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CONTENTS

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MECHANISM PRODUCING THE NEAR-700 nm BRIGHTNESS PEAK IN THE EMISSION SPECTRA OF WATER BODIES AND ITS POSSIBLE APPLICATIONS IN REMOTE SOUNDING OF SUCH BODIES[1]

A.A. Gitel'son and Academician K. Ya. Kondrat'yev

Hydrochemical Institute, Rostov-na-Donu; and
Institute of Limnology, USSR Academy of Sciences, Leningrad

In order to interpret multizonal video information from satellites and to develop remote methods for airborne monitoring of water bodies in terms of spectrometric data for the visible region, we need to elucidate the mechanism producing the "red peak" that occurs in the emission of spectra of such bodies near 700 nm. Various explanations of this peak have been offered. Morel and Prier [1] attribute it to anomalous dispersion in the absorption band of phytoplankton and to chlorophyll A fluorescence. Gordon [2] and Sugihara et al. [3] believe that it is entirely attributable to phytoplankton fluorescence. Vasil'kov and Kopelevich [4] use a simple model to show that it could be produced by a corresponding minimum in the absorption spectrum at chlorophyll A concentrations greater than 1 mg/meter. They also show that the anomalous dispersion makes a negligible contribution to the red peak.

In the present paper we attempt to elucidate the mechanism producing the peak.

We made an extensive study of the spectral brightness coefficients $\rho(\lambda)$ of various water bodies with chlorophyll concentrations of 0.5 to 10 mg/m^3 (Sea of Azov), 10 to 40 mg/m^3 (the Don and Northern Donets rivers), 5 to 100 mg/m^3 (Lake Balaton), and 30 to 400 mg/m^3 (Lake Mügelsee).

The brightness spectra were measured from aircraft with a spectrometer whose wavelength resolution was 1 nm or better [5]. The intensity spectra clearly show a series of Fraunhofer lines that can be used for high-accuracy wavelength calibration (supplementing calibration with a reference light source and with interference filters); the $\rho(\lambda)$ spectra were recorded on an x-y pen plotter and were also stored in a data base [5] for further processing.

We also measured the concentrations of the active components. The chlorophyll concentration C_{chl} was determined from the fluorescence at 685 nm excited by various wavelengths [6] and was also derived analytically [7]. The concentration of suspended matter C_{susp} was found from the scattering index of water at 90° [5] and that of dissolved organic matter from its fluorescence between 470 and 560 nm [8]. The position of the peak was determined with an error of less than 0.5 nm in the fluorescence spectra of water samples at wavelengths from 600 to 800 nm [5]. In all spectra it lie at 685 nm, and its position did not vary with C_{chl}.

We attempted to test, over a wide range of chlorophyll A and phytoplankton concentrations, our earlier results [5, 9-11], which indicated that the position of the red peak in $\rho(\lambda)$ is strongly altered by changes in C_{chl}. A positive result would confirm the hypothesis of Vasil'kov and Kopelevich [4], for while we found no shift in the wavelength of plankton fluorescence in our measurements, the model in [4] does postulate that the wavelength of the peak λ_{max} should increase with C_{chl}. We therefore made especially accurate measurements of λ_{max} and compared them with the values of C_{chl} obtained by various techniques.

All of our experiments showed two extrema of the $\rho(\lambda)$ function in the red region: a minimum between 665 and 675 nm and a peak whose position varied with C_{chl}. With a chlorophyll concentration of about 1 mg/m^3, the plot of $\rho(\lambda)$ showed only an inflection at λ = 685 nm (Fig. 1a); with increasing C_{chl}, the position of the peak shifted, with λ_{max} at 725 nm at C_{chl} > 100 mg/m^3 (Fig. 1c). When C_{chl} was varied from 1 to 100 mg/m^3, the ratio $\rho(\lambda_{max})/\rho(560)$ (560 nm is the global maximum of $\rho(\lambda)$) increases by

[1]Translated from: O mekhanizme obrazovaniya i vozmozhnoye ispol'zovaniye dlya distantsionnogo zondirovaniya maksimuma yarkosti vblizi 700 nm spektrakh izlucheniya vodnykh ob"yektov. Doklady Akademii Nauk SSSR, 1989, Vol. 306, No. 1, pp. 60-63.

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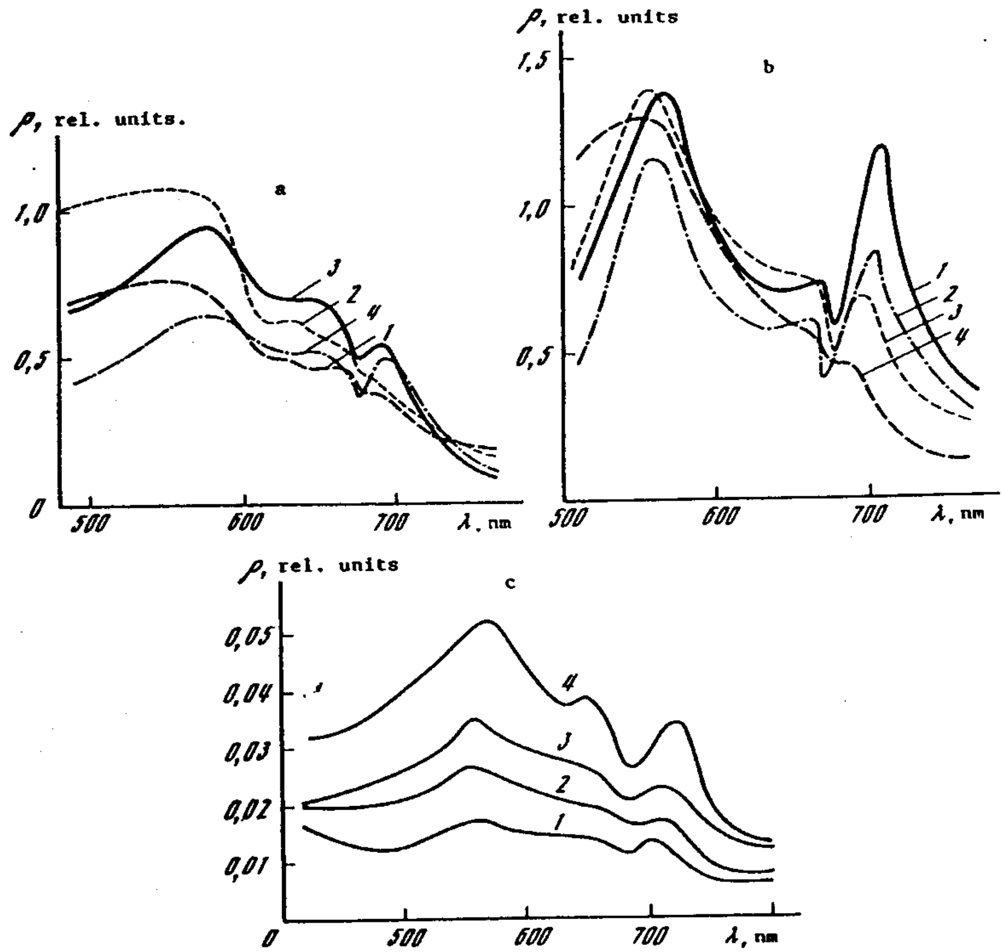

Fig. 1. Brightness spectra of various water bodies: a) Sea of Azov, C_{chl} = 5 (*1*), 5.6 (*2*), 13.2 (*3*) and 16 (*4*), mg/m³; b) Lake Balaton, C_{chl} = 98 (*1*), 82 (*2*), 23 (*3*), 5.3 (*4*), mg/m³; c) Lake Mügelsee, C_{chl} = 40 (*1*), 80 (*2*), 160 (*3*) and 400 (*4*), mg/m³.

more than an order of magnitude. The increase in λ_{max} and $\rho(\lambda_{max})/\rho(560)$ was found in all of the water bodies (more than 10) that we studied, in various stages of hydrobiont development, from early spring to late autumn, and with considerable differences in the species makeup of the phytoplankton.

We found the same phenomenon in experiments in the so-called mesocosms, i.e., parts of a water body or watercourse that were separated from it and were affected by some pollutant [12]. The brightness spectra (Fig. 2) were measured in three different ecosystems (the test ecosystem, a control, and the lake from which the two other systems were separated) for a minute under ideal survey conditions (solar angle, condition of surface and atmosphere, and the like). In this case too, the different phytoplankton concentrations showed up in the spectra $\rho(\lambda)$ as considerable differences in λ_{max}.

Calculations of $\rho(\lambda)$ by a means of a published program [13] (see Fig. 3; the size distribution of phytoplankton particles is log-normal with r_0 = 6 μm, and that for mineral suspended matter is a Junge distribution $f(r) = r^{-\nu}$ with ν ranging from 0.1 to 5.0) for various values of C_{chl} and C_{susp} clearly reproduced the two observed extrema of $\rho(\lambda)$. Figure 4 compares the measured plots with $\lambda_{max}(C_{chl})$ (Lake Balaton, July 1986) with the calculated plots (for $\nu = 1.0$, C_{susp} = 10 mg/liter). They are in good agreement.

Our measurements and calculations indicate (without ruling out a contribution of phytoplankton fluorescence to the emission intensity of water at 685 nm) that the maximum of $\rho(\lambda)$ near 700 nm is caused, when $C_{chl} > 1$ g/m³, by light absorption by phytoplankton pigments, producing a corresponding minimum of the absorption index.

The correlation between C_{chl} and λ_{max} is very close. For example, in Lake Balaton, $\lambda_{max} = 649.2\ C_{chl}^{0.019}$ nm, with a coefficient of correlation higher than 0.96.

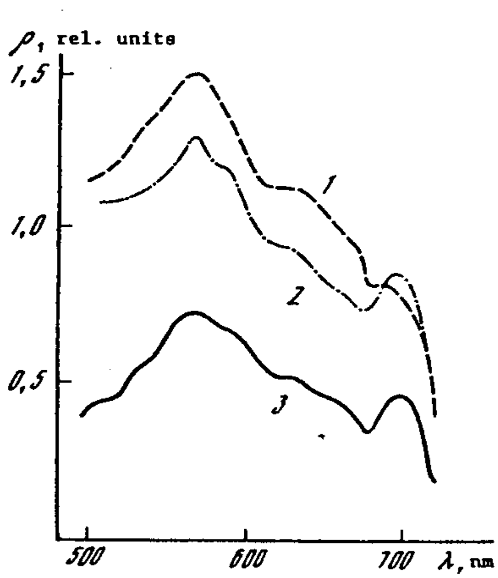

Fig. 2

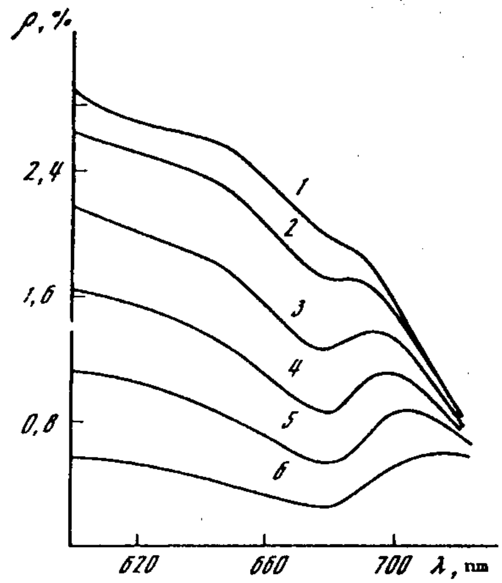

Fig. 3

Fig. 2. Brightness spectra. 1) Lake, C_{chl} = 18 mg/m³; 2) Control "mesocosm," C_{chl} = 24 mg/m³; 3) Test mesocosm, C_{chl} = 40 mg/m³.

Fig. 3. Brightness spectra calculated by program of [13] for ν = 1.0, r_0 = 6 μm, C_{susp} = 10 mg/liter, C_{chl} = 1 (1), 2 (2), 5 (3), 10 (4), 20 (5) and 50 (6), mg/m³.

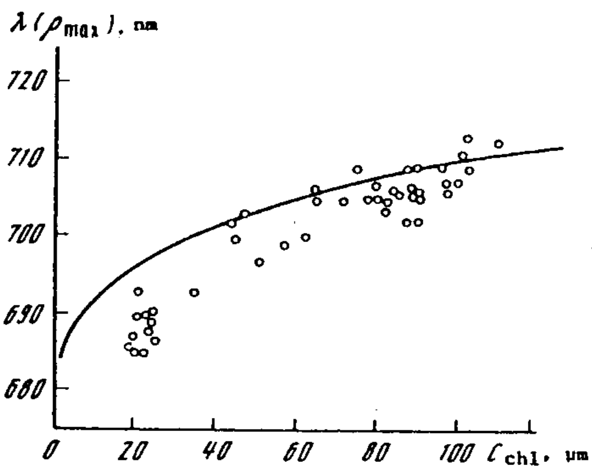

Fig. 4. Wavelength at which red peak of spectrum occurs versus concentration of phytoplankton chlorophyll A. Points represents measurements; curve is calculated [13] for ν = 3, C_{susp} = 10 mg/liter.

Calculations with the help of the same computer program [13] indicate that the parameters of this correlation are virtually independent of the size distribution of mineral particles or on their concentration at C_{susp} between 5 and 20 mg/liter, but are governed primarily by the behavior of the absorption index $\kappa(\lambda)$, i.e., the species makeup of the phytoplankton.

The relationship of λ_{max} to C_{chl} that we have identified makes possible remote determinations of phytoplankton chlorophyll A from λ_{max}. C_{chl} can be determined at concentrations between 5 and 100 mg/m³ with a standard deviation of less than 10 mg/m³.

This phenomenon must be taken into account when choosing the wavelengths at which the spectral brightness coefficient is to be determined in remote determinations of the concentration of optically active substances in aquatic ecosystems [9-11].

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