4 MEASUREMENT OF DENSITY – DENSITY DETERMINATION BY DENSIMETER POLARIMETRY

A MEASUREMENT OF DENSITY – DENSITY DETERMINATION BY DENSIMETER

Theory

The ***density*** (***ρ***), is elementary physical property of matter. For a homogeneous object it is defined as the ratio of its mass (***m***) to its volume (***V***) according equation:

$$\rho = \frac{m}{V} \qquad (\mathrm{kg\ m^{-3}}) \tag{1}$$

Numerically it represents the mass per unit volume of matter. As it follows from equation (1), the SI unit of density is kg m^{-3}. However, g cm^{-3} is another unit commonly used in a laboratory. Its conversion is:

$$1\ \mathrm{g\ cm^{-3}} = 1\ 000\ \mathrm{kg\ m^{-3}}$$

The volume of an object increases with increasing temperature because of the matter's volumetric thermal expansion. Therefore, according to equation (1), the density of an object depends on its temperature, with higher temperature resulting in lower density. Exception is water in temperature range 0-4 °C, for which the density increases with increasing temperature. The density of a gas depends on the pressure as well. Nevertheless, this effect is negligible in a case of liquids.

Several experimental methods are used to determine the density of liquids – pycnometry, density measurement with densimeter and with Mohr-Westphal balance. We will learn how to use densimeter in this assignment.

Densimeters are glass devices (Figure 1), which measure the density on the principle of Archimedes' law. Dipped volume of a floated element is inversely proportional to the density of the liquid, which is directly read from the scale of the densimeter in the level of the liquid's surface.

Densimeters measure in different ranges of the density, with different precision (1-3 decimal places g cm^{-3} or kg m^{-3}). Some densimeters are used for measurements of the concentration of saccharose (saccharometers) or spiritus (spirit gauge).

Aim of the work

To measure the density of distilled water and three solutions of saccharose using densimeter.

Equipment

Densimeter, graduated cylinder, measured solutions, distilled water and thermometer.

Experimental procedure

1. Rinse the graduated cylinder with distilled water and fill it with distilled water approximately 7-10 cm below top margin.
2. Immerse the densimeter carefully in the graduated cylinder filled with the distilled water and read its density from the mark at the water's surface (Figure 2). Write the value to the Table 1.

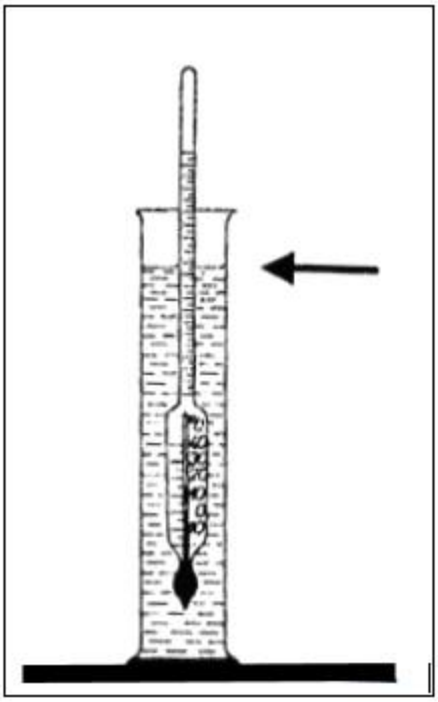

Figure 1 Measurement of the density by densimeter

3. Pour out the distilled water from the cylinder to the waste beaker.
4. Rinse the graduated cylinder with a solution, fill it with this solution and measure its density in the same way as you did with the distilled water.
5. Measure the density of all prepared solutions in the same way.
6. Measure the temperature of one of the prepared solutions and write it to the Table 1.

Table 1 Measured densities of water and solutions.

Solution	**Density - ρ (kg m^{-3})**
Distilled water	
Solution 1	
Solution 2	
Solution 3	

B POLARIMETRY

Theory

In classical physics, ***electromagnetic radiation*** (***EM radiation*** *or* ***EMR***) refers to the waves of the electromagnetic field, propagating through space. It includes radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays. Electromagnetic waves are synchronized oscillations of electric and magnetic fields (Figure 2). In homogeneous, isotropic media, the oscillations of the two fields are perpendicular to each other and perpendicular to the direction of wave propagation, forming a transverse wave. By convention, the "***polarization***" of electromagnetic waves refers to the direction of the electric field $\vec{E}$. In linear polarization, electric field $\vec{E}$ oscillates in a single direction. In the Fig. 2, EMR is polarized in the direction of x-axis.

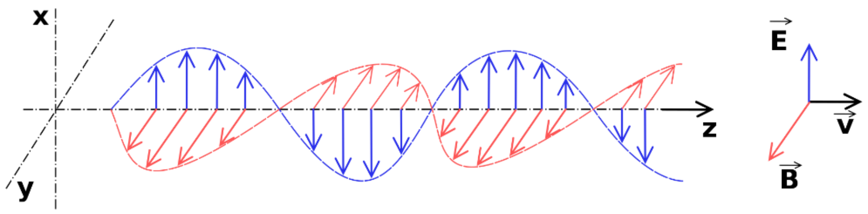

Figure 2 A linearly polarized sinusoidal electromagnetic wave, propagating in the direction +**z** through a homogeneous, isotropic medium. The electric field (blue arrows) oscillates in the ±**x**-direction, and the orthogonal magnetic field (red arrows) oscillates „in phase“ with the electric field, but in the ±**y**-direction.

Light or other EMR from many sources, such as the sun, flames and incandescent filament, consists of short wave trains of its own polarization. The sum of the randomly oriented wave trains results in a wave whose direction of polarization changes rapidly and randomly. Such a wave is said to be ***unpolarized***. Polarized light can be produced by passing unpolarized light through a polarizer, which allows waves of only one polarization to pass through.

An object or a system is ***chiral*** if it is distinguishable from its mirror image; that is, it cannot be superposed onto it. Human hands are a macroscopic analog of this. Typical organic chiral molecules contain a carbon atom with four different groups bonded. A chiral molecule and its mirror image are called enantiomers or optical isomers.

Optical activity is the ability of a chiral molecule to rotate the plane of polarization of linearly polarized light. The rotation of the plane of polarization may be either clockwise, to the right (dextrorotary — D-rotary), or to the left (levorotary — L-rotary) depending on which optical isomer is present (or dominant). For instance, saccharose is D-rotary.

Polarimetry is a sensitive, non-destructive technique for measuring the optical activity exhibited by solutions of inorganic and organic compounds. The measure of optical rotation is determined by the molecular structure and concentration of chiral molecules in the substance. Polarimetry is a tool particularly used in the sugar industry to measure the sugar concentration, and generally in chemistry to measure the concentration or enantiomeric ratio of chiral molecules in solution.

The term ***specific rotation*** $[\alpha]_\lambda^t$ has been established to compare the optical activities of individual substances. The specific rotation is given by the following equation:

$$[\alpha]_\lambda^t = \frac{\alpha}{Wd\rho} \qquad (^\circ\ \mathrm{m^2\,kg^{-1}}) \qquad (2)$$

where ***t*** - is the temperature (°C), $\boldsymbol{\alpha}$ - is the measured angle of rotation of the polarized light plane (°), ***W*** - is the concentration of the dissolved compound - the mass percent of the dissolved substance (%), $\boldsymbol{\rho}$ - is the density of the solution (kg.m^{-3}) and ***d*** - is the length of the sample tube (m).

The specific rotation is a typical property of an optically active substance at a given temperature (***t***; usually ***t*** = 20 °C) and a wavelength ($\boldsymbol{\lambda}$) of the used radiation. According to equation (2), the specific rotation equals to the angle of rotation of the polarized light plane which was induced by a 10 cm thick layer that contains 1 g of an optically active compound in 1 cm^3 of a solution.

In this laboratory exercise you will work with solutions of saccharose. The specific rotation of an aqueous solution of saccharose is

$$[\alpha]_\lambda^t = \mathbf{0.66501\ ^\circ\ m^2\,kg^{-1}}$$

From equation (2) we can calculate the mass concentration (***W***) of the dissolved substance:

$$W = \frac{100\alpha}{[\alpha]_\lambda^t d\rho} \qquad (\%) \qquad (3)$$

Polarimeter

A ***polarimeter*** is a device used for the measurement of optical rotation and its scheme is depicted in Figure 3.

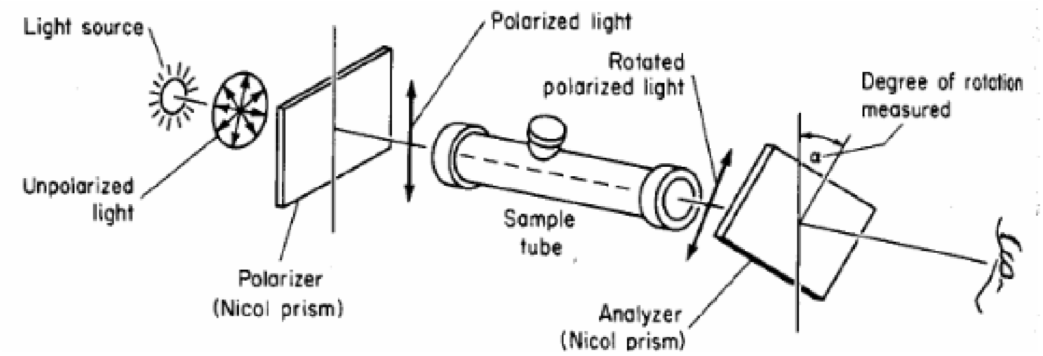

Figure 3 Components of a polarimeter

The main components of the polarimeter are the polarizer (Nicol prism), analyzer (Nicol prism) and the sample tube. The polarizer is used to obtain a polarized light. The analyzer is used to measure the angle of rotation. The sample tube should be filled with a solution of optically active substance so that it does not contain any air bubble (carefully fill the tube until a convex surface of the liquid is formed on the tube thread. This surface is then "cut off" with a lens. This procedure should be performed fast in order to avoid the formation of gas bubbles in the sample tube. After screwing the tube thread, the filling of the tube is checked for possible bubbles, the tube is wiped and inserted into the polarimeter).

When polarized light passes through a solution of optically active substance, the light appears to dim because it no longer passes straight through the analyzer filters. The amount of rotation is quantified as the number of degrees that the analyzer must be rotated by so that it appears as if no dimming of the light has occurred.

The polarimeter, used in this exercise, has two scales on each side to determine the angle of rotation. Outer scales are the circular scales which are divided into 360° (Figure 4). One mark of the circular scale corresponds to $\alpha = 1°$. On the inner sides there are the nonius scales which have marks from 0 to 10. One part of the nonius scale corresponds to 0.05°. When reading the measured value, at first, find the marks of the circular scale which are above and below the zero mark of the nonius scale. Read the smaller value of the two values; this will be the whole part of the value α. According to Figure 4 this value is 2°. The tenths and hundredths of α will be read from the nonius scale. This should be done by finding the first mark on the nonius scale which exactly matches with an arbitrary mark on the circular scale.

According to Figure 4, this value is 0.85°. Finally, calculate the value of α as sum of these two values following Figure 4

$$\alpha = 2\,° + 0.85\,° = 2.85\,°$$

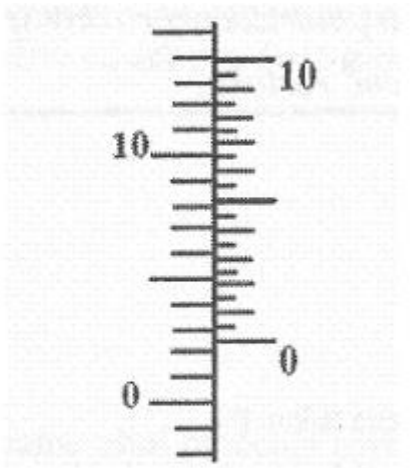

Figure 4 Scales of a polarimeter

Procedure of measuring with a polarimeter

The ***first step*** is to set the zero value on the nonius scale exactly opposite to the zero value on the circular scale. This should be done by using the polarimeter screw which is under the ocular. In this position, polarizer and analyzer are parallel and transmit the light polarized in the same plane. The field of vision observed in the ocular is like in the Figure 5c.

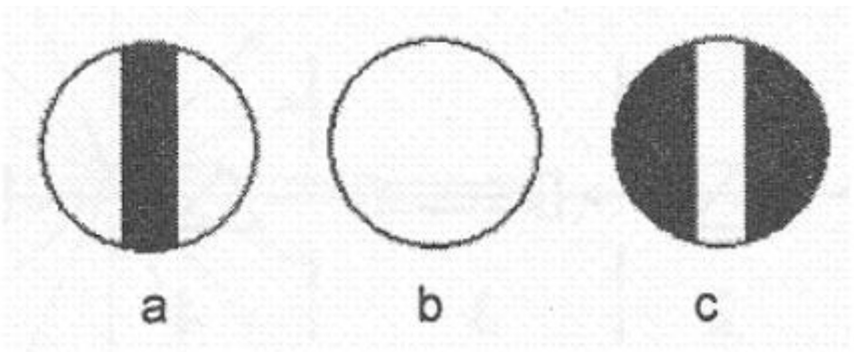

Figure 5 Different fields of vision observed in the ocular during a polarimetric measurement

In the second step, insert the sample tube filled with the sample into the polarimeter. The plane of polarization of light is now rotated by optically active substance in the sample. Light is only partly transmitted through analyzer. The field of vision observed in the ocular is depicted in Figure 5a. This position is denoted as the ***first extreme position***. Then, turn the polarimeter screw left till you will observe the field of vision which is depicted in Figure. 5c. This position is denoted as the ***second extreme position***. The last step is to find the

medium position Figure 5b, where you can observe a regularly illuminated field without strips. In this position, analyzer is turned with respect to the polarizer by the same angle α as is the plane of polarization and light is again transmitted through it. Read the corresponding value of $\boldsymbol{\alpha}$ from the scales of the polarimeter.

Aim of the work

Measuring of angle of rotation (***α)*** and calculation of mass concentrations of prepared saccharose solutions.

Equipment

Polarimeter with tube, saccharose solutions, distilled water

Experimental procedure

1. Wash the polarimeter sample tube with a small amount of the measured solution and fill the sample tube with the solution. Close and wipe the sample tube.
2. Find ***five times*** the angle of rotation of the first solution and write down the values in Table 2. Between two measurements, simply untune the polarimeter.
3. Pour back the solution into the storage bottle and repeat the same procedure for the other solutions.
4. When finished the measurements, check the angle of rotation without inserted sample tube ($\boldsymbol{\alpha_0}$). The value of $\boldsymbol{\alpha_0}$ should be close to zero. Write down the value of $\boldsymbol{\alpha_0}$ in Table 2.
5. Write down the room temperature.
6. Write down the length of the sample tube – ***d***.
7. When finished all measurements, dismantle the sample tube, carefully wash all parts of the tube with distilled water, dry and tidy them up.

Calculation procedure

Calculate the following data and write them down in Table 2:

– The average values of angles of rotation ($\overline{\alpha}$) calculated from the measured values:

$$\overline{\alpha} = \frac{\sum_i \alpha_i}{n} = \frac{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5}{n} \qquad (^\circ) \qquad (4)$$

– The corrected values of angles of rotation (α_C) calculated according to the equation (5):

$$\alpha_C = \overline{\alpha} - \alpha_0 \qquad (°) \tag{5}$$

– The values of mass concentrations of the dissolved substance according to the equation (3). Take the densities of the solutions from the Table 1.

Table 2 Measured and calculated values for polarimetric measurements

t = ...°C ***d*** = ...m $\boldsymbol{\alpha_0}$ = ...°

$[\alpha]_\lambda^t$ **= 0.66501 ° m^2 kg^{-1}**

Solution	α **(°)**	$\overline{\alpha}$ **(°)**	α_C **(°)**	ρ **(kg m^{-3})**	***W*** **(%)**
Distil water	-	-	-		-
1					
2					
3					

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Manual writen

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