Kinetics of the inversion of saccharose

Der Reaktionsverlauf der Zucherinversion wird von einer Änderung des Drehwinkels für polarisiertes Licht begleitet. Während Glucose rechtsdrehend ist, dreht Invertzucker die Polarisationsebene linear polarisierten Lichts nach links. Die zeitliche Änderung des Drehwinkels von polarisiertem Licht wird mit Hilfe eines Halbschattenpolarimeters gemessen

Chemistry > General Chemistry > Chemical reactions > Basics of chemical reaction

Chemistry > Organic chemistry > Biochemistry

Chemistry > Physical chemistry > Chemicalkinetics

Biology > Biochemistry

Applied Science > Medicine > Biochemistry

Difficulty level	Group size	Preparation time	Execution time
medium	2	45+ minutes	45+ minutes

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General information

Application

Experimental setup

Many biologically important substances are chiral. The different conformers can have very different functions in biological systems. Many cell receptors and enzymes are highly enantiomer-specific and are specialised in clockwise or counterclockwise connections. Almost all natural amino acids are therefore present in L-form, whereas the D-form predominates for sugars. A good example of stereoselectivity is the thalidomide scandal in the 1950s/60s. This sedative, which was popular at that time, was often used as a sedative for pregnant women. It was only after years of use that it was discovered that the L-form of the chiral molecule had a strong fruit-damaging effect, which led to numerous births of children with malformations. Only the R-form of thalidomide leads to the desired sedative effect.

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Other information (1/2)

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Prior knowledge

Asymmetric carbon centers are carbon molecules in organic compounds that have four different chemical groups attached. They are also called chiral carbon atoms.

Carbohydrates are chiral, which means that they have a certain number of chiral carbon atoms in their molecular structure.

Scientific principle

The inversion reaction of saccharose, which is catalysed by protons, produces invert sugar, which is a mixture of glucose and fructose. The reaction is accompanied by a change in the optical rotation of the system.

Glucose rotates the polarisation plane of linearly polarised light to the right, while inverted sugar rotates it to the left. A half-shade polarimeter is used for the measurement of the change in the angle of rotation of polarised light during the inversion reaction of saccharose over time.

Other information (2/2)

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Learning objective

Using a polarimeter to determine a rotation angle of an optical active substance.

Determination of the reaction rate of saccharose inversion.

Tasks

1. Determine the specific rotation of saccharose and lactose by measuring the rotation angle of solutions of various concentrations.
2. Determine the rate constant of the inversion of saccharose.

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Safety instructions

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- 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.

Theory (1/6)

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Optical activity is the ability of certain substances to rotate the plane of vibration of linearly polarised light. When linearly polarised light passes through such a substance, the radiation components are shifted in phase due to the interaction of substances which contain asymmetric carbon atoms. This phase shift is seen as a rotation of the plane of polarisation.
The specific rotation of optically active solutions is defined as that angle at which the plane of vibration of sodium-D-light (λ = 589.9 nm) is rotated when the thickness of the layer of the solution is 100 mm, 1 g of substance is dissolved in 1 cm^3, and the measurement is undertaken at a temperature of 20 °C.

The angle of rotation α is proportional to the concentration c of the dissolved substance.

The specific rotation [α]D can be so determined by testing solutions of known concentration:

$$[\alpha]_D^{20} = \frac{\alpha}{c}$$

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Theory (2/6)

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Polarimeter

If the temperature of measurement ϑ deviates from 20 °C, the result can be converted to this temperature by using equation (2) for lactose and equation (3) for saccharose:

$$[\alpha]_D^{20} = [\alpha]_D^{\vartheta} - 0.072 \cdot (20^\circ\mathrm{C} - \vartheta)$$

$$[\alpha]_D^{20} = \frac{[\alpha]_D^{\vartheta}}{1 - 0.00037\ (\vartheta - 20^\circ\mathrm{C})}$$

In an acidic environment, saccharose undergoes hydrolytic cleavage into glucose and fructose, in a process catalysed by oxonium ions.

Theory (3/5)

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Dextrorotatory saccharose is converted into dextrorotatory glucose and laevorotatory fructose.

$$\begin{array}{ccccccc} \text{sucrose} & + & \mathrm{H_2O} & \xrightarrow{[\mathrm{H_3O^+}]} & \text{glucose} & + & \text{fructose} \\ [\alpha]_D^{20} = +66.5^\circ & & & & \underbrace{[\alpha]_D^{20} = +52^\circ \qquad [\alpha]_D^{20} = -92^\circ}_{invert\ sugar} & & \end{array}$$

Overall, this reaction corresponds to a pseudo-first order reaction, i.e. the reaction rate depends only on the saccharose concentration.

$$-\frac{\mathrm{d}c}{\mathrm{d}t} = k \cdot c$$

The rate of reaction is defined as the change in concentration dc per unit of time dt.

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Theory (4/6)

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The reaction rate decreases with the concentration c. The proportionality factor of this relationship is the rate constant k, which is characteristic for a specific reaction. Integration of the last equation results in:

$$\ln \frac{c_0}{c} = k \cdot (t - t_0)$$

where c_0 is the initial concentration at time $t_0 = 0$ and $c(t)$ is the concentration at time t.

A change of the concentration corresponds to a change of the angle of rotation.

$$\ln \frac{c_0}{c} = \ln \frac{\alpha_0 - \alpha_\infty}{\alpha_t - \alpha_\infty}$$

where α_t is the angle of rotation at time t, α_0 is the angle of rotation of pure saccharose solution and α_∞ is the angle of rotation when hydrolysis has been completed.

Theory (5/6)

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Taking the last two equations into account, it follows that

$$k = \frac{1}{t} \cdot \ln \frac{\alpha_0 - \alpha_\infty}{\alpha_t - \alpha_\infty}$$

k can also be calculated from the slope $\frac{1}{k}$ of the straight line resulting from

$$t = \frac{1}{k} \cdot \ln \frac{\alpha_0 - \alpha_\infty}{\alpha_t \ \alpha_\infty}$$

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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	Magnetic stirrer with heater MR Hei-Standard	35751-93	1
6	Magnetic stirring bar 15 mm, cylindrical	46299-01	1
7	Magnetic stirring bar 30 mm, cylindrical	46299-02	1
8	Supp.rod stainl.st.,50cm,M10-thr.	02022-20	1
9	Retort stand, h = 750 mm	37694-00	1
10	Universal clamp with joint	37716-00	1
11	Universal clamp	37715-01	3
12	Right angle boss-head clamp	37697-00	4
13	Weighing dishes, square shape, 84 x 84 x 24 mm, 500 pcs.	45019-50	1
14	Digital stopwatch, 24 h, 1/100 s and 1 s	24025-00	1
15	Volumetric pipette, 10 ml	36578-00	7
16	Pipettor	36592-00	1
17	Pipette dish	36589-00	1
18	Volumetric flask, Borosilicate, 50 ml, IGJ12/21	36547-00	2
19	Volumetric flask 500 ml, IGJ19/26	36551-00	1
20	Funnel, glass, top dia. 50 mm	34457-00	1
21	Beaker, Borosilicate, tall form, 100 ml	46026-00	10
22	Crystallizing dish, boro3.3, d = 150 mm	46245-00	1
23	Spoon, special steel	33398-00	1
24	Wash bottle, plastic, 500 ml	33931-00	1
25	Pasteur pipettes, 250 pcs	36590-00	1
26	Rubber caps, 10 pcs	39275-03	1
27	Rubber tubing, i.d. 6 mm	39282-00	2
28	Hose clip, diam. 8-16 mm, 1 pc.	40996-02	3
29	Hydrochloric acid, 1.0 mol/l, 1000 ml	48454-70	1
30	D (+)-Sucrose 100 g	30210-10	1
31	D(+)-Lactose, powder 100 g	31577-10	1
32	Water, distilled 5 l	31246-81	1
33	Tubing connector, ID 6-10mm	47516-01	2

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Setup and procedure

Setup (1/3)

Set up the experiment as shown in the figure left.

Put up a tripod stand (shown in the pictue) and put the waterbath next to it that the clamp (to fix the tube of the polarimeter) is positioned in the waterbath.

Take the waterbath and fill it with water until the heating system is complete covered with water.

Programme the waterbath temperature at 30°C

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Setup (2/3)

- Prepare the solutions required for the experiment as follows:
- **2 molar HCl solution**: Pour the contents of the ampoule (for 1 l of 1 M hydrochloric acid) into a 500 ml volumetric flask and fill up to the calibration mark with distilled water.
- **Saccharose solutions:** Weigh 12.000 g of saccharose into a 50 ml volumetric flask, dissolve it in distilled water, and fill up to the calibration mark with distilled water (c = 0.24 g/ cm^3). Transfer the solution into a 100 ml beaker. Pipette 10 ml of the solution into a second glass beaker and add 10 ml of water (c/2). Prepare solutions of concentrations c/4 and c/8 by pipetting 10 ml each of the c/2 and c/4 solutions into two further glass beakers and adding 10 ml of water.
- **Lactose solutions:** Weigh 1.500 g of lactose into a 50 ml volumetric flask, dissolve it in distilled water, and fill up to the calibration mark with distilled water (c = 0.030 g/ cm^3). Prepare solutions of concentrations c/2, c/4 and c/8 from this as for saccharose.

Setup (3/3)

Using the Polarimeter

Before the measurement is started, rotate the scale knob until you have an equal illumination of the viewing field.

Check the zero-position of the scale. If If necessary, you can unscrew the four connecting screws in the scale's cover and rotate the scale's shell until it reaches the zero-position otherwise you may add or subtract an error value in the actual measurement reading.

For detailed instructions on how to operate the polarimeter, please use the enclosed manual of the manufacturer.

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Procedure (1/3)

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First experiment part - Determination of α_0.

To investigate the kinetics of saccharose inversion, warm the saccharose solution of concentration c = 0.24 g/cm^3 and the 2 molar hydrochloric acid solution to 30 °C in the temperaturecontrolled bath.

Pipette 20 ml of the warm saccharose solution into a 100 ml beaker and add 20 ml of destillied water.

Angle measurement

Fill the polarimeter cell bubble-free with the saccharose solution and hang it into the thermostatic bath.

Warm the polarimeter cell at least for 5 minutes.

Remove the cell from the bath, dry its exterior surface, and after exactly 5 minutes determine the angle of rotation α_0.

Procedure (1/3)

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Second experiment part - Determination of α_t.

To investigate the kinetics of saccharose inversion, warm the saccharose solution of concentration c = 0.24 g/cm^3 and the 2 molar hydrochloric acid solution to 30 °C in the temperaturecontrolled bath.

Pipette 10 ml of the warm saccharose solution into a 100 ml beaker and add 10 ml of hydrochloric acid.

Start the stopwatch.

Angle measurement

Fill the polarimeter cell bubble-free with the acidified saccharose solution and hang it into the thermostatic bath.

In due good time remove the cell from the bath, dry its exterior surface, and after exactly 5 minutes determine the angle of rotation α_t.

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Procedure (3/3)

Third experiment part - Determination of (α_∞).

Again temperature equilibrate the cell and take a value every 5 minutes, following the same procedure as in part one. Stop the measurement series after 50 minutes.

Parallel to this, mix 10 ml saccharose solution of concentration c = 0.24 g/cm^3 and 10 ml of 2 molar hydrochloric acid solution in a 100 ml beaker and heat it to 70 °C on a magnetic heating stirrer, using a 600 ml beaker as water bath.

After 10 minutes, temperature equilibrate it in the thermostatic bath to 30 °C and then measure the angle of rotation (α_∞).

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Evaluation

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Evaluation (1/5)

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Determine the rate constant of the inversion of saccharose !

Evaluation (3/5)

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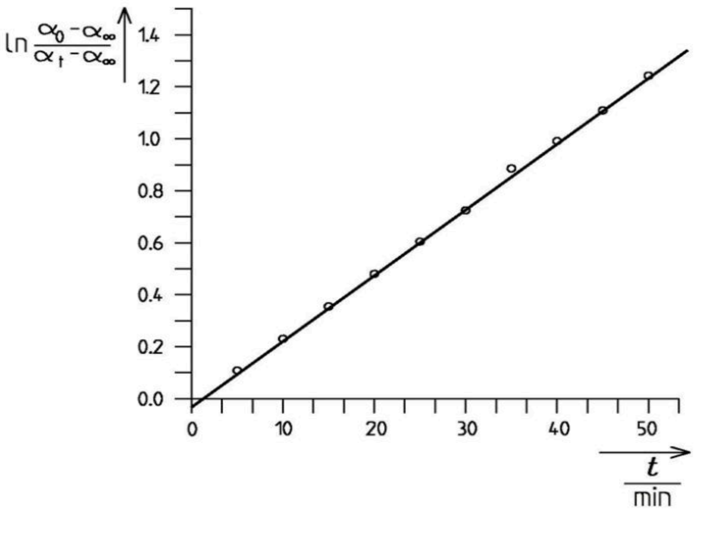

The figure shows the experimental values obtained for $c_0 = 0.12 \frac{\mathrm{g}}{\mathrm{cm}^3}$ and 30 °C.

$$t = \frac{1}{k} \cdot \ln \frac{\alpha_0 - \alpha_\infty}{\alpha_t \;\; \alpha_\infty}$$

They result in a rate constant of $k = 2.5 \cdot 10^{-2}\ \mathrm{min}^{-1}$.

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Evaluation (3/5)

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Name all parameters that influence the optical rotation!

The magnitude of the optial rotation is affected by...

Evaluation (4/5)

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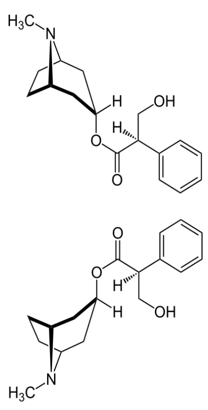

Atropine

What is a Racemat ?

- Optically active mixture of two optically inactive enantiomers.
- Optically active mixture of two constitutional isomers.
- Optically inactive mixture of two optically active enantiomers.
- Optically inactive mixture of two constitutional isomers.

Check

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Evaluation (5/5)

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Which processes do you know for the production of polarized light?

Slide	Score / Total
Slide 23: What is an Racemat ?	0/1

Total Score 0/1

Show solutions | Retry | Export text

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