Technical basics refractometry

The speed of light and the refractive index
In a vacuum, light travels at 300.000 km/s while travelling through water, the speed is about 225.000 km/s, which is 25% less. In a sapphire it will only reach 170.000 km/s.
A refractometer is a measuring instrument for the speed of light. The result will not be indicated directly but related to the speed of light in air. This comparison is called refractive index. The indication, that a certain material has a refractive index of 1.5 thus means, that the speed of light travels 50% faster through air than through this material.

Who is interested in the speed of light in samples? The refractive index is a value specific to a material. It depends on temperature and wavelength (λ = colour) of the light. Thus using a refractometer, will enable you to determine the concentration of a material, if temperature and wavelength are known. But it is also possible, that different materials have the same refractive index at various concentrations. Thus a clear determination of liquid substances may only be successful with binary mixtures (Mixtures consisting of two compounds).
In practice, the refractive index determines the mixing ratio also of multicompound solutions quite exactly and easily as in general only the concentration of one of the componends needs to be determined. Thus it is a quantitative measurement. With known compounds, also quality may be determined. For mixtures like for example olive oil or orange juice, the measuring value within a certain range corresponds to a certain quality.

Thus refractometry is a quality control of substances

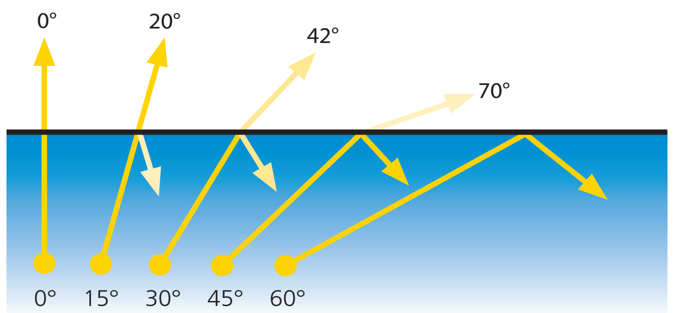
There is a definite correlation between the refractive index and the composition of many two-compound solutions. The best known example for such a mixture is a solution of sucrose in water, which has been studied throughly. A refractometer can be grated in a way that the value may be indicated directly as dry substance %RTS. For sucrose, this unit is also named Brix (abb. Bx). The determination of the density of samples can also be done with refractometry. As a rule in optical measuments density and dry substance corresponds to each other.

Refractometers convert the measured refractive indices in concentration or density.

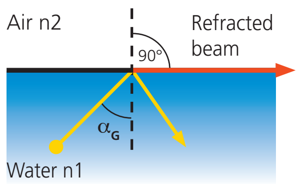
How can the refractive index be measured?

To understand total internal reflection, we begin with a thought experiment. Suppose that a laser beam inside of a water tank aims towards the air-water boundary. Then suppose that the angle at which the beam directed upwards is slowly altered, beginning with small angles of incidence and proceeding towards larger and larger angles of incidence.

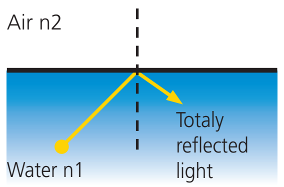
The principles of boundary behaviour let us expect that we would observe both reflection and refraction. We would also observe that the intensity of the reflected and refracted rays do not remain constant. At angle of incidence close to 0 degrees, most of the light energy is transmitted across the boundary and very little of it is reflected. As the angle is increased to greater and greater angles, we would begin to observe less refraction and more reflection. That is, as the angle of incidence is increased, the brightness of the refracted ray decreases and the brightness of the reflected ray increases. Finally, we would observe that the angles of the reflection and refraction are note equal. Since the light waves would refract away from the normal, the angle of refraction would be greater than the angle of incidence. In case the incident angle is 60° there will be no refracted ray any more, we would say: light is totally reflected. These principles are depicted in the diagram below.



A more detailed picture below shows the case where light impinges under such special angle that the refracted beam makes an angle of 90° with the surface normal.



Critical angle



Total reflexion

There comes a time when all of the rays are reflected, this happens when the angle of incidence is equal to or greater than the critical angle α_{crit}, which is defined by the ratio of the two indices of refraction:

$$\sin \alpha_{crit} = n_{air} / n_{water}$$

Where n_{air} and n_{Water} are the indices of refraction of the air and water, respectively. Generally this behaviour can be written down in mathematical form as the snellius law, with the refractive indices n1 for water and n2 for air:

$$n1 \cdot \sin \alpha 1 = n2 \cdot \sin \alpha 2$$

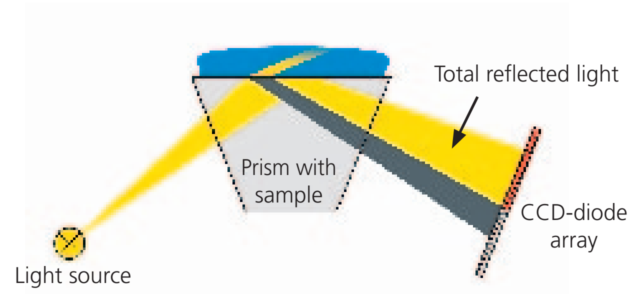
Since the angle $\alpha 1$ can max. be 90°, thus causing $\alpha 1$ becoming one, we can conclude:

$$n1 \cdot \sin \alpha G = n2$$

or in a different way:

$$\alpha_{crit} = \arcsin (n2 / n1)$$

The above formula means: if one knows exactly the refractive index of the more dense medium n1, which could for example be a glass prism or made of artificial sapphire, then by measuring the critical angle of total reflection, one could find out the refractive index of the second medium n2.



Since the light beam only probes a fraction of wavelength into the second medium very dark and turbid samples can be measured without problems. By inserting a drop of liquid on top of the measuring prism a very sharp line will appear dividing regions of below and above the critical angle. SCHMIDT+HAENSCH instruments determine the position of borderline by a high resolution CCD-diode array, thus without moving parts.

Temperature effects
A solution of 40 g of sucrose in 100 g of water has a refractive index (RI) of 1.39986 at a temperature of 20°C. The same solution has a much lower RI value 1.39828 at 30°C.
The difference in the measured values is caused only by the change of the temperature and not by change of the concentration. The so called temperature correction therefore considers the influence of the temperature on the solution to be measured. This is generally a non-linear behaviour (matrix) in dependency of the different concentrations. Usually the product having been described the best is sucrose in purest water solution: the so called Brix scale.
A Brix scale therefore has to take into consideration the exact temperature, to be able to calculate the correct value.
SCHMIDT+HAENSCH pays great attention to high stability of the temperature and temperature control during the measurement while developing and manufacturing our measuring devices. There are two different technical solutions offered:
- an active, external temperature adjustment by thermostat as well as an
- internal Peltier temperature regulation.

Doing a pure sugar measurement, there is no need to apply a temperature regulation as the measured value for the Brix scale is temperature corrected automatically.
SCHMIDT+HAENSCH offers customer specific scales, linearised as far as concentration and temperature dependency are concerned. Most of our devices can be programmed for different products by the buyers themselves, too.

Example: At a temperature of 20°C, cyclohexane has the same refractive index as a sucrose solution of 52.9 Brix.
But at a temperature of 25°C, the same cyclohexane has the refractive index of a sucrose solution of 52.1 Brix. That means that a special scale, which shows the value for cyclohexane in a temperature corrected way, may not be used for measuring sucrose solutions at the same time.

Every temperature correction is substance specific.

40 Brix solution, 0.00015 per °C

Temperature	20.0°C	20.1°C	21.0°C
Refractive index	1.39986	1.39985	1.39971

Paraffine oil, 0.00036 per °C

Temperature	20.0°C	25.0°C	30.0°C
Refractive index	1.48001	1.47825	1.47644

We conclude that it is possible to dertermine a temperature correction for a substance and to program a refractometer in a way that it indicates only the concentration of this substance independent of the measuring temperature.

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