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Short Communication

Gaussian expressions for the absorption spectra of visual pigments

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In 1953, taking absorption bandwidths independent of the absorption maxima, Dartnall [1] devised a visual pigment nomogram to fit the spectral sensitivity curves with the absorption spectra of all visual pigments based on vitamin A_1. Later, Honig and Ebrey [2] discussed the wavelength dependence of the bandwidths of the absorption spectra of these visual pigments. It was reported that shorter wavelength pigments have broader bandwidths and that longer wavelength pigments have narrower bandwidths than the Dartnall nomogram predicts. Recently, Ebrey and Honig [3] recommended that the Dartnall nomogram should be used only when the λ_{max} value is in the range 470 - 530 nm. Using published absorption spectra, they provided a short wavelength and a long wavelength nomogram to supplement the middle wavelength Dartnall nomogram. To describe shapes of absorption spectra or to fit the spectral sensitivity data, various mathematical expressions of the nomogram have been used. Bridges [4] used an eleventh-order polynomial fit in constructing his middle wavelength porphyropsin nomogram. Later, Hárosi [5] used the sum of three gaussian functions to fit the extinction spectra of three goldfish cone pigments, whereas Metzler and Harris [6] used lognormal distribution functions in fitting absorption spectra of visual pigments. More recently, Dawis [7] proposed a polynomial expression for the logarithm of the absorption coefficient at wavelength λ.

Although Dawis's expression for absorption spectra is quite accurate, it is not simple, particularly when the absorption rates of the visual pigment and its intermediates exposed with a non-monochromatic bleaching source are required. The absorption rate (in photons absorbed per cubic centimetre per second) of X-type molecules in a sample at time t is given by [8 - 11]

$$J_X(t) = \int_{\lambda_1}^{\lambda_2} J_X(\lambda, t)\, d\lambda \qquad (1)$$

where λ_1 - λ_2 is the wavelength range of the bleaching source incident on the sample containing visual pigments and $J_X(\lambda, t)\, d\lambda$ represents the number of photons with wavelengths between λ and $\lambda + d\lambda$ absorbed by X-type

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molecules per cubic centimetre per second. For low absorbance of the sample

$$J_X(\lambda, t) = \alpha_X(\lambda)X(t)I(\lambda, t) \tag{2}$$

where $\alpha_X(\lambda)$ represents the extinction coefficient of X-type molecules at wavelength λ, $I(\lambda, t)$ represents the spectral–temporal distribution of the intensity of the bleaching source and $X(t)$ represents the concentration of X-type molecules. If the spectral distribution $I(\lambda)$ of the source is independent of time t then to determine $J_X(t)$ the integral

$$\int_{\lambda_1}^{\lambda_2} I(\lambda)\alpha(\lambda)\, d\lambda$$

has to be solved. For the $\alpha(\lambda)$ given by Dawis's expression [7] the integral cannot be solved analytically. To avoid numerical integration a simple expression for the absorption spectra is required. We have found that the following gaussian expression fits the absorption spectra very well and can also be integrated:

$$\alpha(\lambda) = \alpha(\lambda_{max}) \exp\left[-\left\{\frac{\lambda - (\lambda_{max} + 4)}{f_1}\right\}^2\right] \tag{3a}$$

for $\lambda < \lambda_{max}$ and

$$\alpha(\lambda) = \alpha(\lambda_{max}) \exp\left\{-\left(\frac{\lambda - \lambda_{max}}{f_2}\right)^2\right\} \tag{3b}$$

for $\lambda \geqslant \lambda_{max}$, where

$$f_1 = 69 + 0.25(\lambda_{max} - 470)$$

and

$$f_2 = 47.75 + 0.22166(\lambda_{max} - 470)$$

and the wavelength is in nanometres. The above mathematical expression for absorption spectra has been obtained for visual pigments based on vitamin A_1 with λ_{max} between 470 and 530 nm, a region in which peaks are found for most visual pigments and their intermediates. The error between the data obtained from the nomogram and eqn. (3) is not more that ±1% and this degree of error is also expected in reading values from the nomogram. To test the validity of eqn. (3) in reproducing the Dartnall nomogram, the nomogram absorption spectrum predicted for $\lambda_{max} = 500$ nm was determined. These points are shown as open circles in Fig. 1. The continuous curve through the open circles was obtained from eqn. (3) with $\lambda_{max} = 500$ nm. It can be seen that the absorption spectrum obtained from eqn. (3) fits the points obtained from the nomogram very well.

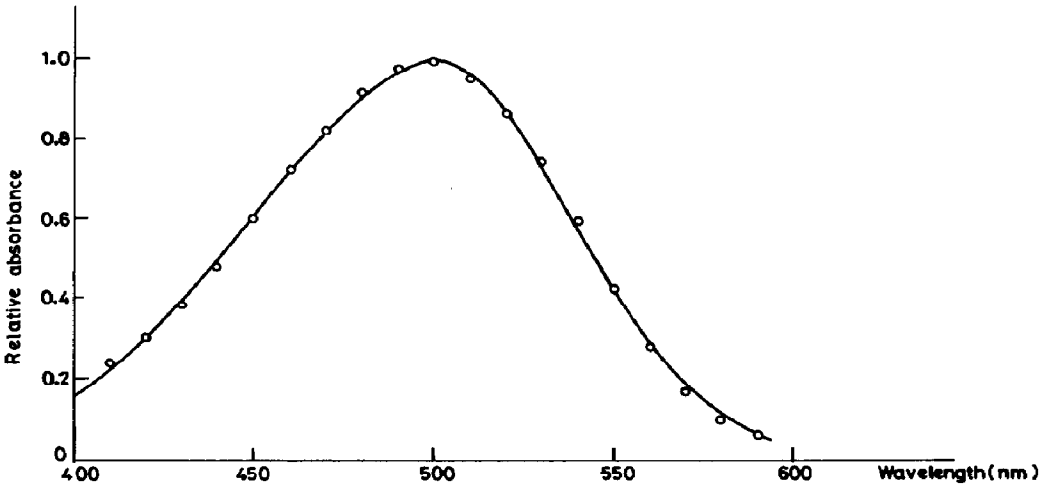

Fig. 1. A comparison of eqn. (3) with the Dartnall nomogram (λ_{max} = 500 nm): ○, data taken from the Dartnall nomogram; ——, obtained from eqn. (3).

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