FTD-HC-23-1845-71

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ABSOLUTE SPECTRAL SENSITIVITY OF PHOTOGRAPHIC MATERIALS MADE BY GOSNIIKHIMFOTOPROYEKT FOR RECORDING SHORT-WAVE ULTRAVIOLET RADIATION

by

A. V. Kravchenko, N. G. Morozova
G. P. Startsev

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B

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12

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Foreign Technology Division
Air Force Systems Command
U. S. Air Force

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

ABSOLUTE SPECTRAL SENSITIVITY OF PHOTOGRAPHIC MATERIALS MADE BY GOSNIIKHIMFOTOPROYEKT FOR RECORDING SHORT-WAVE ULTRAVIOLET RADIATION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Translation

5. AUTHOR(S) (First name, middle initial, last name)

Kravchenko, A. V. ; Morozova, N. G.; Startsev, G. P.

6. REPORT DATE

May 1970

7a. TOTAL NO. OF PAGES

8

7b. NO. OF REFS

12

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. 7660

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

FTD-HC-23-1845-71

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Foreign Technology Division
Wright-Patterson AFB, Ohio

13. ABSTRACT

A determination has been made of the absolute spectral sensitivity and the monochromatic contrast coefficient (gamma) of photographic materials from Gosnikhimfotoproket, Type UF-[illegible]T, UF-ALPHAT, UF-1L, and UFSH-0, over a wide spectral region from 40 to 450 m mu. Measurement of light fluxes was carried out with the aid of an FEU-39A photomultiplier, the end face of which was coated with a layer of sodium salicylate. The photomultiplier and phosphor were previously calibrated by the use of an ionization chamber by the complete saturation method. The results of spectrosensitometric measurements are set out in tables. [AP1050829]

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Photographic Material						
UV Radiation						
Photomultiplier						
(U)UFSH-0 Photographic Material						
(U)UF-1L Photographic Material						
(U)UF-ALPHAT Photographic Material						
(U)UF-2T Photographic Material						
(U)FEU-39A Photomultiplier						

UNCLASSIFIED
Security Classification

UNEDITED ROUGH DRAFT TRANSLATION

by Joint Publications Research Services

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By: A. V. Kravchenko, N. G. Morozova, G. P. Startev

Source: Zhurnal Nauchnoy i Prikladnoy Fotografii i Kinematografii (Journal of Scientific and Applied Photography) 1970, Vol. 15, No. 3, pp. 161-166

English pages: 8

Approved for public release;
distribution unlimited.

UR/0077-70-015-003

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Date 3 April 1972

UDC 771.534.5

ABSOLUTE SPECTRAL SENSITIVITY OF PHOTOGRAPHIC MATERIALS MADE BY GOSNIIKHIMFOTOPROYEKT FOR RECORDING SHORT-WAVE ULTRAVIOLET RADIATION

[Article by A. V. Kravchenko, N. G. Morozova, G. P. Startsev; Moscow, Zhurnal Nauchnoy i Prikladnoy Fotografii i Kinematografii, Russian, 1970, Vol 15, No 3, signed to press 28 May 1968, pp 161-166]

Gosniikhimfotoproyekt [expansion unknown] has developed special photographic materials for recording spectra in the vacuum ultraviolet (UV) region [1-4]. Meanwhile the spectrosensitometric properties of films sensitive to short-wave ultraviolet radiation have been investigated insufficiently: the comparative sensitivity of various photographic materials has been determined for wavelengths 230 mμ and the monochromatic contrast coefficient has been determined [1-4]; the relative [5] and absolute spectral sensitivity [6] of certain types of films have been measured in a limited range of wavelengths (up to 100 mμ). It should be stressed that until now no data were available on the spectral sensitivity of photographic materials in the 20 to 100 mμ range.

The dearth of information concerning the characteristics of photographic films is attributed not only to experimental difficulties encountered in spectrosensitometric analyses in the vacuum UV, but also to a lack of the necessary equipment. The absolute spectral sensitivity was determined in [4] by the standard procedure using a FSR-9 monochromatic sensitometer, which was designed for measurements in the 450 to 250 mμ range [7]. Vacuum spectral devices, equipped with light sources, receivers for calibrating the energy distribution in the source emission spectra, auxiliary attachments and meters were employed in [5, 6].

Presented in this report are the results of determination of the absolute spectral sensitivity of photographic films developed by Gosniikhimfotoproyekt in the broad spectral region from 30 to 450 mμ and the procedure of the measurements and the set-up employed in the work are described.

1. Equipment

The photographic materials designed for recording short-wave ultraviolet radiation were analyzed with the aid of the DFS-29 normal incidence spectrograph. Two grids were used to improve the efficiency of the instrument in the far-vacuum range: one platinized with 1,200 lines/mm and one aluminized with 600 lines/mm, coated with a layer of magnesium fluoride. With the latter grid it was possible to photograph spectra in a wider range of wavelengths from 30 to 500 mμ and it was also more effective in the region below 50 mμ.

To ensure systematic control of the intensity of the spectral lines in the focal plane of the spectrograph a newly designed exit slit assembly was mounted. This assembly permits rapid transporting of the slit to the cartridge part of the spectrograph during photoelectric recording of spectra, and for photographing spectra the slit is transported back and a cartridge with the investigated film is inserted. The light source was a glow discharge in inert gas, passing through a quartz capillary 2-3 mm in diameter and 50 mm long. The pressure in the capillary was maintained at one Torr. The discharge tube was powered by a full-wave high-voltage rectifier with a Π-shaped filter. The current in the discharge tube varied from 50 to 250 ma, and at constant current the intensity of the spectral lines recorded for a period of several hours by the photomultiplier varied by not more than 5%.

In view of the fact that the spectral lines of the inert gases are unevenly distributed in the spectrum, a set of the lines of helium, neon, xenon and argon and, in the 170 to 300 mμ range, the continuous hydrogen spectrum were used for plotting the curve of spectral sensitivity of the films. A PRK-4 quartz mercury tube was used as the source for determining the spectral sensitivity of the films in the 250 to 450 mμ range,

2. Calibrating the Photomultiplier

One of the most common methods of measuring intensities in the vacuum UV-region of the spectrum is the method of converting UV-radiation to visible radiation with subsequent recording of the latter by a photomultiplier. Sodium salicylate films, applied on the FEU [Fotoelektronnyy umnozhitel'; Photomultiplier] lens, are usually employed as the luminophor. In order to use the FEU with a luminophor for energy measurements it is first necessary to determine the absolute spectral sensitivity of such a system.

The photomultiplier is calibrated in the following manner. The energy of the monochromatic emission is measured with the aid of an ionization chamber by the total absorption method [8]. The chamber was attached to the flange of a VM-140 monochromator [9] and was separated from it by a thin film of nitrocellulose. The film measuring 1.7 × 12 mm, with a thickness of 10-20 mμ, transmitted about 50% of the light in the 50 mμ region and maintained a pressure of about 10 Torr. The calibrated FEU-39A was attached by a flange directly to the flange of the chamber. The current of the ionization chamber was recorded with an EMU-3 electrometric amplifier.

The ionization chamber was pre-evacuated to a pressure of $5 \cdot 10^{-5}$ Torr and a line, whose intensity was determined by the photomultiplier in the power mode, was projected onto the exit slit of the monochromator. Then inert gas was admitted into the chamber through a flow regulator to the pressure at which the signal on the FEU anode was equal to the dark current, i.e., the monochromatic radiation was absorbed entirely within the chamber, and the ion current of the chamber was measured directly. Then the working gas of the ionization chamber was evacuated and the anode current of the photomultiplier was again measured.

The photomultiplier was calibrated in the 30-100 mμ range, during which the chamber currents were 10^{-11}-10^{-10} a.

The spectral sensitivity η_λ of the photomultiplier with luminophor was determined as the ratio of the number of electrons sorbed on the photomultiplier anode at a certain source voltage to the number of incident quanta of a given wavelength, i.e.,

$$\eta_\lambda = \frac{n_e}{n_\Phi} = \frac{I_\lambda}{i_\lambda},$$

where n_e is the number of electrons on the photomultiplier anode; n_f is the number of quanta incident on the luminophor; I_λ is photomultiplier current in amperes; i_λ is the current of the ionization chamber in amperes.

The results of calibration of the FEU-39A photomultiplier with the sodium salicylate applied on it are given in Table 1 for a source voltage of 900 V (the dark current on the photomultiplier anode was $7 \cdot 10^{-9}$ a).

Table 1

(1) Длина волны, мμ	(2) Спектральная чувствительность $\eta_\lambda \left(\frac{\text{электр.}}{\text{квант}}\right)$
30,4	$0{,}89 \cdot 10^5$
46,0	$1{,}00 \cdot 10^5$
58,4	$1{,}00 \cdot 10^5$
74,4	$1{,}00 \cdot 10^5$

KEY: 1. Wavelength, mμ
2. Spectral sensitivity $\eta_\lambda\left(\frac{\text{electr.}}{\text{quant.}}\right)$

The calibration error of the "FEU-luminophor" system did not exceed 10%.

Repeated analyses revealed that sodium salicylate films have a constant quantum output in the 50 to 300 mμ range [8, 10, 11]. Long-term storage of the luminophor film in air or in a vacuum in clean conditions did not result in reduction of quantum output [12].

For the 300 to 500 mμ spectral region we employed the FEU-36, the photocathode of which was calibrated for the stated spectral region with the aid of a thermocouple.

3. Measurement Method

The intensities of the spectral lines in the focal plane of the DFS-29 spectrograph were recorded with the aid of a calibrated photomultiplier, attached to a flange behind the exit slit. The photomultiplier was powered by a high-voltage VS-22 rectifier. The photomultiplier current was measured with a M-95 galvanometer.

The width of the entrance slit was set at 0.2 mm with a height of 2 mm, and the width of the exit slit was 0.3 mm.

After measuring the absolute intensities of a group of lines located in a certain region of the spectrum the exit slit was replaced by a cartridge with photographic film and the spectrum was photographed. Then the exit slit was reinserted and the intensities of the spectral lines were rechecked.

The gradations of blackening on the photographic film were found by changing the exposure time within the limits 1:10 during plotting of the linear segment of the characteristic curve. Usually 7-8 blackening gradations were photographed on one film. A MF-2 microphotometer was used for photometric evaluation of the films.

The photographic materials of all types were developed in a D-19 developer at 20 ± 0.5°C. The development time for UFSh-0 and UF-1L films was 6 min, and for UF-2T and UF-αt the development time was 8 min.

The sensitivity S_λ of the photographic material for density D (maximum density of blackening of a given gradation) over the density of the haze was determined according to the equation:

$$S_\lambda = \frac{\int\limits_{(S)} e^{\lambda}_{\text{отн}}\, dS}{I_\lambda h\nu t^{D}_\lambda}\eta_\lambda q\ [\text{см}^2/\text{эрг}],$$

[OTH=rel]

where λ is wavelength; I_λ is photomultiplier current in amperes; $h\nu$ is incident quantum energy in erg; t^{D}_{λ} is exposure time required for achieving blackening density D over haze density; η_λ is the absolute spectral sensitivity of the photomultiplier; q is the electron charge in coulomb; $e^{\lambda}_{\mathrm{rel}}$ is the relative illumination of element dS of the image area of the spectral line.

To calculate $\int_{(S)} e^{\lambda}_{\mathrm{rel}} dS$ we experimentally determined the dependence of the relative distribution of illumination of the spectral line with respect to width and height, whence we determined the desired value graphically.

An example of the height distribution of illumination of the mercury line at 334.1 mμ is shown in Figure 1.

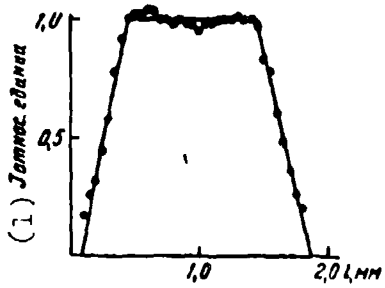

Figure 1. Illumination distribution of mercury line 334 mμ by height.
KEY: 1. Relative units.

4. Results of Spectrosensitometric Tests of Photographic Materials

The equipment and procedures described herein were used for determining the absolute spectral sensitivity and monochromatic contrast coefficient of photographic films developed by Gosniikhimfotoproyekt:

Type UF-2T	in	40-450 mμ range
Type UF-αt	in	30-110 mμ range
Type UF-1L	in	50-450 mμ range
Type UFSh-0	in	200-450 mμ range

The curves of the spectral distribution of the light sensitivity are illustrated in Figure 2 ($D = 1.0$, over haze density) for the above-stated photographic materials. The spectral curves of the contrast coefficient are shown in Figure 3.

The values of monochromatic illumination H_λ, in erg, per cm^2 are presented in Tables 2-5 (for the same criteria), and the monochromatic contrast coefficients are listed in the last column of the tables.

The absolute spectral sensitivity measurement error of the films are attributed to: 1) instability of light source; 2) nonuniformity of photoemulsion; 3) variations in development conditions; 4) error in photometric evaluation; 5) error in photomultiplier calibration with the aid of the ionization chamber.

The first four errors characterize the reproducibility of the determinations, which according to our assessment is 10-15% for UF-2T film. The photomultiplier calibration error did not exceed 10%. Thus the summary measurement error is 20-25%. UF-1L film (1967) was stored for about two months prior to testing, during which time it was discovered that its quality is not completely satisfactory. Accordingly the error in the determination of the characteristics of this film apparently exceeds 25%.

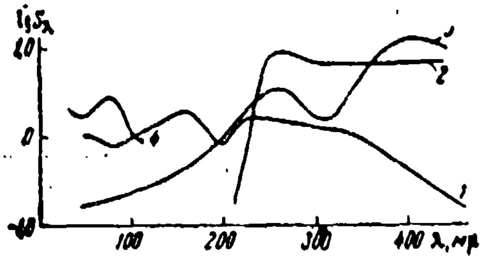

Figure 2. Spectral sensitivity curves of films: 1 -- UF-2T; 2 -- UFSh-0; 3 -- UF-1L; 4 -- UF-αt.

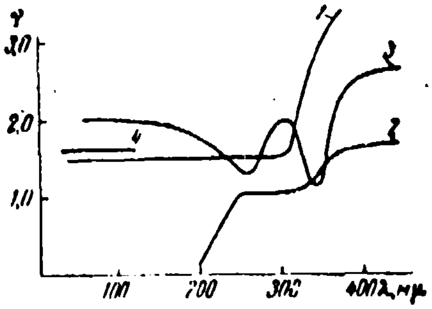

Figure 3. Spectral curves of contrast coefficient of films: 1 -- UF-2T; 2 -- UFSh-0; 3 -- UF-1L; 4 -- UF-αt.

Table 2. UF-2T Film

λ, мμ	Hλ, эрг/см²			γ	λ, мμ	Hλ, эрг/см²			γ
	D = 1,0	D = 0,6	D = 0,2			D = 1,0	D = 0,6	D = 0,2	
40,0	1,00	0,56	0,23	1,55	228,0	0,60	0,31	0,17	1,50
58,4	1,05	0,56	0,23	1,50	248,2	0,69	0,37	—	1,65
73,5	1,20	0,68	0,28	1,50	251,0	0,65	0,33	0,17	1,50
93,9	1,15	0,62	0,29	1,55	271,0	0,77	0,36	0,18	1,50
105,2	0,98	0,53	0,24	1,60	276,3	0,72	0,39	—	1,60
110,2	0,83	0,45	0,21	1,60	289,3	0,74	0,40	—	1,50
121,5	0,72	0,38	0,16	1,50	290,0	0,69	0,36	0,17	1,45
125,0	0,72	0,39	0,18	1,60	313,1	0,87	0,47	0,21	1,60
140,9	0,58	0,31	0,15	1,55	334,1	1,05	0,58	0,25	2,50
169,0	0,56	0,30	0,15	1,55	360,3	1,32	1,00	0,47	3,30
189,0	1,07	0,51	0,28	1,45	404,6	2,46	2,00	1,05	4,20
208,0	1,07	0,51	0,26	1,50	435,8	4,07	3,31	1,95	4,70

It should be pointed out that during determination of the absolute spectral sensitivity of films UF-2T, UF-1L and UFSh-0 the measurements of the absolute spectral line intensities at about 300 mμ were made alternately with two photomultipliers, FEU-39A and FEU-36, calibrated by different methods.

As mentioned above, the former was calibrated with the aid of an ionization chamber and the second with the aid of a thermocouple.

Table 3. UF-1L Film

λ, мμ	H_λ, эрг/см²			γ	λ, мμ	H_λ, эрг/см²			γ
	$D=1,0$	$D=0,6$	$D=0,2$			$D=1,0$	$D=0,6$	$D=0,2$	
58,4	6,16	3,47	1,09	2,00	267,5	0,32	—	—	—
73,5	5,01	2,19	0,69	2,00	271,0	0,32	0,12	0,028	1,35
121,5	3,55	1,95	0,62	2,00	276,0	0,35	—	—	—
169,0	1,74	0,81	0,17	1,80	291,0	0,50	0,24	0,057	1,80
189,0	1,20	0,56	0,11	1,75	312,5	0,63	0,30	0,063	2,00
208,0	0,79	0,46	0,079	1,70	334,1	0,35	0,16	0,049	1,15
228,0	0,41	0,20	0,051	1,65	366,3	0,12	0,069	0,029	2,15
237,8	0,40	—	—	—	404,6	0,08	0,044	0,018	2,60
251,0	0,29	0,10	0,022	1,35	435,8	0,09	0,054	0,022	2,60

Table 4. UFSh-0 Film

λ, мμ	H_λ, эрг/см²			γ	λ, мμ	H_λ, эрг/см²			γ
	$D=1,0$	$D=0,6$	$D=0,2$			$D=1,0$	$D=0,6$	$D=0,2$	
207	4,07	8,70	0,19	0,25	273	0,15	0,062	0,015	1,10
216	3,89	0,50	0,071	0,45	312,5	0,17	0,069	0,018	1,00
228	1,18	0,24	0,032	0,60	313,1	0,17	0,066	0,016	1,00
230	1,12	0.23	0,030	0,60	334,1	0,19	0,093	0,023	1,15
238	0,40	0,12	0,020	0,80	366,3	0,15	0,083	0,017	1,55
250	0,13	0,054	0,013	1,05	404,6	0,14	0,081	0,015	1,65
251	0,11	0,048	0,013	1,10	435,8	0,15	0,085	0,015	1,65
271	0,12	0,054	0,011	1,10					

Table 5. UF-αt Film

λ, мμ	H_λ, эрг/см²			γ
	$D=1,0$	$D=0,6$	$D=0,2$	
30,4	0,50	0,24	0,12	1,60
40,0	0,62	0,34	0,20	1,50
53,7	0,53	0,33	0,15	1,65
74,2	0,35	0,20	0,098	1,60
103,2	1,15	0,66	0,31	1,65
107,4	1,15	0,66	0,31	1,65
110,0	1,15	0,66	0,31	1,00

In both cases the results of the determination of the absolute spectral sensitivity of a given emulsion coincided within the limits of the measurement error. The concordance of results therefore confirms the reliability of photomultiplier calibration, done with the aid of the ionization chamber.

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Department of Chemistry
University of California, San Diego
La Jolla, California 92037

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
Optimized Cluster Expansions for Classical Fluids. III. Applications to Ionic Solutions and Simple Liquids

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*
Hans C. Andersen, David Chandler and John D. Weeks

6. REPORT DATE
May 23, 1972

7a. TOTAL NO. OF PAGES
21

7b. NO. OF REFS
17

8a. CONTRACT OR GRANT NO.
N00014-69-A-0200-6018

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
Technical Report No. 13

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
ARPA Order No. 1479

10. DISTRIBUTION STATEMENT
Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Office of Naval Research
Physics Branch
Washington, D. C. 20360

13. ABSTRACT

In a previous paper we have derived a number of simple approximations for the thermodynamic and structural properties of liquids. Here we test these approximations by applying them to models for ionic solutions and atomic liquids and comparing the results with those obtained from Monte Carlo and molecular dynamics simulations. In particular, the pair-correlation functions for 1-1 primitive model aqueous ionic solutions are calculated using the EXP approximation. The internal energy for 2-2 salts is obtained from the ORPA+B_2 approximation. The pair-correlation function for the Lennard-Jones fluid is calculated with the EXP approximation. In all cases the results obtained agree closely with those obtained from computer experiments. Thus, the ORPA+B_2 approximation for the free energy and the EXP approximation for the pair correlation function provide a theory that is both very accurate and applicable to a wide variety of classical fluids.

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

DD FORM 1 NOV 65 1473 (BACK)

(PAGE 2)

Security Classification