ON THE POSSIBLE WAYS OF VARYING THE RELATIVE INTENSITY OF THE BANDS OF THE DIFFRACTION PATTERN DUE TO A SCREEN

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Some experiments on varying the intensity of the bands of the diffraction pattern due to a screen for the constant parameters of the diffraction scheme, intensity of incident light, and width of the open side of the wavefront are considered. It was found that along with the increase in the diffraction maxima, a reduction of the illumination in the geometric shadow from the screen occurs and vice versa.

A quantitative description of the diffraction pattern due to a screen based on the interference of the edge rays with the directly transmitted rays, which is adequate to the experiment, was given in Refs. 1 and 2. As is well known, the location and the intensity of the bands determined on the basis of Fresnel's ideas under conditions of constant intensity of light across the wavefront are also close to their actual values. In connection with the establishing the factors of this agreement in Ref. 2 it became obvious that Fresnel's ideas are formal. Indeed, if the Huygens–Fresnel principle had been essentially valid, it would have been impossible to vary the intensity of the diffraction bands in the case, in which the parameters of the diffraction scheme, the intensity of the incident light, and the width of the open side of the wavefront were constant. But the experience shows the opposite case. Moreover, the ways of varying the intensity are an organic consequence of Young's ideas about the nature of light diffraction. One of these ways is described in the paper that deals with establishing the real factors of the variation in the axial intensity of light with the change of the width of the collimating slit. Its essence is an increase in the intensity of the edge rays, which interfere with the directly transmitted rays due to the superposition on them of the edge rays initially propagating into the shadow.[3]

Let us consider the effect of this way of varying the intensity on the diffraction pattern due to a screen. The corresponding scheme is given in Fig. 1, where s_1 is the 30–μm wide slit illuminated by a parallel beam of green light with $\lambda = 0.53$ μm and h is the distance from the geometric shadow boundary (GS) to the bands of the diffraction pattern in the plane of the scanning slit s_2. In contrast to the scheme shown in Fig. 4 of Ref. 1, in this scheme a thick screen formed by a glass rectangular prism with the length of the cathetus faces being equal to 10.6 mm was used instead of a thin screen (blade). In order to eliminate falling of the direct rays from s_1 within the face AB, the prism was positioned at an angle $i = 0.076°$ with respect to the beam axis when the edge A (l = 12 mm and L = 99.5 mm) was located up against the axis of the light beam.

The edge rays diffracted by the edge A into the shadow from the prism partially fell within the face AB (*2*) and partially passed by it (*3*). After the reflection from the face, the rays *2* are superposed on the edge rays *1*, which propagate from the edge A to the right of the GS. Due to the loss of the half wave at the moment of reflection, the rays *1* and *2*, which were initially out of phase,[1] turned out to be in phase and, therefore, reinforced each other. As a consequence of the increased intensity of the edge rays, which interfere with the directly transmitted rays *4*, the intensities in the maxima of the diffraction pattern increase, while the intensities in the minima decrease compared to their values of the diffraction pattern due to a thin screen. This is confirmed by the data in Table I, where $h_{\exp}$ and h_c are the experimental and calculated (based on formula (3)) values of h,[1] $\Delta h = (h_{\exp} - h_c)$, J_p is the intensity of the bands when the prism forms a screen, J_l is the intensity of incident light in the plane s_2, J_{ep} and J_{ebl} are the intensities of the edge rays at the edge A of the prism and at the edge of the thin screen (blade), $\Delta J_p = (J_p - J_l)$, $\Delta J_{bl} = (J_{bl} - J_l)$, and J_{bl} is the intensity in the bands of the diffraction pattern due to a blade.

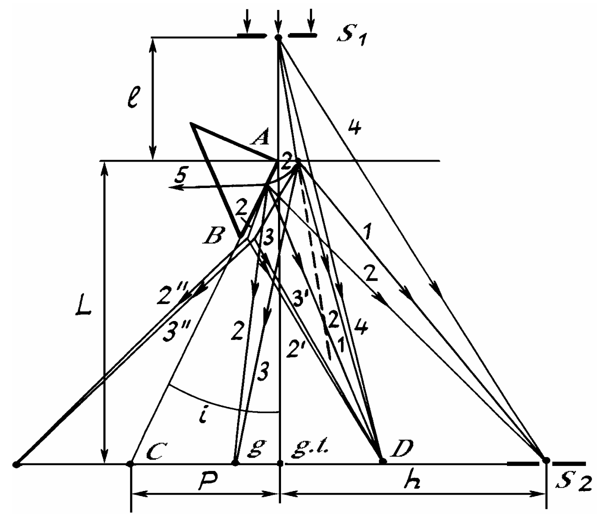

FIG. 1. The scheme of the diffraction of light from the thick screen.

The values of ΔJ_p, J_p/J_l, and J_{ep}/J_{ebl} given in the table are slightly underestimated because of a partial refraction of the rays into the prism resulting in the formation of the refracted beam *5*.[4] Judging from the value J_{ep}/J_{ebl}, in the absence of this refraction, J_{ep} would exceed J_{ebl} by a factor of ~ 4 at all the angles of deviation of the diffracted rays. In this case, the fluxes ϕ_{e1} and ϕ_{e2} produced by the rays *1* and *2*, which interfere with each other, would

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have approximately identical values and their summation would produce the resultant flux ϕ_{e12} exceeding the arithmetic sum of ϕ_{e1} and ϕ_{e2} by a factor of 2. As a result, the interference of the rays *1* with the rays *2* under these conditions does occur without the path difference between the rays.

Along with the increase of i caused by a strong dependence of the intensity of the edge rays on the angle of their deviation from the initial direction of propagation, the number of the rays *2* falling within the face of the prism and being reflected from it rapidly decreases, which causes the attenuation of J_{ep}. As a result, ΔJ_p, J_p/J_l, and J_{ep}/J_{ebl} tend to the corresponding values for the thin screen. The behavior of this attenuation is demonstrated in Tables II–IV. According to them, already at $i = 1.8°$ the perturbation of the light field caused by the thick glass screen is close in value to the perturbation caused by the thin screen while at $i = 10.8°$ the thick screen is virtually equivalent to the thin one.

The correctness of the foregoing explanation of the increase in the light intensity in the maxima of the diffraction pattern due to the thick screen and of the decrease of the light intensity in the minima was supported by the experiments, in which the face AB of the prism was coated with the layer of soot 26 μm thick. In this case, because of the absorption of the incident rays *2* by the soot, the intensity of the reflected rays *2* decreased and for this reason the total flux of the edge rays interfering with the directly transmitted rays, reduced. As a result, the diffraction bands became less contrast, which is evident from the comparison of the data in Tables V and VI characterizing the diffraction patterns in the experiments with clean and blackened faces AB ($l = 12$, $L = 136$ mm, and $i = 0.1°$).

When the face of the prism is covered with soot, an increase of Δh is observed as the order of the bands increases starting from min_2. The reason of this effect becomes clear when we take into account the fact that the phase shift of the reflected rays at the moment of light reflection from the absorbing media differs from π. Under these conditions, this difference is the greater, the higher is the order of the bands, that is, the larger is the distance of deviation h of the reflected rays. The variation of the indicated phase shift results in a mismatch of the phases of the rays *1* and *2*. For this reason, the reflected rays *2* in min_2 and in the subsequent bands, instead of reinforcing the rays *1*, *vice versa* attenuate them. Hence, J_{ep}/J_{ebl} becomes smaller than unity. As a consequence of the phase shift between the rays *1* and *2*, a decrease of the the path difference between the rays derivative from them and the rays *4* by the value not of 0.69 $\lambda/2$, but of $k_0\lambda/2$ takes place. Let us substitute k_0 for 0.69 in Eq. (3) (Ref. 1) and invert the formula. Then $k_0 = \left[\frac{h^2 l}{\lambda L(L + l)} - k\right]$ if $h = h_{\exp}$, $k = 0, 2, 4, \ldots$ corresponds to the maxima and $k = 1, 3, 5, \ldots$ corresponds to the minima of the diffraction pattern.

In contrast to the increase of the intensity of the edge rays in the illuminated side with the thick screen positioned at small angles i with respect to the axis, a significant attenuation of the intensity of the edge rays propagating into the shadow, occurs. This is illustrated by Fig. 2, where curves *1*, *2*, and *3* show the intensities J_e of the light diffracted behind the screen as functions of h at i being equal to 0.076, 0.45, and 10.8°. This intensity slightly increases when a layer of soot covers the face AB in contrast to the attenuation of the intensity of the edge rays propagating to the illuminated side, which is evident from Fig. 3. Here the J_e as functions of h are shown by the curves *1* and *2* at $i = 0.1°$ for the cases of clean and blackened faces AB. The analogous dependence for the thin screen is represented by the curve *3*.

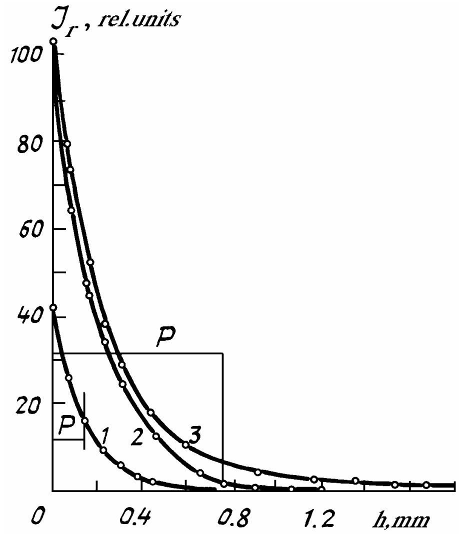

FIG. 2. The plots demonstrating the attenuation of the light intensity in the geometric shadow from the thick screen instead of the thin one.

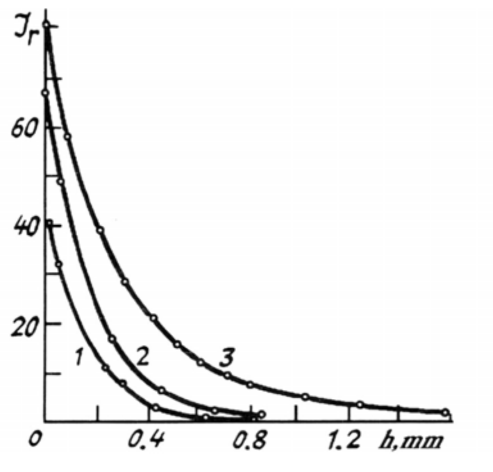

FIG. 3. The curves, which characterize the increase in the light intensity in the geometric shadow from the prism when a layer of soot covers the face AB.

TABLE I.

i =0.076°											
Band	h_{exp}, mm	h_c, mm	Δh, μm	J_p	J_l	J_{ep}	ΔJ_p	ΔJ_{bl}	J_p/J_l	J_{bl}/J_l	J_{ep}/J_{ebl}
max_1	0.564	0.582	−18	52.1	28	3.712	24.1	11.94	1.861	1.426	3.512
min_1	0.901	0.910	−9	10.2	19	1.36	−8.8	−5.32	0.536	0.72	3.123
max_2	1.141	1.148	−7	21.79	13.2	1.071	8.6	4.04	1.651	1.306	3.976
min_2	1.336	1.345	−9	4.63	8.2	1.507	−3.6	−2.4	0.564	0.712	3.27
max_3	1.511	1.516	−5	9.66	5.7	0.519	4	2	1.695	1.354	3.624
max_4	1.811	1.811	0	4.12	1.9	0.423	2.2	1	2.167	1.535	4.013
CS	0	0	–	4.33	36	4.33	–	–	0.12	0.308	0.39

TABLE II.

i = 0.45°										
Band	h_{exp}, mm	Δh, μm	J_p	J_l	J_{ep}	ΔJ_p	ΔJ_{bl}	J_p/J_l	J_{bl}/J_l	J_{ep}/J_{ebl}
max_1	0.564	−18	41.74	28	1.368	13.74	11.94	1.491	1.426	1.294
min_1	0.907	−3	12.31	19	0.724	−6.69	−5.32	0.648	0.72	1.662
max_2	1.145	−3	18.28	13.2	0.413	5.08	4.04	1.385	1.306	1.533
min_2	1.345	0	4.61	8.2	0.515	−3.59	−2.4	0.561	0.712	2.567
max_3	1.522	6	8.21	5.7	0.228	2.51	2	1.44	1.354	1.494
max_4	1.832	21	3.13	1.9	0.152	1.23	1	1.647	1.535	1.403
GS	0	–	10.39	36	10.39	–	–	0.288	0.308	0.935

TABLE III.

i =1.8°										
Band	h_{exp}, mm	Δh, μm	J_p	J_l	J_{ep}	ΔJ_p	ΔJ_{bl}	J_p/J_l	J_{bl}/J_l	J_{ep}/J_{ebl}
max_1	0.564	−18	40.26	28	1.109	12.26	11.94	1.438	1.426	1.05
min_1	0.919	9	13.32	19	0.504	−5.68	−5.32	0.701	0.72	1.158
max_2	1.159	1	17.28	13.2	0.275	4.08	4.04	1.309	1.306	1.02
min_2	1.359	14	6.27	8.2	0.129	−1.93	−2.4	0.765	0.712	0.645
max_3	1.524	8	7.79	5.7	0.163	2.09	2	1.367	1.354	1.07
max_4	1.824	13	2.88	1.9	0.102	0.98	0.98	1.516	1.535	0.94
GS	0	–	10.68	36	10.68	–	–	0.296	0.308	0.961

TABLE IV.

i = 10.8°										
Band	h_{exp}, mm	Δh, μm	J_p	J_l	J_{ep}	ΔJ_p	ΔJ_{bl}	J_p/J_l	J_{bl}/J_l	J_{ep}/J_{ebl}
max_1	0.564	−18	39.7	28	1.019	11.7	11.94	1.418	1.426	0.964
min_1	0.891	−19	13.7	19	0.432	−5.3	−5.32	0.721	0.72	0.993
max_2	1.127	−21	17.3	13.2	0.277	4.1	4.04	1.311	1.309	1.027
min_2	1.332	−13	6.1	8.2	0.155	−2.1	−2.4	0.744	0.712	0.774
max_3	1.522	6	7.65	5.7	0.143	1.95	2	1.342	1.354	0.94
max_4	1.812	1	2.9	1.9	0.105	1	1	1.526	1.535	0.971
GS	0	–	11.1	36	11.1	–	–	0.308	0.308	1

TABLE V.

Band	h_{exp}, mm	Δh, μm	J_p	J_l	ΔJ_p	J_p/J_l	J_{ep}	J_{ep}/J_{ebl}
max_1	0.765	–18	52.53	30.71	21.82	1.711	2.911	2.9
min_1	1.237	11	15.73	23.16	–7.43	0.679	0.715	1.72
max_2	1.539	–7	25.29	17.89	7.41	1.414	0.640	2.37
min_2	1.808	–3	8.67	12.85	–4.18	0.674	0.411	2.69
max_3	2.039	–3	14	9.59	4.41	1.46	0.414	2.86
min_3	2.249	0	4.28	6.29	–2.01	0.681	0.192	1.54
max_4	2.432	–7	6.84	4.28	2.56	1.597	0.297	2.801
max_5	2.782	2	3.16	1.82	1.34	1.737	0.184	–
GS	0	–	3.95	36	–	0.1096	–	–

TABLE VI.

Band	h_{exp}, mm	Δh, μm	k_0	J_p	J_l	ΔJ_p	J_p/J_l	J_{ep}	J_{ep}/J_{ebl}
max_1	0.765	–18	–	44.74	30.69	14.1	1.458	1.321	1.314
min_1	1.252	26	–	16.2	22.36	–6.2	0.725	0.496	1.248
max_2	1.552	6	0.709	21.45	16.92	4.53	1.268	0.268	1.01
min_2	1.832	21	0.775	9.74	12.06	–2.32	0.808	0.124	0.835
max_3	2.078	36	0.857	10.57	8.62	1.95	1.227	0.099	0.712
min_3	2.289	40	0.894	4.1	5.28	–1.18	0.776	0.075	–
max_4	2.482	43	0.930	4.31	3.24	1.07	1.329	0.076	0.743
max_5	2.842	62	1.08	1.64	1.03	0.62	1.6	0.072	–
GS	0	–	–	6.58	35.9	–	0.183	–	–

In the geometric shadow P, for example, at the point G, the illumination is produced by the weakly deviated rays *3* and glancing rays *2*. The face AB prevents these rays from propagating to the side $h > p$. Nevertheless, according to the curve *1* (Fig. 2), when rotating the prism at an angle $i = 0.076°$ the light of an appreciable intensity propagates into the shadow at a distance $h \sim 0.74$ mm, while P is equal to 0.132 mm only. As a result, redeviation of the rays *2* and *3* passing nearby the edge B on either side of the preceding direction of their propagation takes place, which is apparently accompanied by an additional phase shifts similar to the initial phase shift at the moment of the deviation of the rays by the edge A. The secondary reflected rays *2* and *3* are designated in the figure by *2′*, *3′*, *2″*, and *3″*.

As a consequence of a loss of the half–wave by the reflected rays *2*, the rays *2* and *3* arriving within the distance P and the rays *2″* and *3″* propagating to the distances $h > P$ attenuate each other; therefore, the illumination in the shadow is lower than its value behind the thin screen. After blackening the face, the intensity of the reflected rays *2* attenuates and, consequently, they attenuate the rays *3* and *3″* to a smaller degree, which results in the increase of the illumination noted above.

When the prism is rotated at an angle $i = 0.45°$ and more, the intensity of the rays *3″* and *2″* decreases because of the attenuation of the intensity of the rays *2* and *3* in the edge B. As a result, the main part of the illuminated side of the shadow turns out to be limited by the distance P.

Nearby the shadow boundary, to the right of it, for example, at the point D, the rays *1*, *2*, *4*, *2′*, and *3′* converge. Any objective estimate of the light intensity in this region is impossible because of lack of the information about their intensity and the initial phase shifts which at small angles of deviation of the rays, as shown in Ref. 3, differ from the values determined in Ref. 1. Judging by the experience it is smaller compared to the value observed in the diffraction pattern due to the thin screen.

REFERENCES

1. Yu.I. Terent'ev, Atm. Opt. 2, No. 11, 970–974 (1989).
2. Yu.I. Terent'ev, ibid. 2, No. 11, 975–981 (1989).
3. Yu.I. Terent'ev, ibid. 4, No. 4 267–281 (1991).
4. Yu.I. Terent'ev, Izv. Vyssh. Uchebn. Zaved., Ser. Fiz. No. 12, 55–58 (1987).