Polarimetry

Polarimetry is an instrumental analytical method using rotation of polarized light by some substances as a measure of their concentration in a solution. The instrument used is called a polarimeter. When it is adapted for measuring quality of sugar the name saccharimeter is used. In both instruments it is the rotation of polarized light by a substance in a solution which is measured. Usually, it is only one instrument which has two interchangeable scales, one labelled in angular degrees ^{0}, the other in units ^{0}Z, named International Sugar Scale (I.S.S.).

Polarimeter

Figure 1 shows a principle of a polarimeter set up and its main components together with their function. Unpolarized light from the light source is first polarized. This polarized light passes through a sample cell. If an optical active substance is in a sample tube, the plane of the polarized light waves is rotated. The rotation is noticed by looking through the analyser as a change in intensity of illumination. To reach the same illumination as was without an optical active sample the analyser must be turned around for an angle. Readings are taken in degrees (angle) α or sugar degrees ^{0}Z.

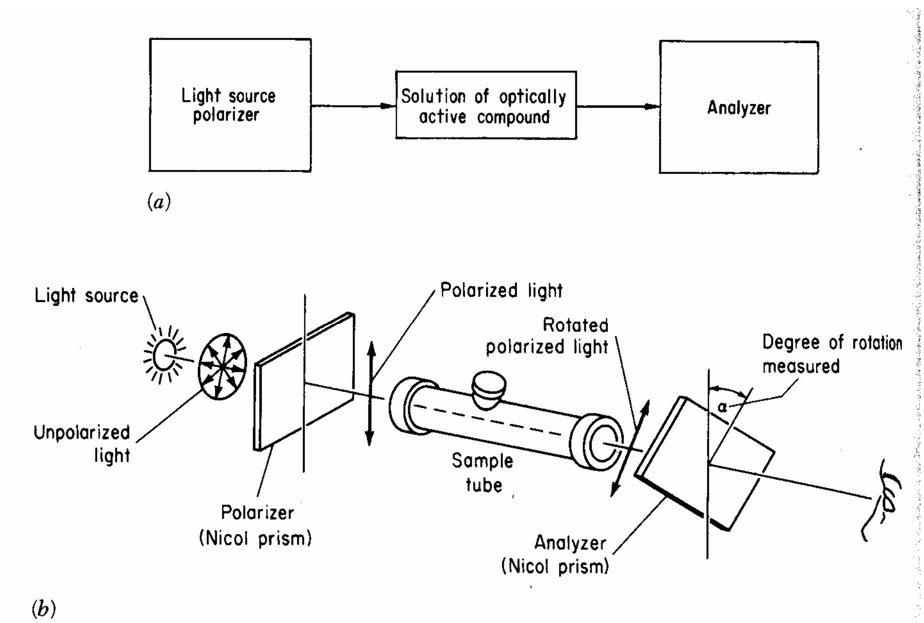

Figure 1: a) principle of a polarimeter set up

b) components of a polarimeter

Figure 2 shows polarizer (P) and analyzer (A) in a perpendicular position with one another. Both have the structure on a molecular level that polarize an unpolarized light. If they are in a position shown no light passes through analyzer. Polaroid films for example have such a molecular structure that filters (block) all planes of light vibrations except one. Nicol prisms are made of calcite ($CaCO_3$) crystals, which show double refraction phenomenon. Both beams are polarized but only one is enough to be used for polarizing unpolarized light.

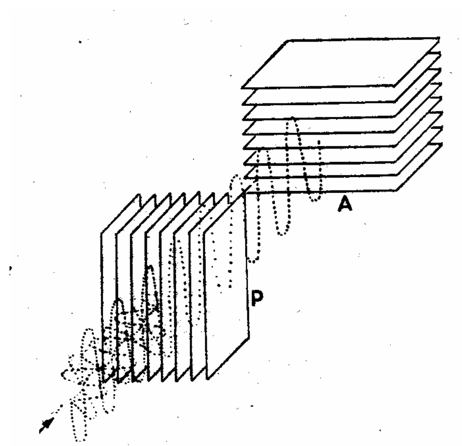

Figure 2: One of mutual positions of a polarizer and an analyzer

Figure 3 shows the passage of polarized light through a sample tube, which is positioned between polarizer and analyzer. The length of the tube is one of important parameters to be fixed if the measurements were comparable.

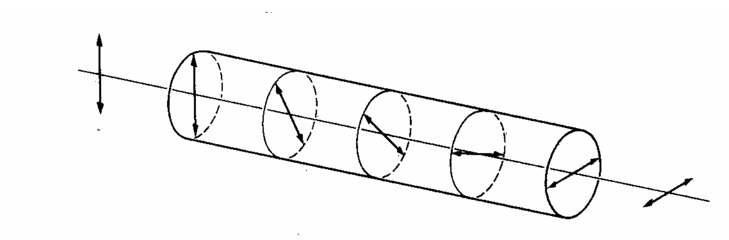

Figure 3: Rotation of polarized light plane by a sample with an optical active substance and the influence of the length of sample tube

Optical Rotation

Certain compounds, mostly organic (notably those containing asymmetric carbon atoms) rotate the plane of polarized light. The phenomenon is called optical rotation and such substances optically active compounds.

Measuring angle of rotation the concentration of a substance in a solution is determined.

The measured angle of rotation depends upon many variables:

- The type or nature of sample (example: sugar solution)
- Concentration of the optical active components
- The length of the sample tube
- The wavelength of the light source
- Temperature of the sample

We describe the nature of a sample by introducing the specific optical rotatory power (or specific rotation) of a substance, defined as

$$[\alpha]_{\lambda}^{\Theta} = \frac{\alpha}{\gamma . l}$$

in SI units: rad m^2 kg^{-1} (Notice: 2π rad = 360 ^{0} (deg of angle))

where α is the angle of rotation in rad, γ is the mass concentration in kg/m^3, and *l* is the length of the sample tube in m. Specific rotation is determined at a specified temperature Θ (usually 20 ^{0}C) and a wavelength of light source (usually sodium lamp with its D line at 589 nm).

Some substances rotate the light to the right (or clockwise) as viewed looking towards the light source, we sign this rotation and α as +, some to the left (or anticlockwise), signing α as -.

In practical measurements readings are taken at different units: α in ^{0} (deg), γ in g/cm^3, *l* in dm and so $[\alpha]_D^{20^0}$ is usually tabulated in ^{0} cm^3/g dm.

Substance in a solution H_2O solvent	Specific rotation $[\alpha]_D^{20^0}$ [^{0} cm^3/g dm]
sucrose	+ 66.54
glucose	+ 52.74
fructose	- 93.78
maltose	+ 137.5
lactose	+ 55.3
dextrose	+ 194.8

For example:

Sucrose (cane sugar) solution $[\alpha]_D^{20^0}$ = + 66.54 ^{0}/dm at a concentration of 1 g/cm^3.

The influence of the wavelength of a light source for sugar solutions is seen from the following table:

Description of the light source	Wavelength [nm]	Specific rotation $[\alpha]_D^{20^0}$ [^{0} cm^3/g dm]
Mercury, green	546.23	+ 78.4178
Sodium, yellow	589.44	+ 66.5885
HeNe Laser	632.99	+ 57.2144
Near Infrared (NIR)	882.60	+ 28.5462

Notice the high precision of specific rotation determined with modern polarimeters.

Temperature dependence of specific rotation is for sugar solutions as follows:

$$\alpha\,(t) = \alpha\,(20.0\ ^0C)[1.0 - 0.000471\ (t - 20.0)]$$

or calculated for some temperatures of a sucrose solution at some concentration:

Temperature ^{0}C	Rotation of a sucrose solution α [^{0} angle deg]
20	40.000
21	39.981
25	39.906

Notice the decrease of the rotation of sucrose solution with rising temperature. Also the effect of temperature is relatively small.

Polarimetry of sugar solutions

Polarimetry is frequently used for determining the quality of sugar products. Measurements are made by polarimeters or saccharimeters with the scale in angle degrees (^{0}) and sugar degrees (^{0}Z). Angle of rotation depends linearly on concentration of sugar in the solution other parameters (temperature, light source, length of the tube) being the same.

Sugar industry with its International Commission for Uniform Methods of Sugar Analysis (ICUMSA) introduces International Sugar Scale (ISS) in ^{0}Z units.
100.00 ^{0}Z units (sugar degrees) belong to Normal Sucrose Solution prepared from exactly 26.000 g of sucrose dissolved in pure water to 100 cm^3. At 20 ^{0}C and D sodium lamp rotation for this solution in a tube of 200 mm will be
α = +34.626 ^{0}. The ISS is linearly divided, i.e. a rotation of +17.313 ^{0}
(13 g/100 cm^3) equals to a reading of 50.00 ^{0}Z.
The 0 ^{0}Z point in ISS is fixed by the indication given by the saccharimeter for pure water.
Normal Sucrose Solution was used to calibrate and standardize polarimetric methods and instruments. Sugar solutions are not very stable and have to be renewed regularly.

Today quartz control plates are used as a standard for the calibration of polarimeters.
Interrelation between both scales is defined from a straight line (y = a.x) equation:

$$^{0}Z = \frac{100.00}{34.626}\,.\,^{0}\,(\mathrm{deg}) = 2.889.\,^{0}\,(\mathrm{deg})$$

Authors: Jelka Sodja-Božič, Tomaž Ogrin
Institution: Josef Stefan Institute

For further information see:
http://micro.magnet.fsu.edu/optics/lightandcolor/polarization.html (animation)
http://micro.magnet.fsu.edu/primer/java/scienceopticsu/polarizedlight/filters (animation)
http://www.oiml.org/publications/R/R014-e95.pdf (ICUMSA Int. Sugar Scale)
http://www.schmidt-haensch.com/v1/datenblatt_gb/polarimetereng.pdf (overview polarimeters, polarimetry for sugar industry)
http://www.topac.com/saccharomat.pdf (short overview technique)
http://www.opticalactivity.com/sugar.htm (polarimeters)
http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html (on polarization)
http://www.glenbrook.k12.il.us/gbssci/phys/Class/light/u1211e.html (polarization)
http://ts.nist.gov/ts/htdocs/230/232/232.htm (then SRM No. 917b and View Certificate of Analysis)
http://mineral.galleries.com/minerals/carbonat/calcite/calcite.htm
http://en.wikipedia.org/wiki/Calcite (double refraction crystal picture)
http://dl.clackamas.cc.or.us/ch106-07/optical.htm

Reference text books

1. G.J. Shugar, J.T. Ballinger, Chemical Technicians' Ready Reference Handbook, McGraw-Hill, Inc. 1996, p. 448-454
2. D.P. Shomaker, Experimental Physical Chemistry, McGraw-Hill, 1989 p 728-729
3. R.H. Petrucci, General Chemistry, Prentice Hall, International, Simon &Schuster/A Viacon Company, 1997 p. 875
4. Official Journal of the European Communities, 1979, No 239/52, Method for determining quality of sugar p. 309