Refraction Index of Fly Rhabdomeres

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Summary. The refractive index reported by Seitz (1968) for the rhabdomeres of flies (1.349) has been corrected for waveguide effects. The presented correction method has yielded \( n_1 = 1.365 \pm 0.006 \).

It is argued that an acceptable estimate for the refractive index of the inhomogeneous surroundings of fly rhabdomeres is \( n_2 = 1.339 \pm 0.002 \).

A. Introduction

A fly rhabdomere has a higher refractive index than its surrounding medium as is generally the case for photoreceptors. Therefore these structures act as optical waveguides. A characteristic feature of (dielectric) waveguides is that the light wave is conducted in modes, i.e. light patterns extending across the boundary of the fibre. The fraction of the wave propagated within the borders depends on wavelength, fibre radius and refractive indices of both the medium within the fibre and that surrounding it.

The phenomenon of the boundary wave is of particular interest in the case of flies, because there exist two rhabdomere types, six wider peripheral rhabdomeres and two more slender central rhabdomeres. As a consequence of this difference in radius the two types of rhabdomere differ also as to their waveguide properties, a property probably essential to the colour vision of flies (Snyder and Pask, 1973b).

Recently we have investigated the visual pigment contained in the rhabdomeres by estimating in vivo difference spectra (Stavenga et al., 1973). In our experiments we have transmitted the test light along the total length of the rhabdomere, thus utilizing the property of the rhabdomere as a waveguide. This technique implies, however, a necessary correction for the inevitable influence of the boundary wave on the measured spectra. After executing this correction with the aid of the refractive index values provided by Seitz (1968) we have been left with discrepancies between the corrected difference spectra of the two rhabdomere types.
There is no reason to doubt Seitz' experimental values, but, as we will discuss in the present paper, waveguide theory leads us to a modified interpretation of the data. The boundary wave also must have interfered in Seitz' estimate of the refractive index of fly rhabdomeres. This effect is treated first. Subsequently a correction method for the boundary wave effect is presented and a more reliable value for the refractive index of the fly rhabdomere is calculated.

B. Rhabdomere Refractive Index Correction Method

With an interference method Seitz (1968) has determined the refractive indices in the fly *Calliphora erythrocephala* (mutants white or chalky). Monochromatic light, transmitted through the medium to be investigated is brought into interference with light having passed a standard medium. The difference in optical path length between the two media has been measured. From the thickness of the medium and the refractive index of the standard medium the unknown refractive index can be calculated. The proper way to study the tiny rhabdomeres is to cut slices perpendicular to the rhabdomere axis, and to apply the test beam parallel to it. The crucial point in the refractive index determination of the rhabdomere as performed by Seitz is that his calculations are based on the implicit assumption that the light wave has been propagated completely within the rhabdomere. However, waveguide optics teach us that this assumption is incorrect.

As is derived in the appendix, the effective refractive index $n_f$ of an optic fibre is determined by both the medium in the core and the surrounding medium. If the refractive indices of the media are respectively $n_1$ and $n_2$:

$$n_f = Kn_1 + (1 - K)n_2. \quad (1)$$

In the appendix the factor $K$ is introduced as

$$K = 1 - U^2/V^2 \quad (2)$$

where $U$ is a function of the fundamental parameter $V$ in waveguide optics, defined as

$$V = \frac{2\pi}{\lambda} (n_1^2 - n_2^2)^{1/2} \quad (3)$$

$\lambda$ is the wavelength of the light in vacuum and $\phi$ the radius of the waveguide.

$U(V)$ is presented in Fig. 1a as well as $K(V)$, the latter being calculated from (2). The implicit dependence of $K$ on the desired refractive

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1 Dr. W. Wijngaard, University of Utrecht, kindly supplied the $U(V)$ as well as the $\eta(V)$-values, which he has calculated to the fourth decimal (in the limit $1 - n_2^2/n_1^2 \to 0$); compare Biernson and Kinsley (1965).