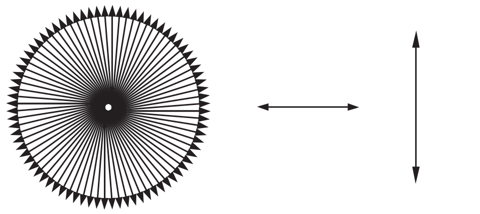
Technical basics polarimetry

Classical physics teaches that light consists of electromagnetic waves, which's vibrations are transverse to the direction of propagation. Polarized light is light, which's vibration pattern exhibits preference. If natural light passes through a so called polarizing filter, most of it's other vibrating directions will be filtered out, leaving only one specific direction. If this light is oscillating then in only one direction, it is called "linearly polarized".



Natural light Polarized light

There is a great number of organic and inorganic substances being optically active in their crystalline, liquid or dissolved state. That means, these substances are able to rotate the direction of oscillation of polarized light around a determined angle.
Typical optically active substances contain at least one asymmetric atom in their molecule structure. Such atoms are C(arbon), S(ulphur), P(hosphor), Si(lica) and few others. This asymmetry leads to the formation of two isomers (+;-) which both cause an optical rotation, but in different directions. Some well known optical substances are tartaric acid, lactic acid, benzoic acid and derivates, amino acids, proteins and of course sugars.
If an optically active substance (f.i. sugar) is dissolved in an optically inactive liquid (as water for instance), the degrees of angle rotation, depend - amongst others - on the concentration of the solution. This angle of rotation is absolutely determined by a polarimeter with highest precision.

General structure of a polarimeter

The principle of the polarimeter is accomplished if a dissolved optically active substance is introduced between two polarizing filters, crossed at 90°.
The intensity of the light on the detector behind the second polarizing filter varies as a function of the angular position of these two filters.
Optical rotation in general means that the polarization of the direction of light will be rotated for a certain angle when penetrating an optically active substance.

A simple polarimeter contains at least the following parts:

Light source · Polarising filter · Sample tube · Polarising filter · Detector

At point zero, polarizer and analyzer are set in an angle of 90° towards each other, which means that no light reaches the detector (0% transmission). As soon as an optically active substance is introduced into the sample room, the transmission will be rising in consequence of the plane of polarization. To measure the angle of the rotation, the analyzer is rotated up to a point where the transmission of the detector is again at a minimum. Optical rotation is measured in degrees of angle; this kind of instruments are thus called circle polarimeters.
In order to determine the exact compensation position, SCHMIDT+HAENSCH uses faraday modulation as an electronic enhancement. Without mechanical transmission by a V-belt or gear being necessary, we applies a direct coupling of optical encoder and analyzer in all measuring instruments.
That is how a high accuracy throughout the entire measuring range is achieved. Additionally, these principles guarantee for short measuring times and no mechanic wear. Consequently, highest sensitivity and fastest compensation time over the entire measuring range is archieved. The continuous measurement is also allowing monitoring of muto-rotation.

Dependency of the optical rotation

1. Nature of the sample
2. Concentration of the optical active components
3. Wavelength of the light
4. Temperature of the sample
5. Optical path length (length of the measuring tube)

The corresponding formula was found by the French physician Jean B. Biot and described as following in the "Biot's law":

$$C = \frac{a}{[\alpha]} \cdot \frac{10000}{L}$$

c = concentration in g/cm^3
L = tube length in mm
$[\alpha]$ = specific rotation (depending of temperature and wavelength)
a = measured rotation in angular degrees

Example

26 g of sucrose dissolved in pure water and filled up to a volume of 100 cm^3 has an optical rotation of 34.626° ang ± 0.001° in a 200 mm sample tube at 20°C under normal pressure (1013 hPa) at a wavelength of 589.44 nm. This solution is called normal sugar solution. It was used to calibrate and standardize polarimetric methods and instruments and is also the origin of the International Sugar Scale (ISS) defined by ICUMSA. The rotation of 34.626° ang corresponds to a concentration of 26 g saccharose respectively 100.00°Z (sugar). ISS is linear, that means a rotation of 17.313° ang corresponds to 50.00°Z (13 g/100 cm^3).
Sugar solutions are not very stable and have to be renewed regularly. Checking a polarimeter by a quartz plate is a much more reliable method. In 1811 already the French physician F. Arago discovered the polarizing qualities and optical activity of natural quartz. The rotation depends on the thickness of the quartz, on the wavelength of the light and, most important, it's wavelength dependency is almost the same as that of a sucrose solution. Quartz control plates are used today as a standard for the calibration of polarimeters.

The influence of the wavelength – optical rotatory dispersion (ORD)

In the polarimeter used in the sugar industry four different wavelengths are being applied. At these wavelengths and at a temperature of 20°C, the following specific rotations $[\alpha]$ and angular rotations of a "standard sugar solution" in a 200 mm tube are being measured:

Description	Wavelength	$[\alpha]$	α
Mercury green	546.23 nm	78.4178°	40.777°
Sodium, yellow	589.44 nm	66.5885°	34.626°
HeNe-Laser	632.99 nm	57.2144°	29.751°
NIR	882.60 nm	28.5462°	14.844°

For more detailed definitions of the International Sugar Scale, please consult "Specification and Standard SPS-1 (1998): Polarimetry and the International Sugar Scale" in the ICUMSA methods book.
The angles measured at the four wavelengths clearly show a significant dependency of the wavelength of the light on the optical rotation. Changing the wavelength for 0.03 nm leads to a shift of the value of optical rotation for 0.01% (that means a change of 0.035 angular degrees for a "standard sugar solution" measured at 589 nm). Thus in polarimetry only light sources with a very narrow spectrum are being applied. Typically, this is achieved today with a halogen lamp and an interference filter with a narrow spectral half width.

The quartz wedge principle

Quartz has an optical rotation dispersion (ORD) almost identical to that of a sucrose solution. This fact is exploited as a unique compensation mechanism using a quartz wedge in SCHMIDT+HAENSCH's SACCHAROMAT®. When a sample is introduced, the quartz wedge slides into the optical path (equivalent to changing the thickness of the quartz) to a point where the optical rotation of the sample is exactly compensated. The position of the wedge is then determined by a linear encoder, giving rise to a very precise measurement.
The principle of quartz wedge compensation is unique and is unrivalled today. With its high precision and high reliability it is used through out the sugar industry.

As the quartz and the sample react in an identical way to small shifts of the wavelength, these shifts are beeing automatically compensated and the effect becomes irrelevant. This ensures highest wavelength stability without the necessity of recalibration over the lifetime of the instrument.
The quartz wedge principle also results in higher optical light input allowing very dark solutions to be easily measured.

- Little influence of wavelength shifts
- Long time stability of measured values without calibration being necessary

Temperature effects

The measured optical rotation values depend on the temperature. The rotation of quartz for example raises with higher temperatures:

Rotation (T) = rotation (20.0°C) x (1.0 + 0.000144 x (T-20.0))

A quartz plate, showing a value of 40.000° ang at a temperature of 20°C, will give a value of 40.006° ang at 21°C and the value will even raise to 40.029° ang at 25°C already.

In contrast, the rotation of a sucrose solution will decrease with rising temperature:

Rotation (T) = rotation (20.0°C) x (1.0 - 0.000471 x (T-20.0))

A solution indicating 40.000° ang at a temperature of 20°C, will indicate only 39.981° ang at 21°C and just 39.906° ang at 25°C.

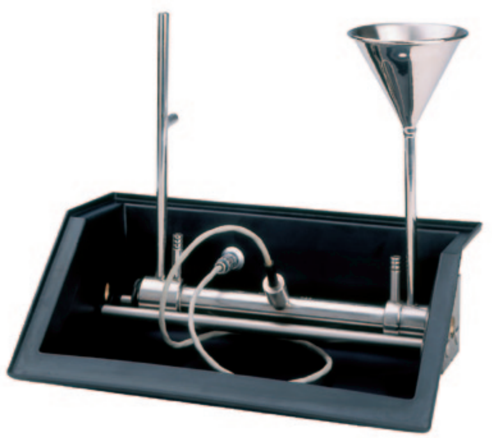
Please consider, that there are three temperature effects on diluted samples:

1. The flask, which is applied to fill up the 100 cm^3 is calibrated for 20°C.
2. The length of the tube is valid for 20°C.
3. The optical activity of the sample is influenced by the temperature.

The formula given above only counts for the third effect. To compensate all temperature effects, the SACCHAROMAT's® quartz wedges are equipped with a temperature sensor that is also optionally available for the tubes.

SCHMIDT+HAENSCH guarantees for the precision of it's Polarimeters only as long as original SCHMIDT+HAENSCH measuring tubes are used. These tubes offer a certified tolerance in length (0.02 mm for a 200 mm tube, 0.01 mm for a 100 mm tube.)

To measure unclarified samples, SCHMIDT+HAENSCH recommends the system AutoFilt®. This semi automatic filtration system filtrates an industrial sugar solution to a turbidity-free state within 30 sec. maximum.



Flow-through tube with T-sensor

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