Experimental Physics I - Lab

Experiment 422

Determination of the specific rotation of sucrose.*

- Instruction based on the material published in a script edited by Grzegorz Derfel: Instrukcje do ćwiczeń I Pracowni Fizycznej", Łódź 1998.

Experiment 422

Determination of the specific rotation of sucrose

The student should assimilate the following topics before attempting to read the instruction and conduct the experiment:

1. Properties of light waves. Light polarisation and methods of obtaining polarised light. [9] or [32].
2. Optical activity of matter. Biot law. [3] or [10] or [32] or [34] or [37].

Objective of the experiment

1. To demonstrate the phenomenon of optical activity.
2. To familiarize with the methodology of measuring optical activity in solutions of optically active substances.
3. To determine the specific rotation of sucrose.

Measurement methodology

A substance is called optically active if the polarisation plane of linearly polarised light passing through that substance changes its spatial orientation. When linearly polarised light passes through an optically active solution, the rotation angle of the polarisation plane depends on the number of molecules of the dissolved substance which the light encounters on its path, and hence on the light path length and on the concentration of the solution. The amount of the rotation α of the light polarisation plane is described by Biot law. In the case of an optically active substance (in optically inactive solvent) this law can be written as:

$$\alpha = k d C , \tag{1}$$

where k is the specific rotation of the substance, d is the light path length in the solution, C is the concentration.

The quantity k appearing in the formula (1), called *specific rotation*, determines the rotation angle of light polarisation plane after passing through a solution layer of unit thickness and unit concentration. That quantity depends primarily on the nature of the optically active substance present in the solution and also on the type of solvent, temperature and wavelength.

The value of specific rotation of an optically active substance present in a solution can therefore be determined by measuring the angle of light polarisation plane rotation after passing a known distance d through a solution of known concentration C.

Plan of the measurements

The device used to measure the rotation angle of the light polarisation plane is called *polarimeter*. Many types of these devices exist. This experiment uses a Jamin saccharimeter with Soleil compensator. A saccharimeter is a type of polarimeter that is specially aimed at measuring the concentration of a sucrose solution in water, employing its optical activity. Its schematic construction is shown in Figure 1.

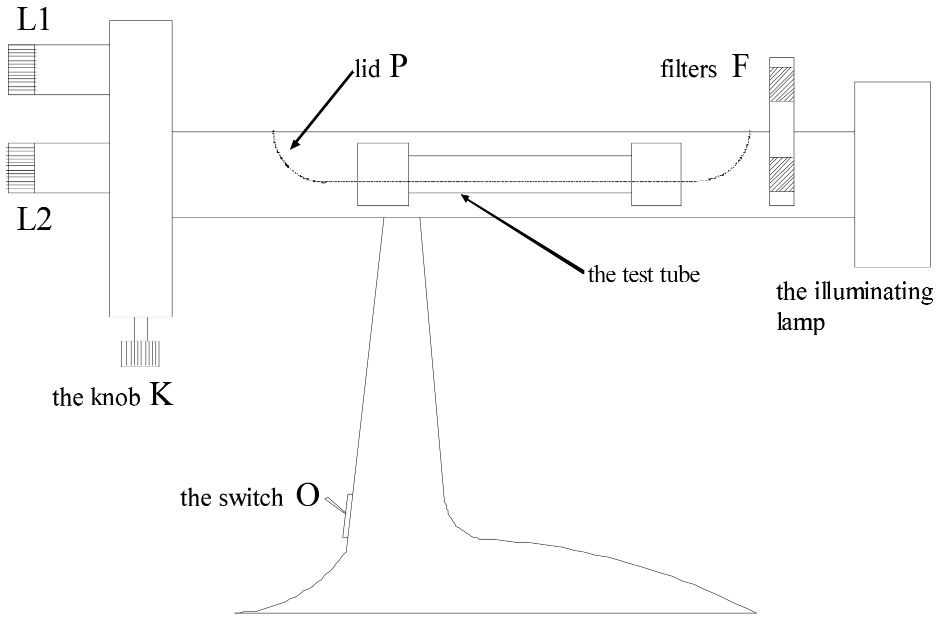

Fig. 1. Schematic construction of a Jamin saccharimeter. L1 - lens for observing the scale, L2 - lens of observing the boundary

A test tube is filled with the analyses solution and placed inside the saccharimeter. The length of the light path is therefore equal to the length of the test tube.

The measuring scale of the device used in the experiment does not give direct readout of the rotation angle of the light polarisation plane, due to certain practical concerns. The saccharimeter readouts i.e. number N of ticks observed on the measuring scale are related to the rotation angle α of the light polarisation plane through the formula

$$N = p\,\alpha, \tag{2}$$

where p is a constant factor. For the saccharimeter used in the experiment, $p = 2.889$ ticks/degree. By including the relation (2) in Biot law (1) we obtain

$$N = p\,k\,d\,C, \tag{3}$$

where d is the length of the test tube. The formula (3) shows the relationship between the saccharimeter readout and the concentration of the analysed solution.

Specific rotation of the given substance can be determined by measuring the value N, proportional to the rotation angle α of the light polarisation plane after passing through a solution layer of thickness d and known concentration C, and then by calculating the value of k from formula (3). A single measurement of N bears a relatively large experimental error, so the value of k calculated from it would not be very accurate. A more accurate value of the specific rotation can be obtained by performing several measurements of N in solutions with different concentration. Such an experiment involves preparing several solutions of an optically active substance, in a few different concentrations, and then determining the respective values of N when light passes through these solutions. According to the formula (3), the dependency of N on the concentration is linear. The plot of that dependency is a straight line with inclination $a = p\,k\,d$. The values of N, being the results of consecutive measurements made for solutions with different concentrations, will lie around that line. The inclination coefficient a of the straight line defined by $N=aC$ can be determined by the least squares method. Knowing the value a, one can then calculate the specific rotation of the studied substance using the formula

$$k = a / p\, d\,. \qquad (4)$$

Sequence of actions

Prepare the saccharimeter for measurements

1. Close the saccharimeter lid P (Fig. 1).
2. Turn on the illumination, using the switch O.
3. Check visibility of the measuring scale by looking through lens L1. If required, correct the focus by gently turning the bushing on lens L1.
4. Check visibility of the boundary between both the halves of the field of view by looking through lens L2. Correct the focus by gently adjusting the bushing on the lens. The field of view should be orange. If it is not, then introduce a yellow filter into the light beam path by turning the knob F.
5. Write down the test tube length *d*. This value is indicated on the tube.

Prepare a water solution of sucrose

1. Weigh an empty weighing container (it must be clean and completely dry). Note its mass m_0.
2. Put some amount of sucrose (agreed with the tutor) in the container – the recommended amount is 2 flat teaspoonfuls.
3. Measure the mass m of the filled container.
4. Put the weighed sucrose amount in a measuring cylinder.
5. Pour approx. 100 ml of distilled water into the cylinder. Stir the solution with a stir rod until the sucrose is fully dissolved. Write down the volume V_0 of the obtained solution. This is the basic solution with concentration C_1.

Fill the test tube with the examined solution

1. Unscrew one cap of the test tube (be careful, as there is glass inside!). Check if the sealing gasket is correctly positioned inside the cap.
2. Make sure the solution is homogenous before filling up the tube (look through the cylinder against a light source to see whether any inhomogenities are visible). **Scrupulous** mixing of the solution is absolutely essential for getting a clear view in the saccharimeter, and hence for proper execution of the measurement.
3. Fill up the tube with the prepared solution. Use enough liquid to form a visible convex meniscus in the tube (perform this activity carefully, so as not to spill the solution).
4. Slide the glass plate onto the tube (cutting off the meniscus) through a horizontal movement, without pressing, so that no air bubble is trapped under the glass. **Gently** screw the cap back onto the tube. Check the sealing by holding the tube upright. Dry up the tube.

Measure the rotation angle of the polarised light plane after passing through the solution

1. Place the test tube filled with the examined solutions in the saccharimeter and close the lid.
2. By turning the compensator knob K, position it in such a way that both halves of the field of view have the same brightness. When the compensator is correctly positioned then even small movements of the knob should visibly change the brightness of both the halves of the field of view (i.e. switching sides of the bright and dark halves).
3. Read the position of the compensator's wedge on the measuring scale visible in lens L1, with accuracy of 1/10 of a mark, by using the visible vernier scale.
   After doing a readout, turn the compensator knob to the leftmost or rightmost position ('untune' the saccharimeter), then again position the compensator as in step 2. Repeat the above procedure three times, writing down the readouts as $N_{1\,1}$, $N_{1\,2}$, $N_{1\,3}$.
4. Empty the test tube after finishing the measurements.

5. By repeating steps 1-3, measure the rotation angle of the light polarisation plane in solutions with different concentrations C_i (i- sequential number of a measurement). Write down the results N_{i1}, N_{i2}, N_{i3}..
   Note: Solutions with other concentrations C_i should be obtained by diluting the basic solution. The method of preparing diluted solutions should be agreed with the tutor.
6. After finishing all the measurements, empty the test tube, turn off the illuminating lamp of the saccharimeter and set the workplace in order.

Prepare the work report

The work report should consist of:

1. Brief description of the measurement methodology, without enumerating the executed steps.
2. Calculation of the concentration C_1 of the basic solution, using the formula

$$C_1=(m-m_0)/V_0. \qquad (5)$$

3. Calculation of the values of concentrations C_i.
4. Results of measurements, arranged in a table.

i	C_i	N_{i1}	N_{i2}	N_{i3}

5. Plot of the $N(C)$ dependency. The straight line representing a linear model of the experimental data should be determined using the method of least squares. Indicate the slope coefficient a and its determination error Δa.
6. Calculation of the specific rotation of sucrose, using the formula (4).
7. Calculation of the experimental error Δk, using the formula

$$\Delta k = \Delta a / p\, d. \qquad (6)$$

8. Final result of the calculations, presented in the form

$$k = k_{\text{calc}} \pm \Delta k,$$

   where k_{calc} is the value of specific rotation obtained from the formula (4).
9. Discussion of the results. Assess the distribution of the experimental data points around the calculated straight line. Analyse possible causes of data points scattering.

Questions

1. What is the meaning of wave polarisation? Can any wave be polarised?
2. What are the types of wave polarisation?
3. Describe the properties of light waves. What is the meaning of light polarisation?
4. Why is the 'natural' light not polarised?
5. How one can determine whether some light is polarised? How to assess the degree of polarisation?
6. Enumerate methods of obtaining polarised light.
7. Explain the process of light propagation in matter.
8. Define the phenomenon of optical activity.
9. Describe the properties of optically active substances.
10. What determines the rotation angle of the light polarisation plane when light passes through a solution of an optically active substance?