As is seen, there is a substantial distinction between the generation conditions and nature of resonances with $l_1 = 37$ and 59. Resonances with $l_1 = 37$ exist in both homogeneous and hollow particles, but they decay for a substantial decrease in shell width. In case of resonances with number $l_1 = 59$ there is no resonance structure inside a homogeneous particle, but it is generated and is quite sharply expressed in hollow particles with shell variations in some definite interval of its width.

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DETERMINING THE SENSITIVITY OF MATERIALS TO POLYCHROMATIC LIGHT

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There are now two approaches for determining the sensitivity of materials to polychromatic light (see, e.g., Ref. [1]). The first is applicable only in the case of the superposition of light and consists in determining the spectral sensitivity of a material $\varphi(\lambda)$ by conducting a series of experiments for the action of nearly monochromatic light $[\lambda_1(\Delta\lambda_1), \ldots, \lambda_m(\Delta\lambda_m)]$. Despite being laborious, the method gives entirely acceptable results for materials possessing a sufficiently efficient response to light, i.e., in conditions when the exposure time does not limit the duration of the measurements. For materials with a low response efficiency, for example, when testing optically stable materials, another approach is used. Here, as a rule, it is attempted to simulate the average spectral operating conditions of the material. So, devices which spectrally simulate natural operating conditions, e.g., solar radiation, exist and have become widely used (for example, devices of the "Xenotest" series of the Original Hanau Co. in the FRG). It is necessary to relate the very concept of "average spectral operating conditions" being underrated to the defects in a similar approach. So, for example, the physical latitude and elevation of a location, the time of year and day, the state of the atmosphere, etc. [2], and in the case of an extremal function of $\varphi(\lambda)$ [3] lead to great differences in the response of a material to such excitation. In view of this, the results of the experiments retain an estimated nature, during which the reliability of similar estimates, as a rule, cannot be analyzed.

The present work examines a nontraditional approach to solving the problem of determining the sensitivity of materials to polychromatic light on the basis of experiments on the effect of polychromatic exposure. The approach is nontraditional in the fact that the problem of determining $\varphi(\lambda)$ is not raised, but a prediction of the response of a material to polychromatic excitation under the conditions of use is made.

The response of a material to polychromatic excitation in the course of the experiments is determined by the expression

$$V_i = \int_{\Lambda} \varphi(\lambda) I_i(\lambda) d\lambda$$

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or in discrete notation

$$V_i = \sum_{\alpha=1}^{m} \varphi_\alpha I_i^\alpha, \tag{1}$$

where V_i is the response of the material to a given excitation spectrum $I_i(\lambda)$ (I_i^α) and $\varphi(\lambda)$ (φ_α) is the spectral sensitivity of the material. The index $i = 1, \ldots, n$ identifies different spectral conditions during performing the experiments, and the index $\alpha = 1, \ldots, m$ identifies the partitioning with respect to the wavelength scale λ_α.

The problem of determining (predicting) the response W to some given excitation $z^\alpha = (z^1, \ldots, z^m)$ is examined:

$$W = \sum_\alpha z^\alpha \varphi_\alpha. \tag{2}$$

Similarly the problem of predicting the sensitivity of a material to polychromatic excitation is raised for the course of a two-quantum process in the system:

$$V = \int_\Lambda \varphi_1(\lambda) I(\lambda)\, d\lambda \int_\Lambda \varphi_2(\lambda) I(\lambda)\, d\lambda = \iint_{\Lambda\Lambda} \varphi_1(\lambda_1) \varphi_2(\lambda_2) I(\lambda_1) I(\lambda_2)\, d\lambda_1 d\lambda_2$$

or in discrete form

$$V = \sum_{\alpha=1}^{m} \sum_{\beta=1}^{m} \psi_{\alpha\beta} K^{\alpha\beta}, \tag{3}$$

where

$$\psi_{\alpha\beta} = \varphi_1(\lambda_\alpha) \varphi_2(\lambda_\beta); \quad K^{\alpha\beta} = I(\lambda_\alpha) I(\lambda_\beta).$$

Going to the one-dimensional indexation $\gamma = 1, \ldots, m(m+1)/2$ (taking into account the possible symmetrization of the matrix ψ) we obtain an expression similar to Eq. (1), where in place of the vectors φ_α — the spectral sensitivity and I^α — the excitation spectra are the vectors $^*\varphi_\gamma$ and $^*I^\gamma$, which can be interpreted as a quasiclassical sensitivity and quasiclassical excitation. Thereby the problem of predicting the sensitivity for a two-quantum process formally reduces to a one-quantum process, where the quasispectrum of the experimental conditions and the quasispectrum of the usage are introduced.

The following algorithm is suggested for solving this problem. First, analysis is done for the entire block of experimental data in relation to the vector $\mathbf{z}$ including the values of ε and δ, characterizing the errors in determining $\mathbf{I}_i = (\mathbf{I}_i^1, \ldots, \mathbf{I}_i^m)$ and $\mathbf{V} = (V_1, \ldots, V_n)$, respectively, in some norms $\|\ \|_1$ and $\|\ \|_2$. Then in the vector space $\mathbf{I}_1, \ldots, \mathbf{I}_n$ are constructed orthonormal (in the norm $\|\ \|_1$) basis $\mathbf{e}_1, \ldots, \mathbf{e}_s$, $s \leq n$, determining the nondegenerate space L_s. The orthonormalizing procedure is recurrent: at the s-th step the vector $\mathbf{I}_s$, is added to the basis, having the most orthogonal complementary minor (complement) $\max \|\mathbf{I}_s^\perp\|$ in some norm) to the subspace L_{s-1}, constructed in the previous step. The construction is complete when one of the following conditions would be violated:

$$\max_{s \leqslant i \leqslant n} \|\mathbf{I}_i^\perp\|_1 > \varepsilon \tag{4}$$

or

$$\max_{s \leqslant i \leqslant n} \left\| V_i - \sum_{j=1}^{s} c_i^j V_j \right\|_2 > \delta, \tag{5}$$

where c_i^j are the decomposition coefficients of the projection of $\mathbf{I}_i$ on L_s in the basis vectors $\mathbf{I}_1, \ldots, \mathbf{I}_s$. Determining the maximum nondegenerate subspace of L_s automatically optimizes the quantity (in single-valued fashion) and spectral conditions (in nonsingle-valued fashion, depending on the choice of $\mathbf{I}_1$) of the experiments for a given set of possible $\mathbf{I}_i$. The quality of information is characterized by the norm of the orthogonal complement $\mathbf{z}^\perp$ to the constructed subspace of L_s:

$$z^{\perp} = z - \sum_{i=1}^{s} (z,\ e_i)\, e_i = z - \sum_{i=1}^{s} a^i \mathbf{I}_i. \tag{6}$$

If $\|z^{\perp}\| \leqslant \varepsilon$, , the information is sufficient and it cannot be refined for a given value of ε. The inverse result attests to the fact that the given set of possible conditions of the experiment $\mathbf{I}_i$ is incomplete, and the solution can be refined by conducting an experiment in a region that is orthogonal to L_s. Note that the above-described procedure for given ε, δ, and $\mathbf{z}$ permits one to realize a set of optimum conditions for conducting the experiments that minimize $\|z^{\perp}\|$.

The second part of the algorithm — finding possible values of W — is done by approximating the vector $\mathbf{z}$ from above and below uniformly in α in the basis $\mathbf{I}_1, \ldots, \mathbf{I}_s$:

$$\sum_{i=1}^{s} a^i_{\min} \mathbf{I}_i = z_{\min} \leqslant z \leqslant z_{\max} = \sum_{i=1}^{s} a^i_{\max} \mathbf{I}_i. \tag{7}$$

By virtue of $\varphi_{\alpha} \geq 0$ for all α we have

$$\sum_{i=1}^{s} a^i_{\min} V_i = V_{\min} \leqslant W \leqslant V_{\max} = \sum_{i=1}^{s} a^i_{\max} V_i. \tag{8}$$

Accordingly, the interval of possible values of W will be determined from below (W_{min}) by the maximum value from the set V_{min} and from above (W_{max}) by the minimum value from the set V_{max}. The construction of such approximation reduces to a typical linear programing problem

$$W_{\min} = \max \sum_{i=1}^{s} a^i_{\min} V_i \text{ и } W_{\max} = \min \sum_{i=1}^{s} a^i_{\max} V_i \tag{9}$$

under the condition

$$\sum_{i=1}^{s} a^i_{\min} \mathbf{I}_i - z \leqslant 0 \quad \text{и} \quad \sum_{i=1}^{s} a^i_{\max} \mathbf{I}_i - z \geqslant 0 \tag{10}$$

and is solved in the usual manner (see for example, Ref. [4]).

In practice as a rule, to vary the spectral composition of the light for the experiments standard absorption light filters are used. In this case for a light filter of a given type (p), the parameter that determines the possible spectral conditions of the experiment is the optical thickness (x_q), varying the optical density of the light filter D^{α}_p.

An analysis of the possible use of BS-3, BS-4, BS-5, BS-6, BS-7, BS-8, BS-10 (p = 1, ..., 7, respectively) light filters of the standard set according to GOST 9411-80 and a light source based on a DKsSh-2000 xenon lamp (p = 0) was done on a SM-4 minicomputer to determine the sensitivity of the materials to polychromatic light in natural and artificial insulation conditions.

In our case

$$I^{\alpha}_i = I^{\alpha}_{pq} = I^{\alpha}_0 \exp(-2{,}3 D^{\alpha}_p x_q),\ V_i = \sum_{\alpha=1}^{m} \varphi_{\alpha} I^{\alpha}_i, \tag{11}$$

where I^{α}_0 is the spectral response curve of the light source used. The thicknesses $x_q = qh$, where h = 0.125 mm, q = 1, ..., 9 were selected for each filter p. Thus, for this example varies from 1 to n = 64, during which i = 1, ..., 9, corresponds to p = 1, q = 1, ..., 9; i = 10, ..., 18 — p = 2, q = 1, ..., 9, etc. In the capacity of error norms were selected $\| \quad \|_1 = \|\mathbf{I}\|^2_1 = \sum_{\alpha=1}^{m} I^{\alpha} I_{\alpha}$, $\| \quad \|_2 = \|V_i - V'_i\| = |V_i - V'_i|/|V_i|$, * and the value of $\varepsilon^2 = 10^{-5}$ (mW/m^2) and δ = 5%,

*The value of the efficiency of the response V_i were calculated from typical sensitivity curves of xanthene dyes to polychromatic light [3].

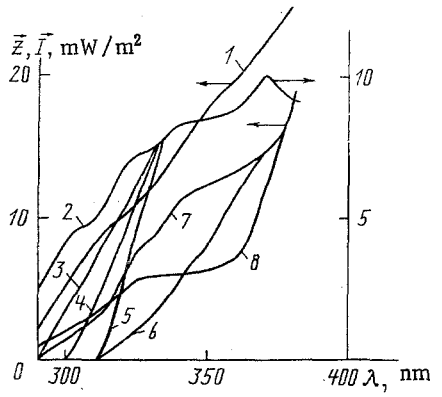

Fig. 1. Spectrum of the light source at the base of the DKsSh-2000 xenon lamp (1); spectra corresponding to usage conditions: solar light beyond the limits of the earths atmosphere (2), in the upper layers of the earths atmosphere (3), the sun at zenith (4), the sun at an angle of 20° (5), and the spectra corresponding to the exposure conditions in "Xenotest 150" devices (6), "Xenotest 250" (7), and "Fedometer" (8).

which corresponds to the experimental photochemical processes. The spectrum was analyzed in the range $\lambda_\alpha \in [290, 380]$ nm, which was divided into 10 equal sections, i.e., m = 10.

The optimum dimension of the vector **I** is determined, on one hand, by stabilization of the dimension of the subspace of L_s for an increase in the number of partition over λ_α, and, on the other hand, the optimum dimension can be reached after exiting the orthogonalization procedure not according to the criterion of Eq. (4), but according to the criterion of Eq. (5).

As a result running the first algorithm, it was obtained that for the given example the dimension of the nondegenerate subspace L_s is equal to 9, i.e., it turned out that the entire block of experimental information can be replaced by nine spectral regimes corresponding to the following values of p and q: (0.0), (3.1), (3.9), (4.3), (4.9), (5.1), (5.3), (5.4), and (5.9). For example, the spectrum of the exposure conditions reached with a BS-5 type light filter 0.125 mm thick correspond to the values p = 3 and q = 1.

Seven different spectra were examined, corresponding to different operating conditions: $\mathbf{z}_1$, solar light beyond the limits of the earths atmosphere, $\mathbf{z}_2$, solar light in the upper layers of the atmosphere, $\mathbf{z}_3$, the sun at zenith, $\mathbf{z}_4$, the sun at an angle of 20° to the horizon [2], which are shown in Fig. 1. For each of the examined spectra, according to the procedure described above, was obtained a set of decomposition coefficients of these spectra over the basis a_j^i, where j indexes the simulated spectra and i refers to the corresponding basis spectrum, i.e., $\mathbf{z}_j$ approaches $\sum_{i=1}^{9} a_j^i \mathbf{I}_i$. Analysis of the totality of experimental data showed that the constructed basis is a complete system for all these spectra which the deviation of the original and computer synthesized spectra illustrates in Fig. 2. The norms $\|z^\perp\|_1^2$ for these spectra equal: $\|z_1^\perp\|_1^2 = 7.7 \cdot 10^{-6}$, $\|z_2^\perp\|_1^2 = 6.8 \cdot 10^{-6}$, $\|z_3^\perp\|_1^2 = 1.2 \cdot 10^{-5}$, and $\|z_4^\perp\|_1^2 = 1.9 \cdot 10^{-5}$ $(\text{mW/m}^2)^2$.

The examined example showed that the 9 spectral regimes cited above, used in accelerated experiments, can describe a wide class of spectral operating conditions in the 290-380 nm region. Approximations of the spectral conditions of exposure in standard devices for test experiments of optical stability were obtained on the same basis (Fig. 1, 6-8 emission spectra of light sources in "Xenotest 150" – $\mathbf{z}_5$, "Xenotest 250" – $\mathbf{z}_6$, and "Fedometer" – $\mathbf{z}_7$ devices).

The method suggested in this work for determining the sensitivity of materials to polychromatic light action in comparison with traditional approaches has the following advantages.

First, it is possible to estimate the completeness of the initial experimental block of experimental regimes; second, it allows one to obtain an estimate of the desired sensitivity characteristic, objectively taking the quality of the information into account; third, it

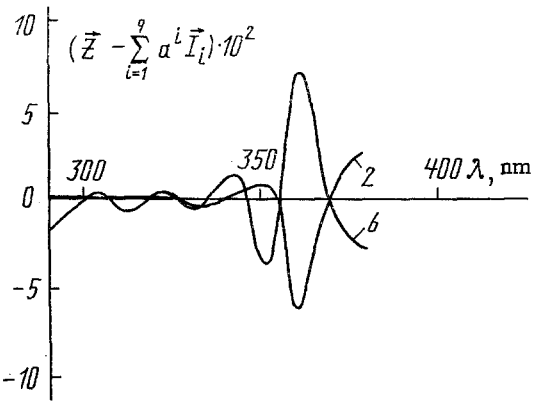

Fig. 2. Differences between original and computer calculated spectra 2 and 6.

permits one to eliminate discrepancies between the results of the accelerated experiments obtained in different devices; and fourth, it does not impose strict requirements on the spectral characteristics of the light sources for the test experiments.

In the case of testing solid materials, when the response to light is determined by a minimal portion of the surface of the sample, it is possible to use light with a spectral composition that is continuously variable along the spatial coordinate of the sample (x) and to subsequently record the response as a function of that same spatial coordinate ($V_p(x)$) [5]. So, for example, using a light filter, defining the spectral composition of the light, for linearly varying thickness we have

$$V_p(x) = \int_{\Lambda} \varphi(\lambda) I_0(\lambda) \exp\left(-2.3 D_p(\lambda) \frac{x}{l}\right) d\lambda. \qquad (12)$$

This equation is the integral Fredholm equation of 1-st order and can be numerically solved over the range variation in $D_p(\lambda)$ relative to the function $\varphi(\lambda)$ inside the integral by a regularization method using of most general assumptions about the form of $\varphi(\lambda)$ (continuity, smoothness, etc.). The algorithm for solving similar equations is developed in Ref. [6].

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