Related topics

Half-shade principle, optical rotatory power, optical activity, saccharimetry, specific rotation, reaction rate, Weber-Fechner Law.

Principle and task

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.

Equipment

Half-shade polarimeter, 220 V AC		08628.93	1
Immersion thermostat A100		46994.93	1
Accessory set for A100		46994.02	1
Bath for thermostat, Makrolon		08487.02	1
Stopwatch, digital, 1/100 sec.		03071.01	1
Crucible tongs, 200 mm, stainl.steel		33600.00	1
Beaker, 250 ml, low form, plastic		36013.01	2
Graduated cylinder, 100 ml, plastic		36629.01	2
Graduated vessel, 1 l, w. handle		36640.00	1
Funnel, plastic, dia 90 mm		36891.00	1
Spoon, w. spatula end, 18 cm, plastic		38833.00	1
Glass rod, boro 3.3, l = 300 mm, d = 8 mm		40485.06	1
Pipette, with rubber bulb, long		64821.00	1
D (+)-Sucrose	100 g	30210.10	1
Hydrochloric acid 1.19	2500 ml	30214.79	1
Water, distilled	5 l	31246.81	1
D(+)-Lactose, powder	100 g	31577.10	1
Balance LG 311, 4 beams		44007.31	1

Problems

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 sugar.

Fig. 1: Experimental set-up for measuring the rotation of sugar solutions.

Set-up and procedure

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).

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

   $$c_0; \frac{c_0}{2}; \frac{c_0}{4}; \frac{c_0}{8}$$

   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).

   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).

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.

Theory and evaluation

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 $\lambda = 589$ nm) would be rotated by a column of solution 100 mm in length, containing 1 g of substance per cm^3 at 20 °C. It is expressed by the symbol

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

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:

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

(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

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

for lactose, or

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

for sucrose.

The mean value found for the specific rotation of the lactose solution was
$[\alpha]_D^{20^\circ} = 53.0°$, with a standard
deviation s $[\alpha]_D^{20^\circ} = 0.3°$

The specific rotation of the cane sugar solution was
$[\alpha]_D^{20^\circ} = 65.3°$, with a standard
deviation s $[\alpha]_D^{20^\circ} = 1.3°$

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.

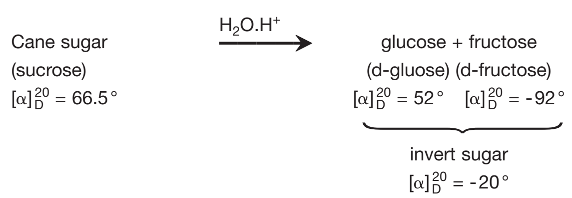

Fig. 2: Diagram of cane sugar inversion

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

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

$$\ln \frac{c_0}{c(t)} = -k\,t \qquad (1)$$

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

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

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

With (1) we obtain

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

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

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

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

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

Evaluating the measured values shown in Fig. 3 (c_0 = 0.24 g/cm^3, ϑ = 29.5 °C) gives

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

Note

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

Fig. 3: Semi-logarithmic plot of the measured values from cane sugar inversion.