta r v, \tag{5}$$

where r is a radius of ball.

This equation is called the *Stokes equation* and, therefore, the resistance force F_S of the surroundings is, for low speeds, called the *Stokes force*. The Stokes equation is conveniently used for the determination of the viscosity of a fluid, for example, using the *Höppler viscosimeter*.

Measurement principle: the falling time of a ball in a glass tube whose axis is diverted by about 10° from the vertical direction is measured. From the measured time or the speed of the movement, the fluid resistance to the movement of the ball (the viscosity) is calculated.

Calculation: if the ball moves uniformly directly during the fall through the fluid, then it means, according to Newton's law of motion, that the total force acting on the ball is equal to 0. But in total there are 3 nonzero forces acting on the ball: the Stokes force (opposite to the speed of movement), the gravity of the ball G (parallel with the ball speed), and the lifting force F_A (directed upward, i.e., opposite to the ball movement which is falling downward). Since the total force is equal to 0, it must be true that

$$F_S + F_A - G = 0 \tag{6}$$

$$F_S + F_A - G = 0 \tag{7}$$

$$\frac{4}{3}\pi r^3 \rho g + 6\pi \eta v r = m g \tag{8}$$

For the calculation of the viscosity from the falling time of the ball, the following equation is used,

$$\eta = t(\rho_1 - \rho_2)K\,, \tag{9}$$

where t is the falling time of the ball (s), ρ_1 is the density of the ball (g.m^{-3}), ρ_2 is the fluid density at the surroundings temperature (g.m^{-3}), and K is a constant (mPa.cm^3.g^{-1}).

Remark: The more precisely it is to determine the density of a fluid, the less it is different from a ball. For glass balls the density of fluid is optimal to measure in 3 decimal places, for metal balls (with the density 8.1 g.m^{-3}) 2 decimal places are satisfactory.

Preparation for the measurement:

- Ball selection: see Tab. 1
- Manipulation with balls: abrasion of balls and a fall of balls on a hard place should be avoided, the balls must be perfectly clean.
- The density of a fluid: if you measure with a known fluid, it is possible to establish the density of the fluid in the analytic tables. Otherwise, the density is measured by, say, densitometer.

Tab. 1 – The set of measuring balls

Number	Diameter of ball	Constant	Minimal falling time	Measurement range	Maximal error	Reproducibility
	mm	mPa.cm3.g-1	s	mPa	%	%
1	15.805	0.009	60	0.6…5	2.0	1.00
2	15.630	0.070	30	3…30	0.5	0.25
3	15.560	0.130	30	25…250	0.5	0.25
4	15.200	0.700	30	200…4800	1.0	0.50
5	14.000	6.400	30	1250…12500	1.0	0.50
6	11.000	34.000	30	70000	1.5	0.75

It is advices not to use times shorter than the minimal times showed in Tab. 1.

Remark: The viscosity is also sometimes called the „internal friction“ in a fluid.
The Stokes equation is valid for low speeds of fluids, i.e., for the situations when a body is flown around by a laminar fluid.
Among the Newtonian fluids are: water, glycerin, and many kinds of oils; a typical example of a non-Newtonian fluid is blood and other organic compounds.

Task 1: Determine the density of a fluid with a densitometer.
Task 2: Verify the measured density in the analytic tables.
Task 3: Measure the falling time of a ball with the Höppler viscosimeter.
Task 4: Calculate dynamic viscosity of a fluid from Eq. (9).

Working with an optical microscope

Even if the microscope has been known form several centuries, the biggest development of the microscope technology was achieved in the 20th century. According to some sources, the first microscope was made by Zacharias Jansen in 1590 in Holland. On his bases, Galileo Galilei constructed his own microscope in 1610. In 1676, a Dutch businessman and researcher Anton van Leeuwenhoek whose works belonged to the top of microscopic observations in the 17th century made one of a simple microscopes. In 1665 Robert Hook published an important publication called „Micrographia" where the construction of a microscope with a separate objective, ocular, and lighting device was described. The first company which began with the production of microscopes was Carl Zeiss in Jena in 1847.

In the study of objects properties investigated with a microscope many kinds of methods are used in dependence on the character of investigated subjects. In optical (lighting) microscopy the electromagnetic radiation with wave lengths from 180 nm to 1300 nm are used. In the interaction of the electromagnetic radiation with investigated subjects there is a change in the radiation properties, for example, the amplitude, polarization, phase, and frequency (wave length).

Using a microscope, we get a qualitative image of the subject and information on the structure which is not possible to observe with eyes. It is necessary to emphasize that the quality of the obtained information is dependent on the quality of the optical systems (objectives, oculars, condensers, filters etc.) used in the microscope.

The microscopic methods were developed step by step, and in many cases their development was conditioned by the state of science and technology in the given time period. The physical basis of various microscopic methods is the principle of electromagnetic field superposition; their properties are influenced partly by the investigated object and partly by a controlled intervention into the field properties (the amplitude, polarization, phase, frequency) in dependence on a given microscopic method.

The first microscopic methods included the dying of biological preparations with proper dyes, which caused the amplitude influence of light passing through an apparatus which was then easily observable and its particular structures were in different colors.

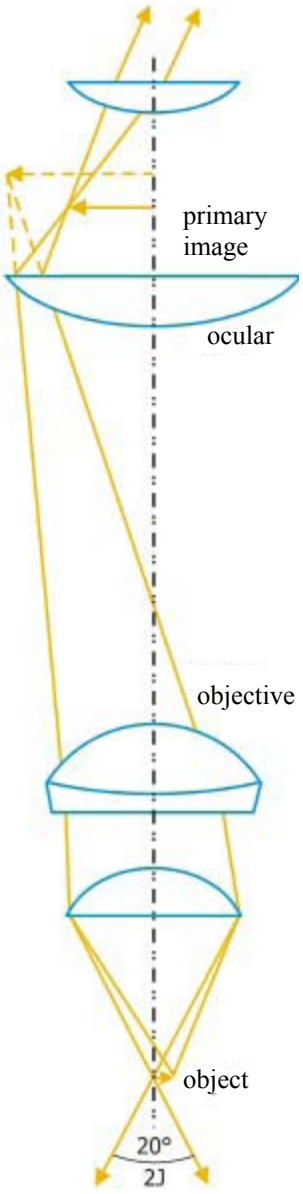
The disadvantage of this method was that in the dying process the biological preparations were usually killed.

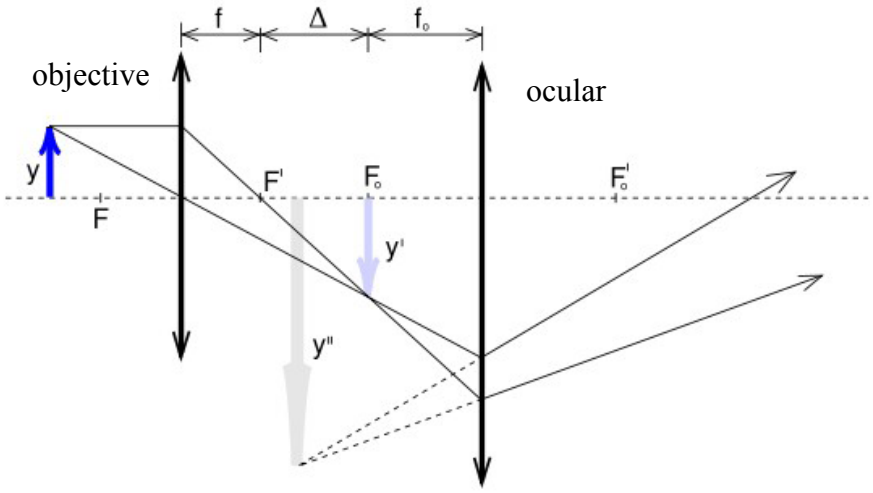
The method of inclined lighting is another method which makes it possible to contrast the observed object. Its principle is that in the object focal plane of condenser we put a diaphragm with a circular aperture with a suitable diameter whose center lies beyond the optical axis of the condenser and which is free to rotate. Then an inclined rays fall on the object, and an observer sees the effect “plastically”, and the object is well visible. By a proper turning of the diaphragm and by a proper choice of the aperture diameter in the diaphragm it is possible to optimize this effect for a given object. This method is easily realized in microscopes with the so-called big Abbe lighting apparatus (a condenser completed with a protruding iris diaphragm).

Observing objects in a polarized light is the basis of the polarized microscopy which is commonly used especially in mineralogy. If we observe a birefringent object in the white light and we place it between two polarizers, their transparency directions are under a certain angle, then the object looks in different colors in different places in dependence on the magnitude of birefringence in a given place of the object.

A classical microscope always displays the whole object size, whereas a sharp (a well defined displayed) is only a certain volume layer of this object whose thickness depends on the sharpness depth of the microscope lens and accommodative depth sharpness of observer’s eyes. The other parts are unfocused, and an observer must carry out the focusing (by shifting the objective with respect to the object), if he/she wants to observe a different layer of the object. The light from other parts of the object goes into the observer’s eyes, and the image is thus affected by noise.

Graphical construction of optical picturing in microscope:





For the angular magnification of the microscope one has

$$Z = \gamma\gamma_0 = \frac{\Delta}{f}\frac{d}{f_0},$$

where γ and γ_0 represent the magnification of the lens and ocular, respectively, f is the focal distance of the objective, f_0 is the object focal distance of the ocular, Δ is the optical interval of the microscope, and d is the conventional visual length.

An optical microscope has usually the magnification 50× to 1000×. The maximal theoretical magnification is about 2000×, but this is bounded by physical barriers due to the limitation of optical wavelengths.

Basic parts of microscope:

- Binocular (monocular) head with an ocular
- Revolver head with four objectives
- Stand – a basis with an embedded lighting system, stage holder, focusing mechanism

- Cross stage – shift of the apparatus in perpendicular directions, the magnitude of the objective movement can be deducted from the scales and nonia on both axis
- Abbe condenser with an iris aperture diaphragm and an adjusting sleeve for the insertion of a light filter

Description and working principle: an optical system of the microscope consists of an illuminant and an observation parts.

In the illuminant system of the microscope, the light of LED diodes is transferred in an optical way into the plane of the aperture diaphragm of the condenser. In a light way it is possible to regulate by the Abbe condenser, and it is possible to control the aperture diaphragm by the ring on the condenser which serves for the regulation of the light amount, so we regulate the brightness and contrast of the image.

The observation system of a microscope includes a revolver head with interchangeable lenses, a binocular head, and oculars.

Lens selection: observing should begin by the objective with the smallest magnification that is used for the choice of the object parts that is going to be studied. Any ocular can be used with an arbitrary objective, it is recommended to use the ocular WF 10x at first that has a bigger visual field. After the choice of the object part for the study by the objective 4x and 10x, set this part into the center of the visual field. Otherwise, it can happen that by using an objective of a larger magnitude, the selected part will be outside the visual field.

Task 1: Prepare your own preparative and put in on a microscope slide.

Task 2: Draw the observed structure and describe it.

Laboratory protocol:

Title page:	Title of experiment
	Student's name (or the members of a study group)
	Date
Protocol:	Short description of the studied materials
	Description of the applied experimental methods
	List of used devices and meters
	Measured values and used constants
	Intermediate and final results
	Evaluation and data interpretation, conclusions