ABBE Zeiss Refractometer

By Cécile PITOT

Refractometers are commonly used in different types of industries. They are used to measure the concentration of fat in milk, butter or sugar in food industry. They are also used to measure the refractive index in chemical industry or in jewelry.

This Abbe Refractometer serves for the determination of the refractive **index and the color dispersion of liquids, plastic and solid substances** within the range of n_d **1,3 to 1,7**.
Apart from exceptional cases, white light is used; the refractive indices so obtained exactly correspond to those of **yellow sodium spectral** line (wavelength = 589 nm).

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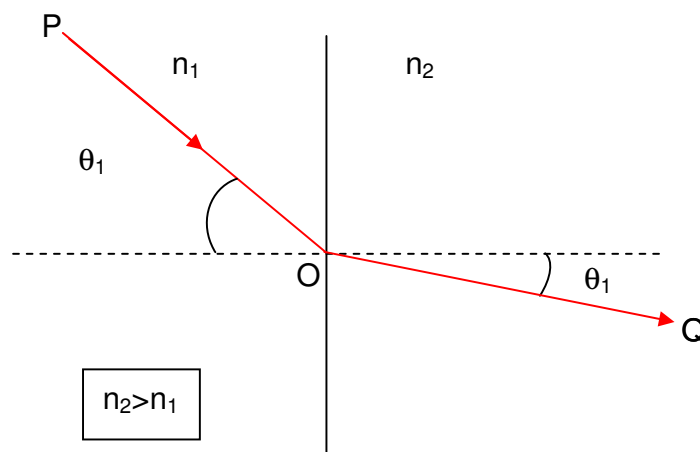
The phenomenon by which the direction of the light is modified after passing through an optic medium is called the refraction. It comes from a change of propagation velocity of the light. The refractive index n characterizes the propagation velocity of a medium and depends on temperature, concentration and pressure.

n = propagation velocity of the light in the vacuum / propagation velocity of the light in the medium

Snell-Descartes law

In the diagram below, two media of refractive indices n_1 (on the left) and n_2 (on the right) meet at a surface or interface (vertical line). $n_2 > n_1$, and light has a slower phase velocity within the second medium.

A light ray **PO** strikes the interface at the point **O**. From point **O**, we project a straight line at right angles to the line of the interface; this is known as the normal to the surface (horizontal line). The angle between the normal and the light ray **PO** is known as the *angle of incidence*, θ_1.

The ray continues through the interface into the medium on the right; this is shown as the ray **OQ**. The angle it makes to the normal is known as the *angle of refraction*, θ_2.

Snell's law gives the relation between the angles θ_1 and θ_2:
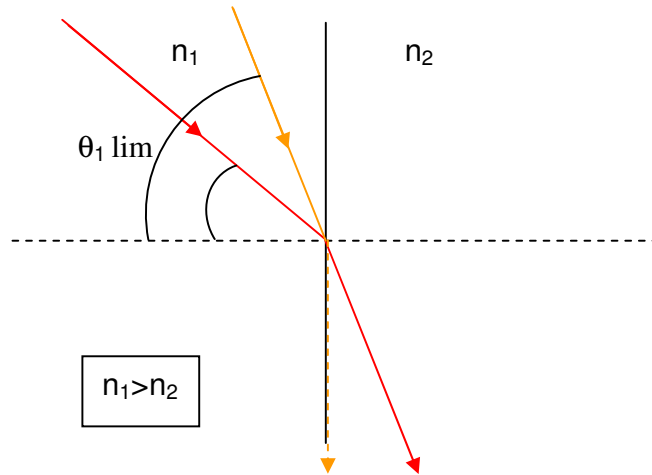
$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

Note: Snell's law is only generally true for isotropic media. In anisotropic media such as some crystals, birefringence may split the refracted ray into two rays, the *ordinary* or *o*-ray which follows Snell's law, and the other *extraordinary* or *e*-ray which may not be co-planar with the incident ray.

Total reflection

As we can see in the expression above, the angle of a ray passing from a medium with a high refractive index to a medium with a weak refractive index ($n_1 > n_2$) is increased. As a consequence, an angle (θ_{1lim}) exists from which there is no more refractive ray. It is the total reflection. The refractive angle is equal to 90°.

$$\theta_2 = 90° \rightarrow \sin(\theta_2) = 1 \rightarrow \sin(\theta_1) = n_2/n_1 \rightarrow \theta_{1lim} = \arcsin(n_2/n_1)$$
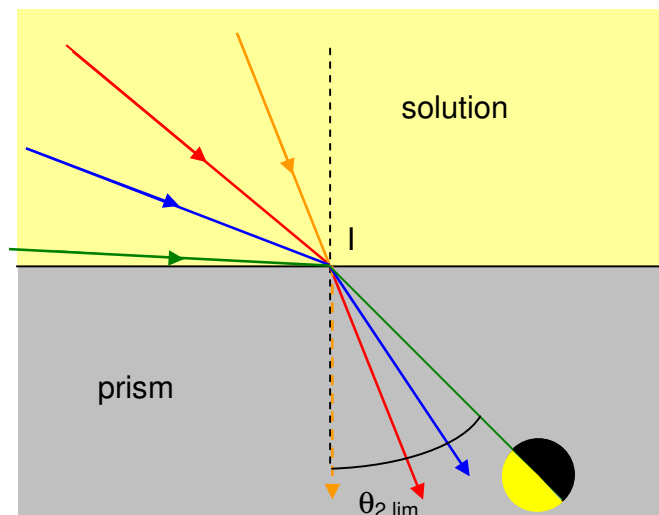

This phenomenon is used in the refractometer.

According to the principle of reverse return of the light, the ray passing from a medium with a weak refractive index (solution index n_s) to a medium with a higher refractive index (prism index n_p) comes from the angle of incidence equal to 90°.
With this grazing incidence, the refractive angle is:

$$\theta_{2\,lim} = \arcsin(n_S/n_P)$$

As we can see on the figure below, all rays are refracted in a region defined between the normal and $\theta_{2\,lim}$. $\theta_{2\,lim}$ defines the limit between the bright area (refracted rays) and the dark area (no refracted ray) in the prism P.
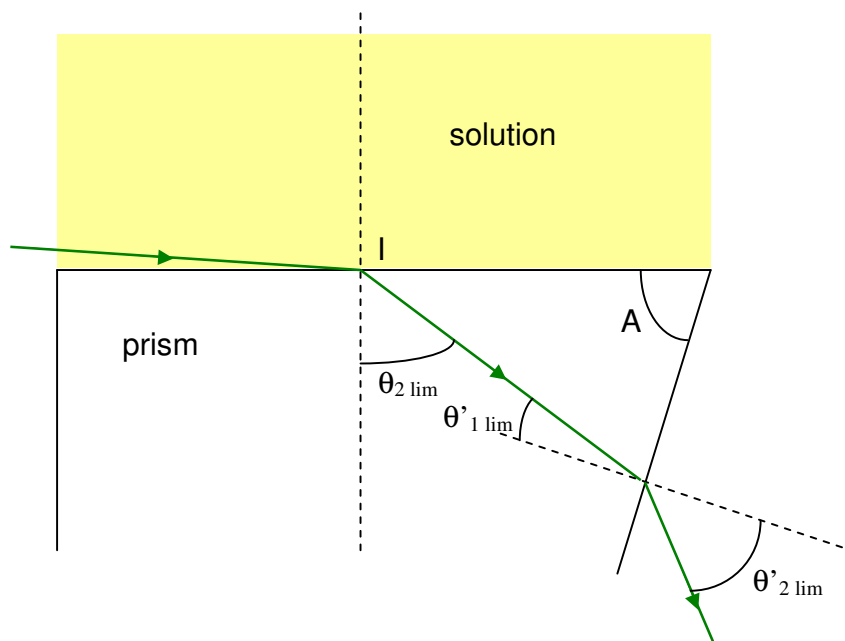

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But to read this value ($\theta_{2\,lim}$) we need glasses and an eyepiece. So the rays have to pass through another interface: prism / air. The direction of the ray is thus modified.
Let's call $\theta'_{1\,lim}$, the angle of the ray in the prism, $\theta'_{2\,lim}$, the angle of the ray in the air and A, the point angle of the prism.

$n_P \sin(\theta'_{1\,lim}) = \sin(\theta'_{2\,lim})$ (air index = 1)
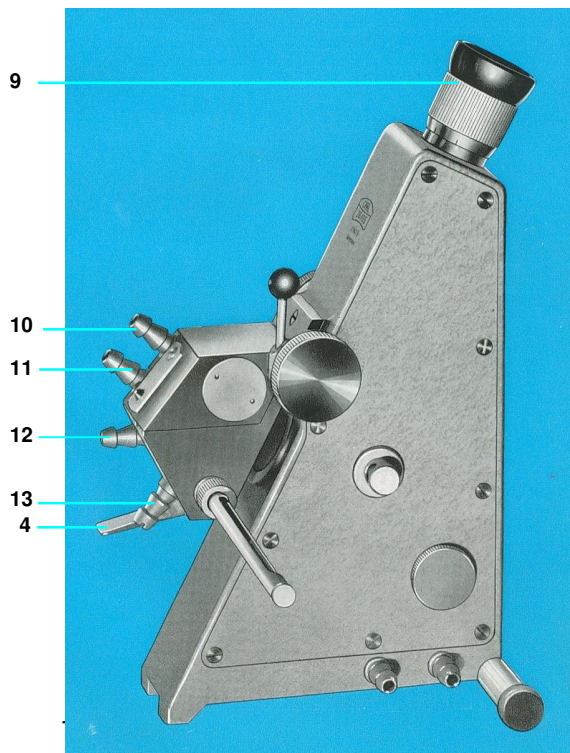$\theta'_{1\,lim} = A - \theta_{2\,lim}$
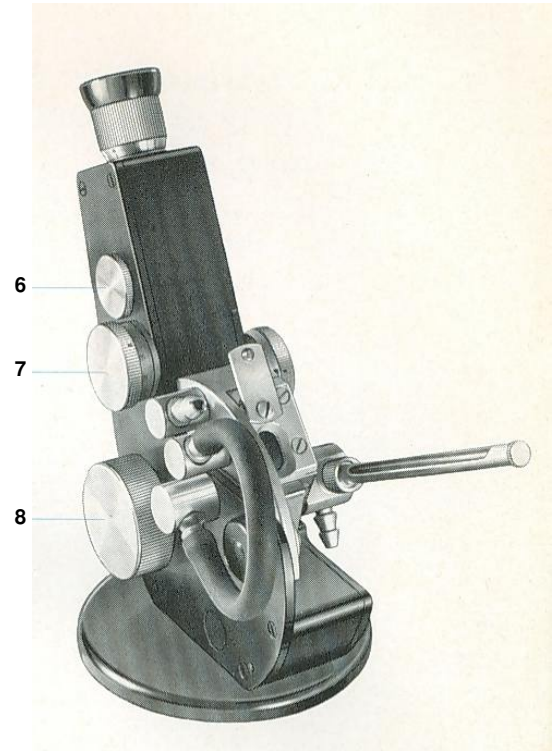$\sin(\theta'_{2\,lim}) = n_P * \sin(A - \arcsin(n_S / n_P))$

$$n_S = n_P * \sin(A - \arcsin(\sin(\theta'_{2\,lim}) / n_P))$$
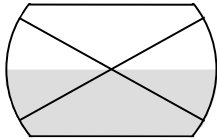
1   Illuminating prism
2   Window for scale illumination
3   Measuring prism
4   Mirror
5   Light admission aperture (closed)
6   Locking of adjusting screw
7   Compensator knob
8   Knob for adjusting boundary lines
9   Eyepiece
10   Connection for the supply of tempering water
11   Connection for circulation of tempering water
12   Connection for circulation of tempering water
13   Connection for discharge of the tempering water

1- Place a few drops of sample on the polished surface of the measuring prism (3) which must be entirely covered. Avoid bubbles.
2- Bring the illuminating prism (1) into contact to the measuring prism (3)
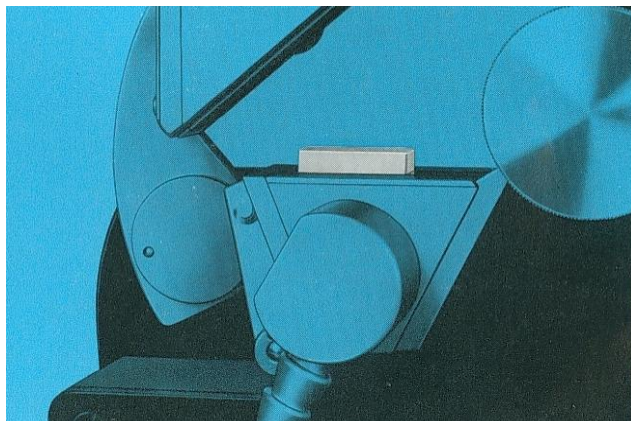
Note for rapidly vaporized solutions: the illuminating prism is merely lifted by the closing knob sufficiently to permit the liquid to be pipetted into the funnel-shaped opening of a narrow channel in the mount of the illuminating prism. The instrument should be slightly tilted during this operation.

3- Orient light entrance apertures (2, 4, 5) toward a window or an artificial light.
4- Open the right apertures and adjust

Highly transparent and light colored substances	Dark, heavily colored, plastic substances and solid bodies
Transmitted light • Open (5) • Open closely (4)	**Reflected light** because of their light absorption • Close (5) • Fully open (4)
Bring the dark field from below towards the middle of the field of view by turning the big knob (8): 	Bring the dark field from above towards the middle of the field of view by turning the big knob (8):
Eliminate the colored border between dark and bright by turning the compensator knob (7)	The borderline is color-free

5- Read the index line in the lower part of the field of the view (see p7) (refractive index or sugar percents).
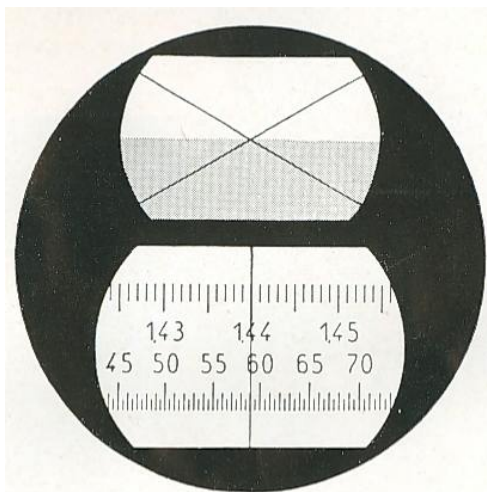
Concerning solid bodies:

Solid bodies are measured in reflected light or in light with "grazing incidence". The samples are placed only on the measuring prism; **the illuminating prism is swung upward.**

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The solid sample to analyze must have at least a plane and polished surface. There are two different procedures:

One polish surface (non-translucent bodies)	Two polished surfaces at right angle one to another with a sharply defined intersection
Reflected light • Put a droplet (<1mm diam.) of highly refractive liquid (monobromine-naphtaline nd = 1,66) on the polish surface • Place this surface on the measuring prism • Follow previous instructions for reflected light Note: if the sample does not cover the entire surface of the measuring prism, mask the measuring prism by a black paper cover.	Grazing transmitted light • Adjust the light source to directly admit the light from the front (parallel to the surface of the measuring prim). A piece of transparent paper interposed between light source and prism usually considerably improves outline and adjustment of the boundary line. • Open (4) • Put a drop of intermediate liquid on the largest polished surface • Place this surface on the measuring prism and the second polished surface in front of the illuminating prism

HOW TO READ THE FIELD OF VIEW

1- Unscrew the eyepiece to its limiting stop
2- Turn the knurled ring of the eyepiece until the crosshairs are clearly defined in the upper illuminated field of view.

The upper field of view
By turning the big knob (8), put the borderline between bright and dark on the crossline in the upper field of view of the eyepiece. If the contrast

The lower field of view
The lower field of view has two scales: the upper to read the refractive index for yellow sodium light and the lower to read the dry substance percents (percentage of sugar in aqueous sugar solution).

HOW TO CONTROL THE TEMPERATURE

As it is mentioned in "How it works", the refractive index depends on temperature. So, measurements have to be made at a definite temperature.
This ABBE Refractometer (Model B) can be used up to **200°C** (***ATTENTION***: *this is possible only if the sample does not damage the prism cement layer even at high temperaturze).* The prisms of the refractometer are tempered by running water.

Connection to thermostat: see "The instrument".
IN: upper nipple of the illuminating prism
OUT: nipple on the other side of the measuring prism (thermometer side)

Maximum rate (heating or cooling): **1°C/min**

NOTES:
- There is a difference between value indicated on the thermometer and actual temperature of the sample.

Operational temperature	Sample temperature
40°C	1°
60°C	2°
100°C	3°
120°C	4°

- Wait until the temperature is stabilized before reading the refractive index.

HOW TO ADJUST THE REFRACTOMETER

The procedure is the same as for measurement of liquids in **transmitted light**.
Distilled water (very high purity) and its following table are used.

°C	n_D	°C	n_D	°C	n_D
10	1,3337	17	1,3332	24	1,3326
11	1,3336	18	1,3332	25	1,3325
12	1,3336	19	1,3331	26	1,3324
13	1,3335	20	1,3330	27	1,3323
14	1,3335	21	1,3329	28	1,3322
15	1,3334	22	1,3328	29	1,3321
16	1,3333	23	1,3327	30	1,3320

If the mean value of several carefully effected determinations of the refractive index at a given temperature does not deviate from the values given in the table by more than 2 units of the 4th decimal, the adjustment may be considered sufficiently accurate.
If there is deviations of the refractive index from table values, adjust by removing the cover on the right side of the instrument and re-setting the adjustment screw.

IMPORTANT NOTES

- **Avoid** hot samples on cold measuring prism and cold samples on hot measuring prism (danger of cracking).
- **Take care to mix efficiently** the sample, especially for viscous substances. Solid, undissolved particles do not influence measurement but may have a disturbing effect. It is expedient therefore to keep away from the measuring prism.
- **Clean** the surfaces of the prism with dust-free linen provided either dry or moistened with an appropriate solvent until they shine.

All pictures come from the original instruction manual.