PHYSICS EXPERIMENT

Optical Activity

INVESTIGATE THE ROTATION OF THE PLANE OF POLARISATION BY SUGAR SOLUTIONS

- Measurement of the angle of rotation as a function of the length of the sample.
- Measurement of the angle of rotation as a function of the solution concentration.
- Determining the specific rotation for different light wavelengths.
- Comparing the directions of rotation and angles of rotation for fructose, glucose and saccharose.
- Measurement of the angle of rotation during the inversion of saccharose to give an equimolar mixture of glucose and fructose.

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BASIC PRINCIPLES

The term optical activity is used to describe the rotation of the plane of polarisation of linearly polarised light when it passes through certain substances. This rotation is observed in solutions of chiral molecules such as sugars and in certain solids such as quartz. Substances that rotate the plane of polarisation to the right (i.e., clockwise) as viewed against the direction of propagation of the light are described as dextro-rotatory, whereas substances with the opposite behaviour are described as laevo-rotatory. Glucose and saccharose solutions are dextro-rotatory, whereas fructose solutions are laevo-rotatory.

The angle α through which the plane of polarisation is rotated by a solution depends on the nature of the dissolved substance, and it is proportional to the concentration (mass per unit volume) c and to the length or thickness d of the sample. The relationship is expressed as:

$$(1) \quad \alpha = [\alpha] \cdot c \cdot d$$

where $[\alpha]$ is called the specific rotation of the dissolved substance.

The specific rotation depends on the wavelength λ of the light and the sample temperature T, and the relationship has the form:

$$(2) \quad [\alpha] = \frac{k(T)}{\lambda^2}$$

Values of $[\alpha]$ in published tables are usually given for yellow sodium light at an ambient temperature of 25°C. If $[\alpha]$ is known, the concentration of a solution can be determined by measuring the angle of rotation in a polarimeter.

In the experiment, measurements are made on solutions of different sugars in a polarimeter under different conditions, and the angles of rotation are compared. The colour of the light can be changed by choosing between four LEDs. The effect of adding hydrochloric acid to a solution of ordinary cane sugar (saccharose) is also investigated. This causes a slow reaction whereby the double-ring structure is split to give an equimolar mixture of glucose and fructose. During this process the direction of rotation becomes "inverted" from clockwise to anti-clockwise, because the angle of rotation after completion of the reaction is the sum of the angles of rotation of the dextro-rotatory glucose and the more strongly laevo-rotatory fructose.

Fig. 1: Experiment set-up

LIST OF APPARATUS

1	Polarimeter with 4 LEDs	1001057
1	Graduated Cylinder, 100 ml	1002870
1	Beaker 500 ml low form	1025691
1	Electronic Balance 220 g	1022627

Additionally required:

Fructose (fruit-sugar), 500 g
Glucose (grape-sugar), 500 g
Saccharose (cane-sugar), 500 g
Hydrochloric acid, technical grade

PROCEDURE FOR MEASURING THE ANGLE OF ROTATION

When the measurement chamber is empty, the light intensity seen through the viewing hole of the analyser is at a minimum for all colours when the pointer is at the 360° position.

A dextro-rotatory substance in the measurement chamber rotates the plane of polarisation in the clockwise direction as viewed from above. If the analyser disc is now also rotated clockwise – starting from the 360° position – until the light intensity is again at a minimum, the pointer indicates an angle α_P (α_P < 360°). This gives the required angle of rotation as:

$$\alpha = 360° - \alpha_P$$

With a laevo-rotatory substance the analyser must instead be rotated anticlockwise to find the position of minimum light intensity, giving a scale reading α_P. In this case the angle of rotation is:

$$\alpha = -\alpha_P$$

The position for minimum light intensity obtained by rotating the analyser is not sharply defined, because the light from the LED of the polarimeter is not spectrally pure – its spectrum contains different wavelengths, each with a slightly different angle of rotation. Consequently, instead of seeing a definite minimum of light intensity as the analyser is rotated back and forth through the optimal position, one sees a slight colour change.

SET-UP

- Connect the polarimeter to the mains supply using the mains voltage adapter plug.

EXPERIMENT PROCEDURE

Measuring the angle of rotation as a function of the sample length

- Dissolve 50 g of fructose in 100 ml of distilled water by stirring.
- Take the cylindrical sample cell out of the measurement chamber and pour 10 ml of the fructose solution into it (10 ml corresponds to a sample length *d* = 19 mm).
- Wipe the outside of the sample cell dry and place it in the measurement chamber, ensuring that no liquid is transferred to the wall of the measurement chamber.
- Move the selector switch to choose the red LED.
- Place the analyser disc on the top and, observing the light spot of the LED through the viewing hole in the analyser, rotate the analyser until a minimum brightness is reached.
- Record the angle of rotation α, with the correct sign, in Table 1.
- Replace the red LED in turn with the yellow, green and blue LEDs, measure the angle of rotation α in each case, and record the results, with the correct sign, in Table 1.
- Take the sample cell out of the measurement chamber, add a further 10 ml of the fructose solution, and place it in the measurement chamber, ensuring that no liquid is transferred to the wall of the measurement chamber.
- Measure the angle of rotation α for all four colours as before, and record the results, with the correct sign, in Table 1.

Measuring the angle of rotation as a function of the solution concentration

- In a beaker, dissolve 10 g of fructose in 200 ml of distilled water by stirring.
- Take the sample cell out of the measurement chamber, pour 100 ml of the fructose solution into it, and place it in the measurement chamber, ensuring that no liquid is transferred to the wall of the measurement chamber.
- Measure the angle of rotation α for each of the four colours and record the results, with the correct sign, in Table 2.
- Repeatedly take the sample cell out of the measurement chamber, pour the fructose solution back into the beaker, and dissolve a further 10 g of fructose in it.
- Pour 100 ml of the new fructose solution into the sample cell and place it in the measurement chamber, ensuring that no liquid is transferred to the wall of the measurement chamber.
- Measure the angle of rotation α for each of the four colours and record the results, with the correct sign, in Table 2.

Comparing the direction of rotation and angle of rotation for fructose, glucose and saccharose

- Choose the yellow LED.
- Dissolve 35 g of glucose in 100 ml of distilled water by stirring.
- Take the sample cell out of the measurement chamber, pour 50 ml of the glucose solution into it, and place it in the measurement chamber, ensuring that no liquid is transferred to the wall of the measurement chamber. (50 ml corresponds to a sample length *d* = 95 mm.)
- Place the analyser disc on the top and, observing the light spot of the LED through the hole in the analyser, rotate the analyser until a minimum brightness is reached.
- Measure the angle of rotation α and record the result, with the correct sign, in Table 3.
- Dissolve 30 g of saccharose in 100 ml of distilled water by stirring.
- Pour the solution into the sample cell.
- Measure the angle of rotation α and record the result, with the correct sign, in Table 3.
- Also enter in Table 3 the results obtained earlier for fructose.

Measuring the angle of rotation during the inversion of saccharaose

- Choose the yellow LED.
- Take the sample cell containing the saccharose solution out of the measurement chamber.
- Add a little hydrochloric acid, stir, and heat the solution to about 50°C in a water bath.
- Put the sample cell back into the measurement chamber, ensuring that no liquid is transferred to the wall of the measurement chamber.
- Measure the angle of rotation α and record the result, with the correct sign, in Table 4.

- Measure the angle and direction of rotation at intervals of 2-3 minutes, then later at longer time intervals, and enter the results in Table 4.

SAMPLE MEASUREMENTS

The angle of rotation as a function of the sample length

Table 1: Angle of rotation α for fructose as a function of the sample length d for four different light wavelengths. Solution concentration c = 0.48 g/cm³ (50 g fructose in 105 ml water)

d / mm	α			
	red (630 nm)	yellow (580 nm)	green (525 nm)	blue (468 nm)
19	-6°	-7.5°	-10°	-11.5°
38	-15°	-16°	-20°	-23.5°
57	-20°	-25°	-33°	-42°
76	-30°	-32°	-40.5°	-53°
95	-39,5°	-42°	-53°	-68°
114	-42°	-49.5°	-61°	-78°
133	-55°	-58°	-70°	-90°
152	-61°	-70°	-88°	-103°
171	-71°	-80°	-98°	-123°
190	-74°	-83°	-103°	-128°

Note: The two series of measurements in Table 1 and Table 2 were made with fructose of different grades of purity.

The angle of rotation as a function of the solution concentration

Table 2: Angle of rotation α for fructose as a function of solution concentration for four different light wavelengths. Sample length d = 190 mm, volume V = 100 ml

m / g	*c* / mg/cm³	α			
		red (630 nm)	yellow (580 nm)	green (525 nm)	blue (468 nm)
10	50	-7°	-8°	-9°	-10°
20	100	-14°	-16°	-19°	-24°
30	150	-21°	-24°	-30°	-36°
40	200	-27°	-32°	-37°	-43°
50	250	-34°	-37°	-45°	-56°
60	300	-41°	-45°	-53°	-72°
70	350	-47°	-52°	-62°	-73°

Comparing the directions of rotation and angles of rotation for fructose, glucose and saccharose

Table 3: Angle of rotation α for fructose, glucose and saccharose (yellow LED)

	m / g	*V* / ml	*c* / mg/cm³	*h* / mm	α	[α] / deg cm²/g
fructose	50	105	480	190	-83°	-9.2
glucose	35	100	350	95	26°	7.8
saccharose	30	100	300	190	32°	5.6

Measurement of the angle of rotation during the inversion of saccharose

Table 4: Angle of rotation α as a function of the time t during the inversion of saccharose (yellow LED)

t / min	α	*t* / min	α
0.0	33°	20.0	-3°
2.0	23°	24.0	-6°
5.0	16°	27.5	-5°
8.0	9°	33.0	-8°
10.0	6°	42.0	-8°
12.0	3°	45.0	-9°
14.5	-2°	50.0	-9°
16.0	-4°		

EVALUATION

Angle of rotation as a function of the sample length

Figure 2 shows the data of Table 1 as a graph of angle of rotation α against sample length *d*. The data points fit the straight lines drawn through the origin within the limits of accuracy of the measurements, in agreement with the linear relationship for an optically active solution that is described by Equation 1.

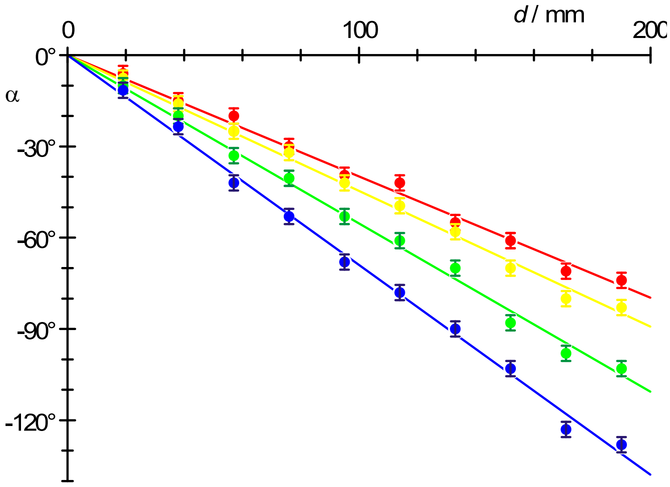

Fig. 2: Angle of rotation of a fructose solution ($c = 0.48$ g/cm³) as a function of sample length for four different light wavelengths

Angle of rotation as a function of the solution concentration

Figure 4 shows the data of Table 2 as a graph of angle of rotation α against solution concentration *c*. The data points fit the straight lines drawn through the origin within the limits of accuracy of the measurements, in agreement with the linear relationship for an optically active solution that is described by Equation 1.

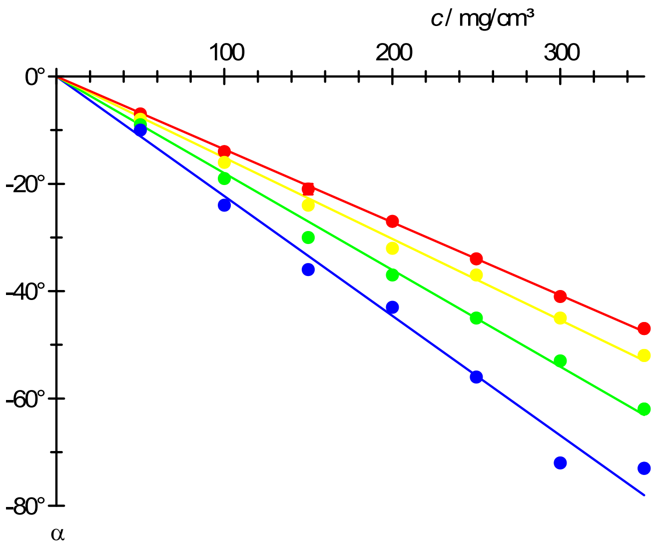

Fig. 4: Angle of rotation for a fructose solution as a function of the solution concentration for four different light wavelengths

Specific rotation as a function of the light wavelength

As the solution concentration of the sample is known, Equation 1 can be applied to determine the specific rotation values [α] for the polarimeter's four wavelengths from the gradients of the straight lines in Figure 2.

The results are shown in Table 5 and Figure 3. The curve drawn in the figure was calculated using Equation 2.

$$k(T) = -3{,}2 \cdot 10^9 \frac{\text{grd}}{\text{g}}$$

Table 5: Specific rotation as a function of the light wavelength

λ / nm	630	580	525	468
[α] / deg cm²/g	-8.4	-9.4	-11.6	-14.5

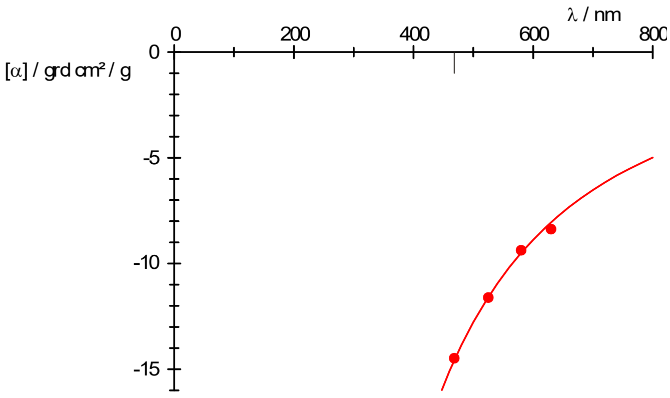

Fig. 3: Specific rotation as a function of the light wavelength

Comparison of the directions of rotation and angles of rotation for fructose, glucose und saccharose

Table 3 lists the specific rotations for the three sugar solutions investigated, calculated from the experimental data using Equation 1. It can be seen that the different sugar solutions behave differently with regard to both the magnitude and the direction of the rotation.

Measuring the angle of rotation during the inversion of saccharose

Figure 5 shows a plot of the data from Table 4. The inversion of the direction of rotation from clockwise to anticlockwise occurs after about 15 minutes.

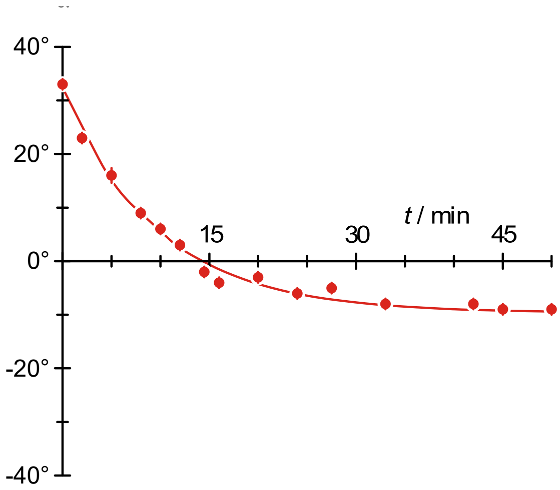

Fig. 5: Angle of rotation as a function of time measured with yellow light during the inversion of a saccharose solution ($c = 0.3$ g/cm³, $d = 190$ mm)