Peculiarities of light scattering near an edge of a thin opaque screen. Part 1

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It has been found experimentally that rays deflected near an edge of a thin opaque screen toward or outward the screen are repeatedly deflected by the second screen only in the directions toward the screen or outward it. The second screen was separated by less than 4.5 mm from the first one. The rays deflected toward and outward the first screen, upon passage of 25 mm, were deflected near the edge of the second screen both toward and outward it. Some rays passed near the screen edges without changing the direction.

This paper presents the experimental results of my research into the nature of light propagation near screens. The research is based on the following experimental facts and regularities established earlier:

1. There exist zones of deflection of light rays above the surface of opaque screens, as well as on each side of an interface between optically homogeneous media. The width of these zones many times exceeds the wavelength of the visible light. They deflect rays in the opposite directions relative to the initial direction.[1] The efficiency of deflection toward a screen or outward it decreases with the distance from the screen.[2]

2. The edge light from the screen consists of the rays deflected toward or outward the screen in the deflection zone (they form the principal component) and the rays reflected from the edge, partly after their prior deflection in the zone. These rays form the component that is called the Sommerfeld one because after reflection they propagate directly from the screen.[1]

3. The phases of the edge components deflected from the screen and to the shadow zone experience initial shift by $\pi/2$ in the direction of propagation and the opposite one with respect to the phase of the incident wave,[3–5] rather than by π and 0, as was asserted by Rubinowicz.[6] As a results, the mutual shift between them is π (Ref. 3). The Sommerfeld component propagating along the illuminated side experiences the shift by $-\pi/2$ at deflection toward the screen and by π in the process of reflection. Thus, it turns out to be in phase with the principal component. The Sommerfeld component propagating in the shadow zone loses half wave and turns out to be, conversely, in the opposite phase with the principal component of the same direction.

4. If the screen is covered with soot, the energy in the edge wave redistributes markedly from the illuminated side to the shadow zone without changes in the total edge flux, because soot partially absorbs the Sommerfeld component, thus decreasing the extinction of the principal component in the shadow zone and its amplification on the illuminated side.[1]

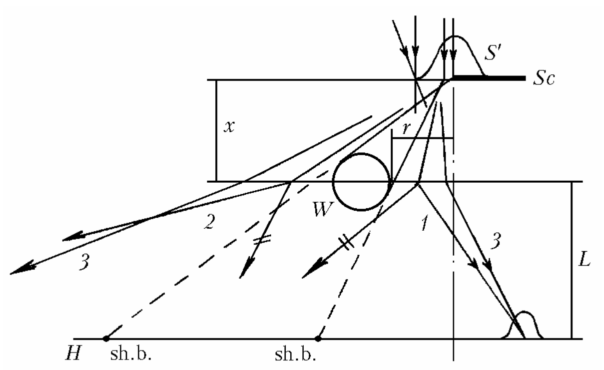
5. The amplitude of the edge light from a thin weakly absorbing screen with straight edge is inversely proportional to tangent of the diffraction angle at its values $\geq 0.04 - 0.07°$. Consequently, the main part of the edge flux propagates within $0 - 1°$ (Refs. 3 and 7).

The experimental schemes are shown in Figs. 1*a* and 2*a*. In these figures, S' is an image of a slit S 36 μm wide (it is shown as an approximate intensity distribution over the image width drawn with the use of a Jupiter-8 objective; Sc is a thin screen (blade) set in the plane S' and cutting off a half of the flux from the objective; W is a nichrome wire 90 μm in diameter parallel to the screen edge and spaced by $x = 4.5$ mm from the plane S' and by $L = 96$ mm from the plane of scanning the diffraction pattern with a 0.1-mm-wide slit along the axis H; sh.b. is the boundary of the geometric shadow of the wire. The slit S is illuminated by a parallel beam of green light ($\lambda = 0.53$ μm) from a filament lamp.

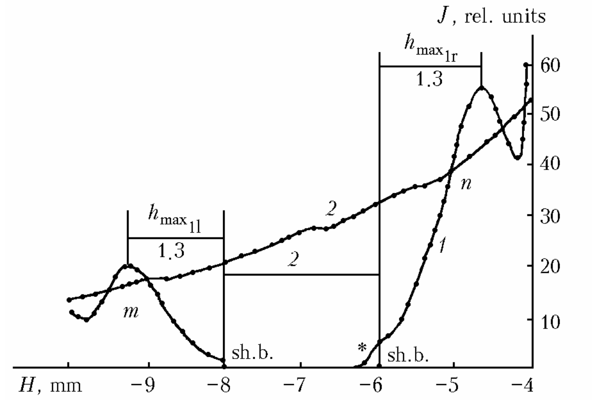
In Fig. 1*a*, the wire is in the edge flux propagating on the side opposite to the screen shadow. The flux passes from the deflection zone near the screen edge. It almost completely consists of rays deflected in the direction outward the screen, because the screen is covered with soot reducing reflection of rays deflected toward the screen and incident on its edge.

To exclude overlapping of the incident light and this edge light, the right edge of the 1.5-mm-wide aperture slit sl_0 in front of the objective was set at the axis of the light beam. In this case, its left screen limited the beam by $\min_1$ from the slit S. (When overlapping was excluded, the left edge of sl_0 was at the beam axis). The wire is spaced by $r = 255$ μm from the axis of the incident beam. Therefore, the edge rays deflected in the thin (about 1 μm wide) deflection zone of the screen pass through deflection zones of the wire. When determining the boundaries of the geometric shadow of the wire, the screen deflection zone, which is very thin, can be considered as a point-like source near the screen edge. This follows from the equation $h_z = (259.5-0.786\varepsilon)/\varepsilon$ (Ref. 2), where h_z is the distance, in μm, from the screen to the point at which the ray is deflected; ε is the angle of ray deflection, in minutes of arc, (ε = $3438r/x$). At such r, the edge rays passing near the wire from the deflection zone of the right-hand edge of sl_0 have low intensity as compared to the intensity of the edge light from the deflection zone of the screen Sc.

In this experiment, the intensity J distribution in the scanning plane in the diffraction pattern from the wire and the edge wave from the screen Sc is characterized by curves *1* and *2* (Fig. 1*b*), where H is measured from the axis S'.



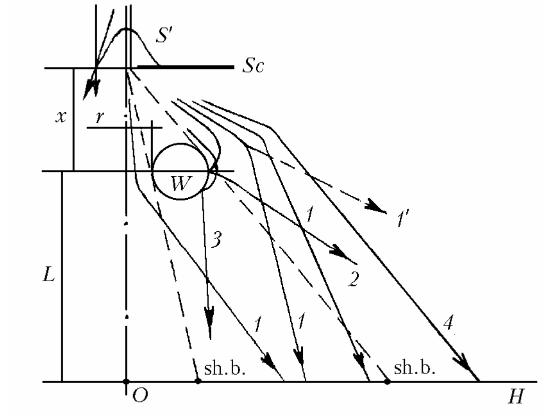
a



b

Fig. 1. Experiment on diffraction of edge light passing from the zone near the edge of a thin opaque screen in the direction opposite to its shadow on the wire (*a*). Intensity distribution in the edge wave passing from the zone near the edge of the screen on the side opposite to its shadow and in the diffraction pattern formed by the edge wave from the wire (*b*).

According to data presented by curve *1*, the light almost does not reach the geometric shadow of the wire. The rays *1* and *2*, deflected in the screen deflection zone outward the screen, pass the path x and enter the deflection zones of the right and left edges of the wire. In these zones, they are repeatedly deflected only outward the screen (wire). The low illumination (marked by asterisk) in the wire shadow near its right boundary is likely due to low-intensity edge rays from the right edge of sl_0 and the rays reflected from the screen edge (after deflection) because of incomplete absorption by soot.



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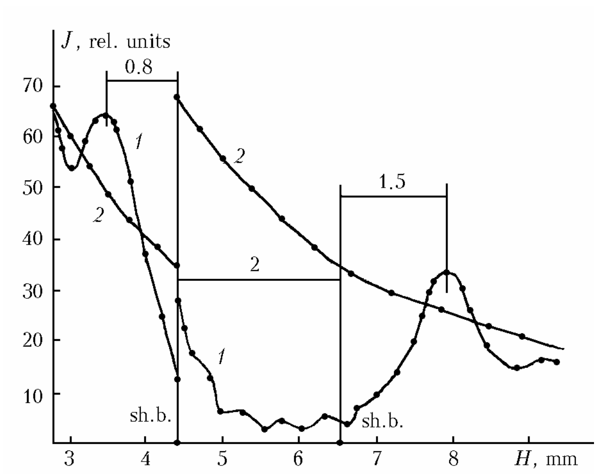

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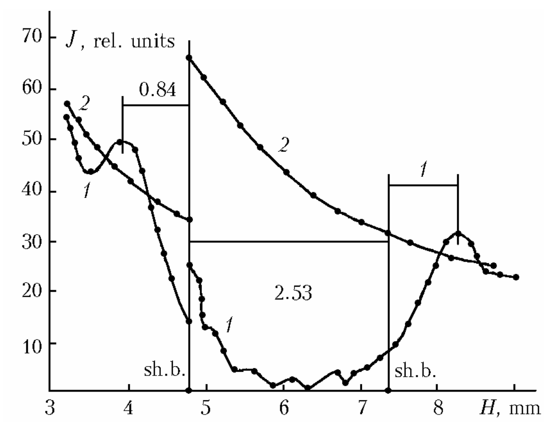


c

Fig. 2. Experiment on diffraction of the edge light passing from the zone near the edge of a thin opaque screen into its shadow on the wire (*a*). Distribution of light intensity in the edge wave propagating into the screen shadow and in the diffraction pattern of clean (*b*) and soot-covered wire (*c*).

The rays *1* and *2* interfere with rays *3* that pass far from the wire and, therefore, are less deflected. As a result, interference fringes are formed beyond the wire shadow. These fringes are shifted by 0.4–0.55 mm relative to their positions calculated by Eq. (3) from Ref. 3. The lower value of J in the diffraction pattern at the areas between the shadow boundary and the points m and n as compared to J of the edge wave is caused by deflection of the edge rays from the wire deflection zones (near the shadow boundary) and initial and geometric propagation difference between the rays *1*, *2*, and *3* (at a distance from the shadow boundary).

In Fig. 2*a* the wire is set in the screen shadow at the distance r = 197 μm from the axis S'. In this case, the distribution of light intensity in the scanning plane in the diffraction pattern from the wire and in the edge flux consisting of rays deflected toward the screen in its deflection zone is characterized by the curves *1* and *2* in Fig. 2*b* (J at H < 4.4 mm is halved).

As curve *1* (Fig. 2) shows, in this experiment, in contrast to the first one, the shadow zone of the wire proves to be illuminated. This can be explained in the following way. Some of the rays deflected toward the screen enter the deflection zones near the left and right edges of the wire upon passage of the path x. They, as before, deflect toward the screen (wire) and thus propagate in the wire shadow zone directly (rays *1*) and after reflection (rays *3*). The rays coming from the deflection zones near the opposite edges of the wire interfere and thus form shadow diffraction fringes.

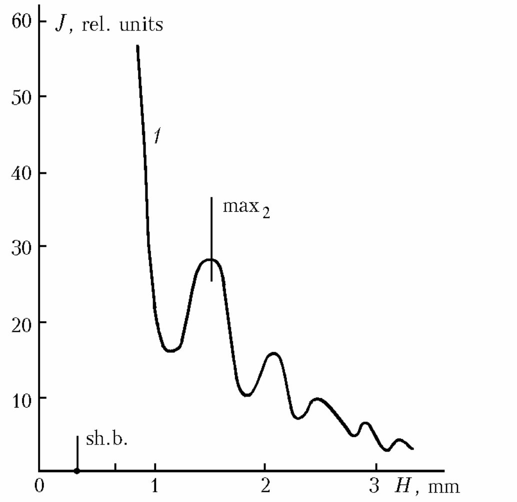
The existence of diffraction fringes beyond the shadow is not indicative of deflection of some edge rays (*1'*) in the direction outward the wire, because when the wire was coated with soot that partially absorbed incident rays, the difference between the intensities of the fringes and the edge wave decreased significantly according to Fig. 2*c*. (In the corresponding experiment, the diameter of the soot-covered wire was equal to 112 μm, and r = 214 μm).

In the experiment with a screen (blade) set in the shadow of the first screen instead of the wire at r = 14 μm (x = 4.5 mm), the diffraction fringes proved to be on the brink of disappearance because of the stronger effect of soot. It is seen in Fig. 3, where curve *1* characterizes the distribution of J in the diffraction pattern for the case of the clean second screen, the curve *2* corresponds to the case of the second screen covered with soot, and the curve *3* describes the distribution of J in the edge wave.

The significant decrease in J of the diffraction fringes after sooting the wire and the second screen proves that they are formed due to interference of the rays *2* deflected toward the wire and reflected from it with the edge rays *4* deflected only slightly in the remote part of the wire deflection zone.

If the rays in the wire deflection zones were deflected not only outward the wire but also toward it, then the wire shadow area in the experiment considered above would be illuminated and diffraction fringes would be observed as well. However, it was dark according to the above-said.

As is seen from the above, the rays deflected in the screen deflection zone in some direction upon passage of the path x are repeatedly deflected in the same direction in the deflection zone of the next screen.



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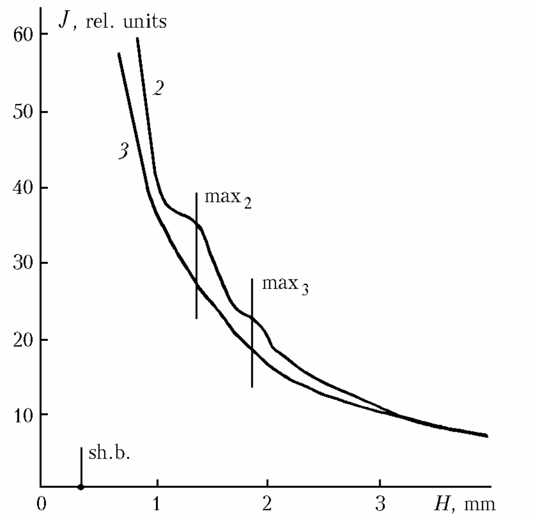

b

Fig. 3. Distribution of light intensity in diffraction patterns from (clean and soot-covered) second screen as the edge light deflected to the shadow of the first screen propagates near it.

This fact was also confirmed in the experiments with a slit instead of the wire, as well as with two screens set in series or oppositely (without a gap between screen projections or with small overlap of screen projections).

In the experiment with the first scheme, coating of the screen with soot is critical. The clean screen does not absorb rays deflected and incident on it, and after reflection toward the wire these rays are deflected toward the wire in the wire deflection zone. As a result, the wire shadow zone proves to be illuminated. Consequently, the experiment loses its meaning.

In the experiment according to the second scheme with the clean and sooted screen, the edge flux in its shadow zone consists only of the rays deflected toward the screen and coming to the shadow zone directly or after prior reflection from the screen edge. Sooting only intensifies the shadow flux.

It should be noted that the soot effect varies as soot is repeatedly applied to the clean screen. This is seen in Fig. 4. The curves in this figure characterize the intensity ratio in the scanning plane (spaced by 100.6 mm from *Sc*) at the distance *H* from the axis *S*′, in the shadow edge wave J_{2s}/J_2 and in the edge wave propagating on the side opposite to the screen shadow J_1/J_{1s} (J_{2s} and J_{1s} are the intensities of the edge light with the sooted screen; J_2 and J_1 are the intensities in the case of the clean screen). Curves *1* characterize the effect of soot in the experiments considered above; and curves *2* characterize the effect of soot at its repeated application.

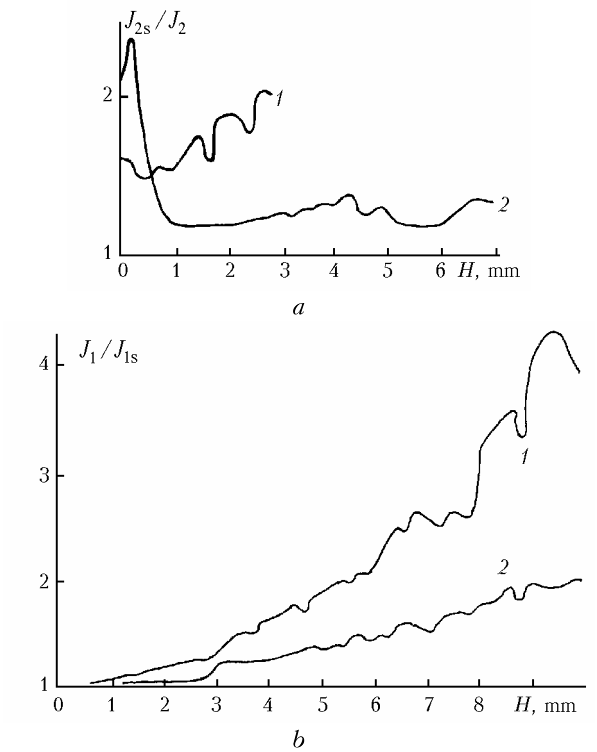

Fig. 4. Effect of soot covering the screen on the intensity of edge light coming from the zone near the screen edge.

According to data presented in the figure, soot in both of the cases has insignificantly changed the intensity of the edge rays coming in the direction outward the screen at small diffraction angles (H/L; r/x).

Because of a relatively high value of *r*, in the first experiment the soot significantly attenuated the rays reflected from the screen in the direction toward the wire (Fig. 4*b*, curve *1*, $H = 6$–8 mm), thus having provided the success of the experiment.

In these experiments, the screen was sooted by exposing it for a short time to the outer part of the flame of a burning rubber (polyethylene, polystyrene).

Possibly, the effect of soot on *J* of the edge light depends on the presence of unburned residues in it, the size of particles, and packaging density.

In Ref. 5, it was established based on the experimental data that the edge fluxes coming from the deflection zone of a thin screen with a straight edge to its shadow zone and in the opposite direction are separately equal to 1/7 of the flux $\Phi_{i.z}$ incident on the zone. Even assuming that there is no propagation difference between them before splitting (in the incident flux), their sum is equal to 0.57 $\Phi_{i.z}$, i.e., some of the incident rays pass through the zone without deflection.

Reference 3 describes the experiment proving the phase shift of π in parts of the edge light passing to the shadow of the diffracting screen and on the opposite side. In this experiment, the light flux in the image plane *S*′ of the slit *S* 30 μm wide was cut off by a copper wire 200 μm in diameter parallel to *S*′. A screen (blade) was set above the wire at the distance $x = 25$ mm from it. The screen edge was situated in the beam axis in parallel to the wire. The edge ray from the screen deflection zone deflected to the screen shadow passed near the left edge of the wire, and the rays deflected outward the shadow passed near the right edge. These rays were deflected in the wire deflection zones toward the wire shadow, and thus diffraction fringes were formed in the wire shadow.

If the rays deflected outward the screen continued to deflect only outward the wire, then one would observe illumination decreasing gradually from the left boundary of the shadow to the right one rather than diffraction fringes in the wire shadow. However, I observed fringes with equal intensities on both sides from the central minimum (in the same orders). This is indicative of the equal fluxes of the rays deflected to the wire shadow on the left and right sides. Consequently, if after the path of $x < 4.5$ mm the rays of each edge flux passing in the screen shadow and on the opposite side were deflected in the same direction in the zone of the next screen, then after the path from 4.5 to 25 mm they were deflected in both the initial and opposite directions.

The experimentally determined character of deflection of light rays near the edges of the screens arranged in series, as well as earlier unknown facts on the significant influence of screen absorption on light diffraction must manifest themselves in peculiarities of the formation of diffraction component of the light scattered by coarse particles of atmospheric aerosol (water droplets in clouds and rain, ice crystals, dust particles) at rather high concentration of particles or in the presence of strongly absorbing admixtures in them.

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