

Refractive Index.

The index of refraction or refractive index is an extremely important parameter in optics as it characterises the optical behaviour of materials. It is simply defined as the ratio of the speed of light in a vacuum $c = 299792458$ m/s, generally approximated to 3×10^8 m/s, and the speed at which light propagates through the material, i.e. the index of refraction n is given by:

$$n = \frac{c}{v}$$

For example, crown glass has an index of refraction $n = 1.52$ meaning that light travels only about 66% of the speed of light in a vacuum whilst travelling through that material. Much of optics comes down to the study of light travelling through media of different refractive indices.

When light is incident upon a dielectric material such as glass, some of the light is reflected at an angle equal to the angle of incidence, and some light is transmitted or "refracted" through at an angle defined by Snell's law

$$n_0 \sin \theta_r = n_1 \sin \theta_t$$

Where n_0 is the index of refraction of the incident medium, n_1 is the index of the refracting medium, θ_r is the angle of incidence/reflection and θ_t is the angle at which the light is refracted.

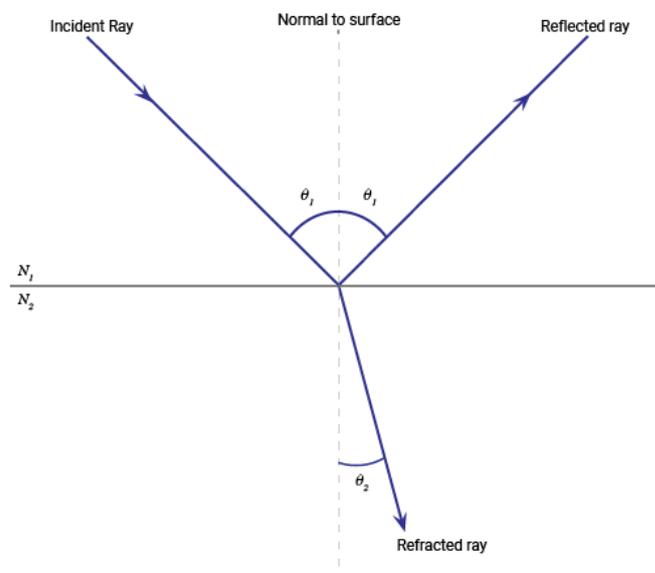


Figure 1: A ray of light incident obliquely upon a medium of differing refractive index is reflected at the angle of incidence, and refracted at an angle determined by Snell's law.

The amount of light that is reflected and transmitted is determined by the so called “Fresnel” equations which will be covered by a future technical note. Additionally, the “phase” of the light is shifted by 180 deg ($\pi/2$) when light is reflected of a (dielectric) surface of higher index of refraction, though the refracted light retains the same phase.

Dispersion

The refractive index of a material varies with the wavelength of the light passing through, this is an effect known as dispersion. A well-known, illustrative example of this is white light incident upon a prism. White light is made up of lots of different colours which experience different refractive indices when they enter the prism. Thanks to Snell’s law they will transmit through the prism at different angles and so the white light is split apart.

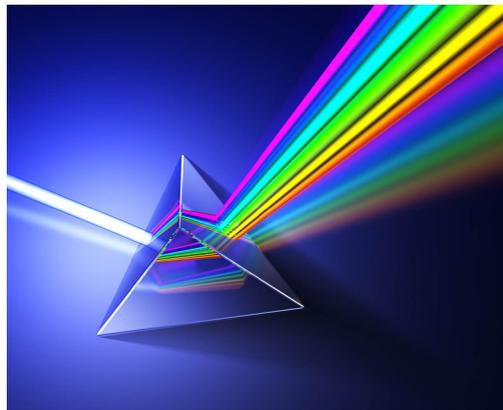
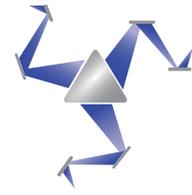


Figure 2: Refraction of light through glass

Accounting for dispersion is very important in the design of optical systems, especially those that operate across multiple wavelengths or large bandwidths. In optical coatings the refractive index can also depend on the production process and the exact nature of the coating microstructure. In bulk substrates the dispersion depends on the glass type though it is often low for standard materials like Fused Silica and BK7. In substrate material specifications the dispersion is characterised by a quantity known as the “Abbe number” commonly denoted as V_d . The Abbe number is defined by

$$v_d = \frac{n_d - 1}{n_f - n_c}$$

Where $n_{d,f,c}$ is the refractive index value at 587.56nm, 486.13nm and 656.27nm respectively. Glasses characterised by a low index and low dispersion tend to have a high Abbe number, whereas the number is low for high index, high dispersion glasses. The Abbe number along with the principal dispersion $n_f - n_c$ are of course loose estimates for the characterisation of dispersion. For more details refer to partial dispersions provided by glass manufacturers and the Sellmeier dispersion formula.



Glass Type	Refractive Index	Abbe Number Vd	Principal Dispersion
Schott Fused Silica	1.45843	67.87	0.0675
Schott N-BK7	1.5168	64.17	0.008054
N-BAK1	1.57250	57.55	0.009948
N-LAK10	1.72003	50.62	0.014224
N-SF2	1.64769	33.82	0.019151
N-FKS	1.48749	70.41	0.06924
N-KZFS2	1.55836	54.01	0.010338
SF6HT	1.80518	25.43	0.031660

Table 1: Refractive indices and dispersions of various glass types. Optical constants provided by Schott Glass.

Absorption Coefficient

A closely related number to the refractive index is the extinction coefficient commonly denoted by k . The extinction coefficient determines how much the intensity of light is reduced as it penetrates a material, i.e. the absorptance of the material. Together with the index of refraction it constitutes the imaginary part of the “complex refractive index” $N=n+ik$ where i is the imaginary unit. In optics the distinction between dielectrics and metals is that metals have a non-zero extinction coefficient and are hence absorbing whereas dielectrics do not and absorb no light. Like the refractive index, the extinction coefficient can also be dispersive. For example whilst fused silica is an excellent dielectric material across the visible spectrum, it can suddenly become absorbing in the UV.

Realistically many dielectric materials, both substrates and coating materials in fact have small extinction coefficients and so are slightly absorbing. Appropriate choice of material is incredibly important when designing and producing high LIDT parts as even a tiny degree of absorption can have catastrophic results!

Glass Type	Refractive Index @633nm	Extinction Coefficient @ 633nm
Fused Silica	1.4570	0
Zirconia	2.1517	0
Geranium	5.4699	0.81446
Silver	0.056206	4.2776
Hafnia	2.1056	0
Aluminium	1.37289	7.617691

Table 2: The refractive indices and extinction coefficients for various materials.

References and further reading

Thin Film Optical Filters Third Edition, H. A. Macleod, Institute of Physics publishing, J W Arrowsmith Ltd. Bristol (2001), ISBN 0 7503 06887 2

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M. N. Polyanskiy, "Refractive index database," <https://refractiveindex.info>. Accessed on 2020-02-03

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