Publications

The PSD School

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In chapter 13 we studied several of the most common metals and alloys that are used in the construction of electro-optical instruments. This chapter will focus on optical glass.

Optical glass

The first more systematic study of how - time after time - it would be possible to produce molten glass with the same refractive index and dispersion1 was carried out by the German scientist Joseph von Frauenhofer starting in 1811. However, it was Ernst Abbe who, together with Otto Schott, really laid the foundations for the optical glass types that are in use today by starting - in 1879 - to develop different optical glass qualities with properties that were unsurpassed until then. Through adding different elements in the molten glass it is possible to vary the refractive index and dispersion of the finished glass within wide limits. Through adding the rare earth metal lanthanum it is possible e.g. to produce high refractive optical glass with low dispersion. Nevertheless, all these exotic additives of different elements sometimes meant that the finished glass acquired certain undesirable properties such as the formation of small bubbles inside the glass as well as the fact the glass did not stand certain chemicals and - at times - even water. Table 1 below shows the refractive index of certain different types of optical glass.

Glass designation	Glass number	n_F	n_d	n_C	ν_d
FK51	487845	1.49056	1.48656	1.48480	84.47
BK7	517642	1.52238	1.51680	1.51432	64.17
F2	620364	1.63208	1.62004	1.61503	36.37
SF6	805254	1.82775	1.80518	1.79609	25.43
SFL6	805254	1.82780	1.80518	1.79609	25.39

The alphabetical designation in the table above indicates different wavelengths. This began by using upper-case letters and when this was insufficient it continued with lower-case letters. Since there are so many different spectral lines there was a gradual move to indicating the wave-lengths of the spectral lines in nm (1nm= 10-9m). In the table below the alphabetical designation is shown for certain known spectral lines.

Letter	Wavelength in mm	Spectral line
F	486.1327	blue hydrogen line
e	546.0740	green mercury lin
d	587.5618	yellow helium line
D	589.2938	yellow sodium line
C	656.2725	red hydrogen line

n_d thus indicates the refractive index for the glass in question at a wavelength of 587.5618 nm. The dispersion or colour spread for an optical glass is normally indicated by means of the inverted relative dispersion, also called Abbés ν_d value which is defined as

$$\nu_d = \frac{n_d - 1}{n_F - n_C}$$

Since the refractive index for most optical glass varies between 1.5 and 2 then this means that the numerator in the definition of Abbés value above is of the magnitude of 0.5 to 1. If an optical glass has large dispersion this means that there is a larger difference between n_F and n_C than if the glass has low dispersion. This means that if the optical glass has a high dispersion then the numerator that varies between 0.5 and 1 should be divided by a greater number than if the glass has a small dispersion. This means therefore that a glass with a low ν_d value (25-30) has a large dispersion and a glass with a high ν_d value (65-70) has a small dispersion or colour spread.

The glass designations above are obtained from the German company Schott´s glass catalogue. There are some ten or so other optical glass manufacturers in the world and their glass designations and catalogues show great similarities with Schott´s glass catalogue. In addition, it is customary to designate the different glass types with a 6-figure number whose first three numbers are the first three decimals of the refractive index of the glass in question and whose last three numbers are the first three figures of Abbe´s ν_d value for the glass in question.

On grounds of historical tradition it is customary to differentiate between crown glass and flint glass. The dividing line between crown glass and flint glass in terms of definition is to ν_d found at the ν_d value 50. In general, it is the case that crown glass is harder than flint glass which means that it is not as easy to scratch optical components manufactured of crown glass.

When modern optical design programs are used there are frequently several different glass catalogues stored in the program and there are optimisation procedures which mean that the program attempts to optimise the optical design through searching for optimal glass combinations.

Frequently, this optimisation ends in different extreme positions so far as glass selection is concerned. For example, as regards the glass FK51 in table 1 above there are many optical lens manufacturers that refuse to work on this glass. This is due to the fact that FK51 has a coefficient of linear expansion of 15.3 ppm compared with BK7 that has 8.3 ppm.

The coefficient of thermal conductivity for FK51 is 0.911 W/m·K compared with 1.069 W/m·K for BK7. What happens when one washes the FK51 glass during the different manufacturing phases is that if the washing water´s temperature deviates too much from the FK51-glass´s current temperature then it cracks on account of the unfavourable combination of high linear expansion co-efficient and poor heat conductivity. On the other hand there is no problem in manufacturing components of BK7-glass. This, combined with the fact that BK7 is relatively hard means that prisms and optical windows are frequently manufactured in BK7-glass. Nor do many optical lens manufacturers like to work on the SF6-glass in table 1 above. This is due to white stains on polished optical surfaces of SF-6 glass being easily formed if water ends up on the glass already after 10 to 20 minutes. In order to avoid this it is therefore necessary to dry the surfaces every time one finishes polishing and this takes time. If, instead, one selects the somewhat more expensive glass SFL6 (see table 1) these problems are eliminated.

The price per kg of optical glass varies between USD 15 and USD 20.000. Therefore, it is important to check, at an early stage of the design process, that you have not included too expensive an optical glass. You should always try to get the optimum design by means of the most stable, bubble-free and least costly optical glass types.

I have specially taken up the aforementioned problems since it has happened more than once that designers of optical systems have presented a finished design that has entailed so many difficulties and costs in production that the designers have had to return to their computers and more or less start again from the beginning. My advice, therefore, is that it is always very sensible to contact the glass cutters that are going to manufacture the optics and consult with them at a very early stage on whether the glass combination in question offers any problems from a production viewpoint. One should therefore take the opportunity of enquiring whether the thickness of the centre and edges of the lenses entails any problems. If, for example, a negative lens is too thin in the centre then the glass may be elastic during the polishing and thereby make it impossible for the already polished surface to acquire a sufficiently precise spherical form. On the other hand, if a biconvex lens has too small an edge thickness then this entails that there is insufficient material when the lens is to be centred to finished size, since this operation is always carried out after both surfaces of the lens are ready polished.

The next chapter of the PSD school will be the last chapter in the series about how to design the optics and mechanics of a triangulation probe. It will focus on problems caused by faulty mechanical design solutions.

(1). If two prisms are produced with the same geometry but from two different optical glass qualities, one with high dispersion and the other with low dispersion, this means that the prism with high dispersion produces a broader spectrum than the prism that is made from glass with lower dispersion. Thus, dispersion is a measurement of the colour spread of the glass.