On the temperature dependence of the lower wavelength cutoff of a series of Schott glass filters

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ABSTRACT

The authors have extended the work of Ångström & Drummond concerning the temperature dependence of the three meteorological standard filters (Schott OG 1, RG 2 and RG 8) and here give values of the temperature coefficient of the center of lower cutoff for seven other Schott sharp cutoff filters. The results demonstrate that there is a definite relationship between the normalized cutoff wavelength and this coefficient, the coefficient increasing semi-logarithmically with wavelength over the region 440–920 millimicrons.

I. In a series of papers Ångström & Drummond (1959*a*, 1959*b*, 1960, 1961) have reported the results of their investigations into the principal optical characteristics of the Schott OG 1, RG 2 and RG 8 filters, primarily from a meteorological standpoint. It was shown that a proper knowledge of the wavelength position of lower transmission cutoff is essential in order to accurately interpret data obtained in the measurement of filtered solar radiation. A significant portion of the study was devoted to the examination of the shift in the center of lower cutoff because of changes in temperature of the filter material. It was also demonstrated (Ångström & Drummond, 1960) that over small ranges of temperature around normal conditions, changes of transmittance[1] in the main transmission band can be neglected in practice.

Since the realm of radiometric measurements is rapidly being expanded to include measurements under the most diverse conditions, such as those in polar regions and in studies of high-temperature processes, the work summarized above has been extended to include a series of seven other Schott sharp cutoff filters, in order to provide the investigator with a quantitative means of determining corrective factors necessitated by changes in transmission properties on account of temperature.

[1] Definitions used in this discussion are those adopted in the article by Ångström & Drummond (1959*a*).

The experimental procedures were similar to those described previously (Ångström & Drummond, 1959*a*).

II. As a result of the original work of Ångström & Drummond, the World Meteorological Organization accepted (at its New Delhi meeting; CIMO, January 29–February 16, 1962) an idealized standardization of 525, 630 and 700 mμ for the center of lower wavelength cutoff of the OG 1, RG 2 and RG 8 filters, respectively, and temperature coefficients practically identical to the mean values listed in Table 1.

In order to establish that the data already published are closely representative of the three filter types, regardless of the glass melt or variability within a specific melt, two additional specimens of each type were tested. The temperature coefficient values (ε) and "normalized" center of cutoff (λ_m) together with the range of temperatures over which measurements were taken are also given in Table 1. In each instance, set II denotes the specimen examined by Ångström & Drummond. The new experimental work (Brett & Hickey) is summarized in sets III and IV for OG 1, sets IV and V for RG 2 and sets III and IV for RG 8. The data which appear against set I have been included to render more complete the existing information regarding the transmission characteristics of these filters, especially as the Davos Observatory series of filters were employed, on many occasions, to calibrate, indirectly, filter

TABLE 1. *Position and temperature dependence of center of lower cutoff of the OG 1, RG 2 and RG 8 filters (center of cutoff referred to a standard thickness of 2.0 mm and a standard temperature of +20°C).*

Type	Specimen	Thickness mm	Normalized center of cutoff λ_m (mμ)	Temperature coefficient (mμ/°C)	Temperature range (°C)	Authority	Owner
OG 1	I	2.4	523	—	—	Feussner & Hinzpeter	Davos Observatory
	II	1.6	532	0.12	−17 +87	Ångström & Drummond	Eppley Laboratory
	III	3.0	518	0.13	+28 +49	Brett & Hickey	Belgian Meteorological Service
	IV	3.0	524	0.11	−12 +48		
	Mean		524	0.12			
RG 2	I	1.5	630	—	—	Feussner & Hinzpeter	Davos Observatory
	II	1.9	627	0.14	−13 +79	Ångström & Drummond	Eppley Laboratory
	III	2.0	613	—	—	Drummond	Eppley Laboratory
	IV	2.0	636	0.14	+29 +50	Brett & Hickey	Belgian Meteorological Service
	V	2.9	639	0.16	−8 +55		
	Mean		629	0.15			
RG 8	I	3.0	706	—	—	Bossy	Davos Observatory
	II	2.0	695	0.18	−10 +79	Ångström & Drummond	Eppley Laboratory
	III	1.9	701	0.22	+29 +50	Brett & Hickey	Belgian Meteorological Service
	IV	2.9	703	0.16	−12 +49		
	Mean		701	0.19			

specimens which were used in the recent International Geophysical Year program. Specimen III (RG 2) demonstrates that variation in the center of cutoff in excess of 10 mμ from the "standard" values has occurred.

In Table 1 the "normalized" center of cutoff is that wavelength at which the filter transmits 50% of the main band transmission and is adjusted to standard conditions of filter thickness of 2.0 mm and filter temperature of +20°C. All tests were conducted in air at a relative humidity of approximately 50%.

The variation, from specimen to specimen, in the determined values of temperature coefficient of each filter type would appear to be a consequence of differences in melt or other manufacturing inconsistency, since it considerably exceeds the expected errors of the experiment ($\tau = \pm 0.3\%$, $\lambda = \pm 0.5$ mμ, $T = \pm 0.2$°C). The temperature coefficient (expressed in mμ/°C) obviously increases as λ_m increases. The empirical relationship is

$$\varepsilon = \varepsilon_0 e^{b\lambda m}. \quad (1)$$

Fig. 1 shows a plot of λ_m versus ε on semilogarithmic paper. The equation of this straight line is

$$\varepsilon = 0.033 \exp\,[0.0024\,\lambda_m]. \quad (2)$$

TABLE 2. *Position and temperature dependence of center of lower cutoff of the second series of Schott filters (standard conditions 2.0 mm and +20°C).*

Type	Thickness (mm)	Normalized center of cutoff λ_m (mμ)	Temperature coefficient (mμ/°C)	Temperature range (°C)
GG 3	2.0	439	0.08_5	+21 +44
GG 5	1.8	470	0.09	+24 +44
GG 14	2.5	502	0.11	+24 +44
OG 2	2.2	568	0.19	+23 +44
RG 5	2.0	677	0.22	+24 +46
RG 10	2.0	717	0.26	+20 +46
RG 7	2.0	919	0.56	+20 +57

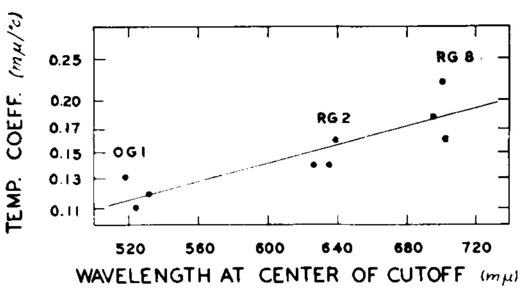

FIG. 1. Variation of the temperature coefficient of the position of center of lower cutoff with wavelength, for Schott present-day OG1, RG2 and RG8 filter glasses.

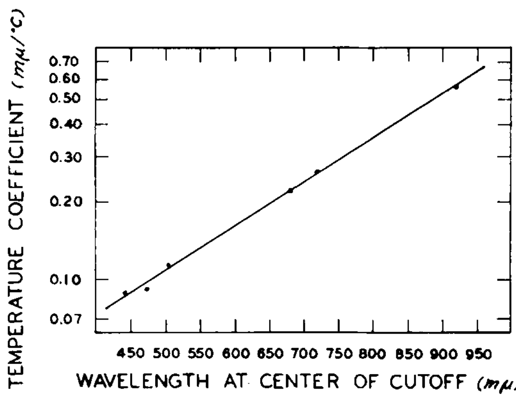

FIG. 2. Variation of the temperature coefficient of the position of center of lower cutoff with wavelength, for a pre-war series of Schott filter glasses (GG3, GG5, GG14, OG2, RG5, RG10 and RG7, in order of increasing λ_m).

III. A study of the dependence, on temperature, of filter transmittance of another series of Schott sharp cutoff filters was undertaken to determine whether the representation arrived at in the primary study could be extended to other filter types. In order to minimize the effects of changes in the formulae employed in the manufacture or in the associated techniques, a series of filters understood to be produced at approximately the same time (about 1937) was selected as a representative set.

The main results of this investigation are shown in Table 2. In Fig. 2 the temperature coefficient is plotted against cutoff (semi-log scale). This relationship can be expressed by Eq. (1) but with the assignment of different values to the constants ε_0 and b, viz.

$$\varepsilon = 0.016 \exp [0.0039\, \lambda_m]. \qquad (3)$$

It must be emphasized here that equations (1)–(3) refer to the varying conditions from one filter to another within the same series (OG 1, RG 2, RG 8, for instance), whereas the investigations of Ångström & Drummond (1960, 1961) have dealt chiefly with the influence of the temperature conditions in the case of a given filter. For a given filter the value of $\varepsilon(=d\lambda_m/dT)$ is a constant independent of λ_m.

IV. The fact that the temperature coefficients of center of cutoff are correlated to the normalized cutoff wavelength is established by observation. It must be borne in mind, however, that this is an empirical and not a theoretical approach, and that no attempt is made, at present, to discuss the extent of the change associated with the base glass and that associated with the coloring material. As the main transmission band is relatively less sensitive to changes in temperature, and as the long-wave cutoff does not exhibit the temperature effect to the same degree as the shorter wavelength cutoff (Ångström & Drummond, 1960), it may be valid to assume that the observed phenomena exist primarily in the coloring agent. According to the mathematical treatment of Ångström & Drummond ε is related to two other fundamental filter constants σ and γ by:

$$\varepsilon = \frac{\sigma}{\gamma}. \tag{4}$$

Here σ *is the temperature coefficient of the absorption coefficient* (α) within the cutoff region, and defined by:

$$\sigma = \frac{1}{\alpha} \frac{d\alpha}{dT}, \tag{5}$$

and γ is for a given filter *a measure of the steepness of the change in transmission with wavelength around the center of cutoff.* Equation (4) expresses in a condensed way the natural result that the shift of the center of cutoff with temperature is (1) proportional to the temperature coefficient of the absorption coefficient and (2) inversely proportional to the slope of the transmission curve around the center of cutoff.

Ångström & Drummond (1959, 1960) have given values for ε, σ and γ for the three filters OG1, RG2 and RG8. It was found that σ increases and γ decreases when we pass from a filter with shorter to a filter with longer λ_m. Consequently ε is subject to a still more pronounced change, which, as has been demonstrated in the present paper, can be expressed through an exponential formula.

The now established dependence of the constants ε, σ and γ on the transmission conditions of some practically important series of glass filters may, as a contribution to the knowledge of the physical properties of the coloring agent of the filter, be of some general interest.

With the aid of experimentally determined values of the temperature coefficient of the ten filters discussed here, corrections may be applied to the radiation intensity measured behind a filter exposed to temperature conditions considerably different from the basic calibration references. This study is currently continuing, with extension to other glass types and with respect also to natural and artificial aging of the materials.

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