Polarimetry

Physics > Light & Optics > Polarisation

Applied Science > Engineering > Renewable Energy > Basic Principles

Applied Science > Engineering > Photonics > Basic Principles

Difficulty level	Group size	Preparation time	Execution time
hard	2	10 minutes	20 minutes

This content can also be found online at:

http://localhost:1337/c/6002e25ceefa9f0003fe608b

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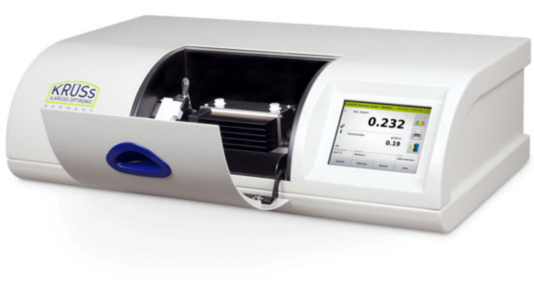
General information

Application



A polarimeter

A polarimeter is a tool to measure optical activity of substances. Its applications can be found in:

- sugar industry: to measure the sugar concentration of syrup
- chemistry: to measure the concentration of chiral molecules in solution.
- target detection: applied as a contrast-enhancing technique

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Other information (1/2)

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Prior knowledge

Chiral molecules are defined as molecules that cannot be superimposed on its mirror image by any combinations of rotations and translations. They are able to rotate the plane of polarized light and the angle by which the polarization plane is rotated is called optical rotation.

Scientific principle

The rotation of the plane of polarisation through a sugar solution measured with a half-shade penumbra polarimeter and the reaction rate constant for the inversion of cane sugar determined.

Other information (2/2)

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Learning objective

Understanding principles of polarimetry and the utilisation of polarimeter.

Tasks

1. To determine the specific rotation of cane sugar (sucrose) and lactose by measuring the rotation of various solutions of known concentration.
2. To determine the reaction rate constant when cane sugar is transformed into invert

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Safety instructions

For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

Do not use your hand or body to touch high temperature solutions.

Theory (1/6)

Optical activity is the ability of many substances to rotate the plane of vibration of a ray of plane-polarised light passing through them. It is caused by the two components of a plane polarised ray of light travelling at different speeds through the asymmetric medium and, in so doing, undergoing a phase shift with respect to one another, this phase shift being indicated as a rotation of the plane of polarisation.

The specific rotation (rotatory power) of solutions of optically active substances is defined as the angle through which the plane of polarisation of a ray of sodium-D light (wave-length λ = 589 nm) would be rotated by a column of solution 100 mm in length, containing 1 g of substance per cm33 at 20°C. It is expressed by the symbol

$$[\alpha]_D^{20^o}$$

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Theory (2/6)

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If we assume that the rotation is proportional to the concentration c, then the specific rotation can be determined from the rotation α at a known concentration:

$$[\alpha]_D^{20^o} = \frac{a}{c}$$ (related to a column length of 100 mm)

If the measurment temperature starts at 20°C, the value obtained must be corrected in accordance with

$$[\alpha]_D^{20^o} = [\alpha]_D^{\theta} - 0.072(20^o - \theta) \qquad (1)$$

for lactose, or

$$[\alpha]_D^{20^o} = \frac{[\alpha]^{\theta}}{1 - 0.00037(\theta - 20^o)} \qquad (2)$$

for sucrose.

Theory (3/6)

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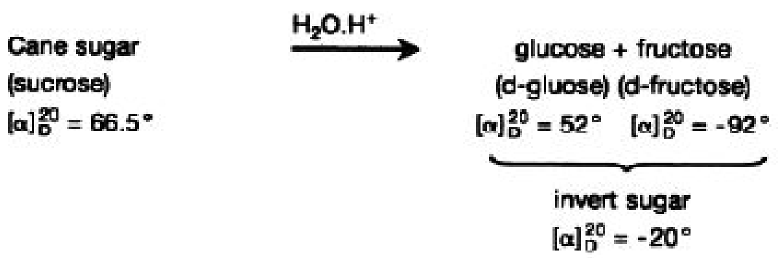

Diagram of cane sugar inversion

In the presence of H+ ions, which have a catalytic effect in this case, an aqueous solution of cane sugar breaks down into optically active glucose and fructose.

This is a first order reaction, i. e. the reaction rate is proportional to the concentration of the cane sugar.

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Theory (4/6)

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Since the reaction rate is defined as the decrease in concentration per unit of time, the differential equation

$$-\frac{dc}{dt} = k \cdot c$$

can be used, from which

$$ln\frac{c_0}{c(t)} = -kt \qquad (3)$$

is obtained after integration, and where kk is the reaction rate constant, c_0 the initial concentration at time $t = 0$ and $c(t)$ the concentration at time.

Theory (5/6)

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If $\alpha(t)$ is the rotation at time t , α_0 the rotation of the pure cane sugar solution and the rotation β of the solution which has been fully inverted, then

$$\frac{c_0}{c(t)} = \frac{\alpha_0+|\beta|}{\alpha(t)+|\beta|}$$

With (3) we obtain

$$k = -\frac{1}{t}ln\frac{\alpha_0+|\beta|}{\alpha(t)+|\beta|}$$

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Theory (6/6)

We can now calculate the reaction rate constant k for each pair of values for t and $\alpha(t)$, and obtain the average value k, or determine it using the expression

$$t = A + B \cdot ln \frac{\alpha_0 + |\beta|}{\alpha(t) + |\beta|}$$

from the slope β of the regression line, applying the relation

$$k = \frac{1}{\beta}$$

Note: The detailed instruction manual of the polarimeter gives examples for several other materials which can be analyzed and will give reproducable results.

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Equipment

Position	Material	Item No.	Quantity
1	Polarimeter, LED, 590 nm	35907-99	1
2	Immersion thermostat Alpha A, 230 V	08493-93	1
3	External circulation set for thermostat Alpha A	08493-02	1
4	Bath for thermostat, makrolon	08487-02	1
5	Digital stopwatch, 24 h, 1/100 s and 1 s	24025-00	1
6	Crucible tongs, 200 mm, stainless steel	33600-00	1
7	Beaker, 250 ml, plastic (PP)	36013-01	2
8	Graduated cylinder 100 ml, PP transparent	36629-01	2
9	Graduated beaker with handle, 1000 ml, plastic (PP)	36640-00	1
10	Funnel, diameter = 100 mm, plastic (PP)	36891-00	1
11	Spoon, with spatula end, 180 mm, plastic	38833-00	1
12	Glass stirring rod, d = 8 mm, l = approx. 300 mm	40485-06	1
13	Pipette with rubber bulb, long	64821-00	1
14	D (+)-Sucrose 100 g	30210-10	1
15	Hydrochloric acid 37 %, 1000 ml	30214-70	1
16	Water, distilled 5 l	31246-81	1
17	D(+)-Lactose, powder 100 g	31577-10	1
18	Balance OHAUS LG 311, 4 beams, 0...311 g	44007-31	1
19	Tubing connector, ID 6-10mm	47516-01	2

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Setup and procedure

Setup

Experimental set-up

To measure optical activity we use a polarimeter in which light of wave-length 589 nm (sodium-D line) is first plane-polarised by a polariser and then studied by a second polariser to find its new plane of polarisation after passing through the sample substance.

In order to increase the accuracy of measurement, in one half of the field of view there is a Laurent's quartz plate which rotates the plane of polarisation through a further small angle. The analyser is now set to equal brightness on the two sides of the field of view: this gives a sharp setting and is easy to reproduce (Weber-Fechner Law).

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Procedure (1/3)

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Task 1

First prepare a cane sugar solution of known concentration c. For example, a solution of concentration $c_0 = 0.24\, g/cm^3$ is made by dissolving 12 g of cane sugar and making up to a total volume of $50\, cm^3$ with distilled water in the measuring cylinder.

The rotation of this solution is determined in the half-shade polarimeter by adjusting the two halves of the field to identical brightness. In all, four concentrations

$c_0; c_0/2\,; c_0/4;\ c_0/8$

are made by making up the solution remaining in the measuring cylinder each time with exactly the same volume of distilled water (it may be necessary to pour some off first).

Procedure (2/3)

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The temperature of the solutions should be the same in all cases. The containing vessels are tempered in the water bath for approx. 5 minutes prior to each measurement.

The same procedure is used for measuring the rotation of lactose (concentration $c_0 = 0.30\, g/cm^3$, for example).

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Procedure (3/3)

Task 2

12 g cane sugar are placed in the measuring cylinder and made up to 50 ml with distilled water ($c_0 = 0.24\, g/cm^3$). When the sugar has dissolved completely (stir it), the measuring vessel is filled and heated in the water bath for approx. 5 minutes at test temperature T (approx. 30°C). This temperature must be maintained throughout the experiment. The measurement of the angle of rotation gives a value α_0 .

The solution remaining in the measuring cylinder is now made up to exactly double the volume with 2n HCl, stirred, placed in the measuring vessel and brought to the test temperature in the water bath. The stop clock is started at this time. The vessel is removed from the water bath after approx. 5 minutes and the angle of rotation measured. The series of measurements is dicontinued after 40–50 minutes and the final angle of rotation determined. For this purpose, the solution is heated to 70°C in the water bath for approx. 5 minutes: this completes the inversion process very quickly. The vessel is then brought back to the test temperature and the final angle of rotation β determined.

Evaluation (1/4)

Using Eq (1), the mean value found for the specific rotation of the lactose solution was

$[\alpha]_D^{20^o} = 53.0^o$,

with a standard deviation:

$s[\alpha]_D^{20^o} = 0.3^o$.

Using Eq (2), the specific rotation of the cane sugar solution was

$[\alpha]_D^{20^o} = 65.3^o$,

with a standard deviation:

$s[\alpha]_D^{20^o} = 1.3^o$.

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Evaluation (2/4)

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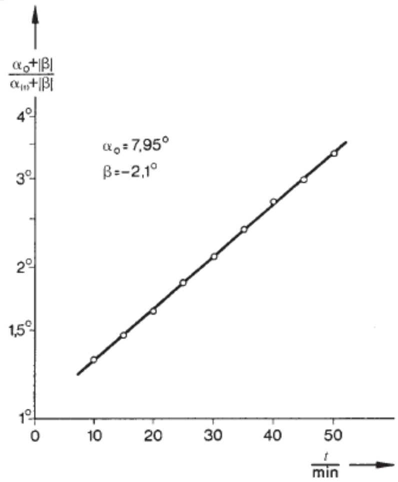

Semi-logarithmic plot of the measured values from cane sugar inversion

Evaluating the measured values shown in the figure, where

$c_0 = 0.24\, g/cm^3$ and

$\theta = 29.5^\circ C$ give

$$k = 23.7\, \pm\, 0.2 \cdot 10^{-3}\, min^{-1}$$

Evaluation (3/4)

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Fill in the blank:

Optical activity is the ability of many substances to rotate the ______ of vibration of a ray of plane-______ light passing through them. It is caused by the two components of a plane polarised ray of light travelling at different ______ through the ______ medium and, in so doing, undergoing a ______ with respect to one another, this phase shift being indicated as a ______ of the plane of polarisation.

- rotation
- asymmetric
- speeds
- polarised
- phase shift
- plane

Check

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Evaluation (4/4)

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What is the principle of a polarimeter?

- ○ Measure angle of rotation of an optical active substance
- ○ Measure concentration of the substance
- ○ Measure rate of reaction
- ○ Measure polarity of the substance

Check

Slide	Score / Total
Slide 20: Optical activity	**0/6**
Slide 21: Principle of polarimeter	**0/1**

Total Score **0 / 7**

Show solutions Retry

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