Wavelength dependence of ray deflection angles of edge light

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Received April 30, 2004

The dependence of the deflection angles of the edge light rays on the distance between their initial trajectories and the edge of a diffracting screen is established at different wavelengths in the visible spectral region.

As has become known with publication of papers by Maggi, Sommerfeld,[1] Rubinowicz,[2] Malyuzhents,[3] and other investigators, the explanation of light diffraction by interference of the edge and primary waves has turned out to be more adequate to the physical nature of this phenomenon as compared to the explanation based on interference of the secondary waves from fictitious Huygens–Fresnel sources.[4]

Appearance of light diffraction due to interference of the edge (boundary) wave with the incident wave is also confirmed by my experimental results.

In particular, in Refs. 5 and 6 it was found that in air above a screen surface, as well as on both sides of the interface between solid and liquid media with different optical density, there exists a zone about 80 μm thick[7] (deflection zone), in which the rays of the incident light are deflected in the direction from the screen and toward its shadow, thus becoming the edge rays.

Generation of the boundary wave above a screen, rather than at its edge,[2] indicates that, in the visible region, either the surface Poincare currents,[8] considered in the Sommerfeld theory as real sources of secondary waves, are not induced by the wave incident on the screen or the wave emitted by them contribute insignificantly to the resulting flux of the edge light. This conclusion is in agreement with Malyuzhents's statement[8] about the wrong idea of the surface currents as the primary cause of the diffraction field.

This circumstance and the absence of conditions for excitation of currents in the zone of generation of the edge wave, which lies beyond a screen, contradiction of the Young–Malyuzhents diffusion hypothesis to experimental facts,[5] and deflection of edge rays at separations from the screen exceeding λ by several times are likely indicative of the truth in the Newton hypothesis about the existence of a long-range interaction between light particles (photons) and physical bodies,[9] which leads to deflection of the rays from their initial direction.

If this interaction is real, the cause for ray deflection under the considered conditions becomes clear, if the ray is understood as a trajectory, along which a photon, together with its related elementary light wave,[10] propagates.

Being parts of a whole, wave and corpuscular properties of light cannot be isolated from each other. Therefore, any phenomenon is a result of the combined manifestation of these properties, each of which is responsible for different aspects of this phenomenon. Thus, in the diffraction phenomena, the wave properties cause the appearance of diffraction fringes. At the same time, the existence of light in the form of corpuscles – photons, capable of remotely interacting with bodies, leads to deflection of light rays, i.e., light diffraction itself.

Based on the experimental results,[11] the deflection of light rays with $\lambda = 0.53$ μm in the zone near a straight edge of a thin screen (razor blade) is described by the equation obtained for $h_s \geq 0.9$ μm:

$$\varepsilon = 259.5/(h_s + 0.786), \quad (1)$$

where ε is the deflection angle, in minutes of arc; h_s is the separation between the initial ray trajectory and the screen edge, in μm.

The equation determining the distances H from the centers of diffraction fringes to the shadow boundary (sh.b.) in the case of diffraction of a light beam from a linear source S (see Fig. 1) on a thin screen with a straight edge was obtained in Ref. 12. This equation has the form

$$H = (r + h) = [h_s(L + l)/l + \sqrt{(k_0 + k)\lambda L(L + l)/l}\,]. \quad (2)$$

Here $(k_0 + k)$ is the number of half-waves in the geometric propagation difference between the interfering rays 1 and 2; $k = 0, 2, 4, \ldots$, correspond to max, while $k = 1, 3, 5, \ldots$, correspond to min; $k_0 = 0.5$ is the initial λ/4 shift between the rays of the incident and edge light[12] in the direction of propagation of the edge rays.[13] This shift occurs upon deflection of the edge rays in the direction out from the screen. This equation allows us calculating H

0235-6880/04/07 482-03 $02.00

once finding $h = \sqrt{(k_0 + k)\lambda L(L + l)/l}$, $\varepsilon = (h/L)57.3°\times$ $\times 60' = 3438h/L$, in minutes of arc, and h_s by Eq. (1).

Tables 1–3 compare the values of H calculated in this way with the values obtained by the Fresnel equation[14]: $H_F = \vartheta\sqrt{\lambda(L + l)L/2l}$ with the use of ϑ values from Ref. 14. As can be seen from $\Delta H = (H - H_F)$ and H, the values of H for all the fringes, except for max_1, almost coincide with the corresponding values of H_F.

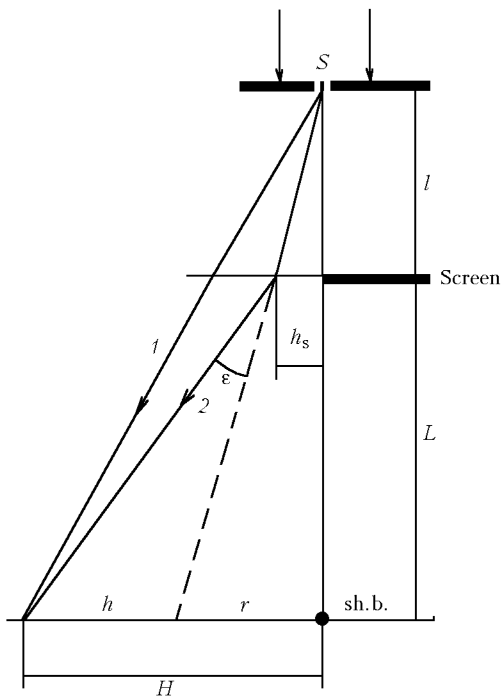

Fig. 1. Geometry of diffraction of light beam from a linear source on a thin screen with a straight edge.

Table 1. Distances from fringe centers to sh.b. in the diffraction pattern from a screen as calculated based on Eqs. (1), (2), and the Fresnel equation at l = 12 mm, L = 99.5 mm, λ = 0.53 μm

Fringe	k	H, mm	ε, arc min	h_s, μm	H_F, mm	ΔH, μm
max_1	0	0.629	17.1	14.39	0.6025	26.5
min_1	1	0.9313	29.62	7.975	0.927	4.3
max_2	2	1.1625	38.24	6	1.1617	0.8
min_2	3	1.3555	45.25	4.949	1.356	−0.5
max_3	4	1.5246	51.307	4.2717	1.5255	−0.9
min_3	5	1.6768	56.72	3.789	1.6786	−1.8
max_4	6	1.8164	61.67	3.422	1.8187	−2.3
min_4	7	1.9461	66.24	3.1316	1.949	−2.9
max_5	8	2.0676	70.51	2.894	2.0706	−3
min_5	9	2.1825	74.55	2.645	2.1859	−3.4
max_6	10	2.2917	78.37	2.525	2.2952	−3.5
min_6	11	2.3958	82.02	2.378	2.3997	−3.9
max_7	12	2.4957	85.51	2.2486	2.4997	−4
min_7	13	2.5917	88.866	2.1341	2.5958	−4.1
$I_{sh.b.}$ = 0.2604, $I_{sh.b.F}$ = 0.2855						

Table 2. Distances from fringe centers to sh.b. in the diffraction pattern from a screen as calculated based on Eqs. (1), (2), and the Fresnel equation at l = 35.5 mm, L = 99.5 mm, λ = 0.53 μm

Fringe	k	H, mm	ε, arc min	h_s, μm	H_F, mm	ΔH, μm
max_1	0	0.4038	10.94	22.936	0.3854	18.6
min_1	1	0.598	18.95	12.909	0.593	5
max_2	2	0.7454	24.46	9.822	0.7426	2.8
min_2	3	0.8688	28.95	8.178	0.8675	1.3
max_3	4	0.977	32.82	7.12	0.976	1
min_3	5	1.0743	36.28	6.366	1.074	0.0003
max_4	6	1.1636	39.445	5.793	1.1636	0
min_4	7	1.2466	42.37	5.338	1.2469	−0.0003
max_5	8	1.3244	45.109	4.967	1.3248	−0.0004
min_5	9	1.3979	47.69	4.6653	1.3985	−0.0006
max_6	10	1.4677	50.14	4.39	1.4685	−0.0008
min_6	11	1.5343	52.47	4.16	1.5353	−1
max_7	12	1.5982	54.7	3.96	1.5993	−1.1
$I_{sh.b.}$ = 0.244, $I_{sh.b.F}$ = 0.2845						

Table 3. Distances from fringe centers to sh.b. in the diffraction pattern from a screen as calculated based on Eqs. (1), (2), and the Fresnel equation at l = 90 mm, L = 99.5 mm, λ = 0.53 μm

Fringe	k	H, mm	ε, arc min	h_s, μm	H_F, mm	ΔH, μm
max_1	0	0.3011	8.14	31.09	0.2867	14.4
min_1	1	0.4451	14.1	17.62	0.4411	4
max_2	2	0.5552	18.2	13.47	0.5524	2.8
min_2	3	0.647	21.537	11.263	0.6453	1.7
max_3	4	0.7275	24.42	9.84	0.7261	1.4
min_3	5	0.8	27	8.825	0.7989	1.1
max_4	6	0.8664	29.35	8.06	0.8656	0.8
$I_{sh.b.}$ = 0.2453, $I_{sh.b.F}$ = 0.2768						

If the screen is rearranged into the mirror-image position, the distance between the max_1 centers in both diffraction patterns is equal to the double distance from them to sh.b. The relative light intensity $I_{sh.b.}$ is the ratio of intensities of the beam with and without the screen determined in the experiment with l = 117 mm and L = 376.5 mm turned out to be approximately equal to 0.25.

According to the values of $I_{sh.b.}$ and $I_{sh.b.F}$ (Tables 1–3) measured at the distances H and H_F from the max_1 centers in the experiments (at the corresponding values of l, L, λ), $I_{sh.b.}$ are closer to 0.25 than $I_{sh.b.F}$. Consequently, the significant value of ΔH for max_1 is caused by inexact determination of the distance from the max_1 center to sh.b. in the Fresnel method.

The analysis has shown that, in the case of λ different from 0.53 μm, Eq. (1) becomes incorrect. In place of it, the dependence of h_s on ε is described by the equation

$$\varepsilon = 259.5\lambda/0.53(h_s + 0.786) = 489.623\lambda/(h_s + 0.786), \quad (3)$$

where λ and h_s are in μm; ε is in minutes of arc.

It can be easily seen (based on the data from Tables 4 and 5) from the conservation of the minor discrepancy between H and H_F in the red and violet light with the use of h_s values determined by Eq. (3) in Eq. (2).

Table 4. Distances from fringe centers to sh.b. in the diffraction pattern from a screen as calculated based on Eqs. (2), (3), and the Fresnel equation at l = 12 mm, L = 99.5 mm, λ = 0.6328 μm

Fringe	k	H, mm	ε, arc min	h_s, μm	H_F, mm	ΔH, μm
max_1	0	0.6876	18.686	15.795	0.6583	29.3
min_1	1	1.0183	32.366	8.787	1.0128	5.5
max_2	2	1.2709	41.785	6.629	1.2683	2.6
min_2	3	1.4818	49.442	5.481	1.4816	0.0002
max_3	4	1.6666	56.062	4.741	1.667	−0.0004
min_3	5	1.8329	61.981	4.213	1.8343	−1.4
max_4	6	1.9855	67.38	3.812	1.9873	−1.8
min_4	7	2.127	72.378	3.495	2.1296	−2.6
$I_{sh.b}$ = 0.2474						

Table 5. Distances from fringe centers to sh.b. in the diffraction pattern from a screen as calculated based on Eqs. (2), (3), and the Fresnel equation at l = 12 mm, L = 99.5 mm, λ = 0.428 μm

Fringe	k	H, mm	ε, arc min	h_s, μm	H_F, mm	ΔH, μm
max_1	0	0.564	15.37	12.847	0.5414	22.6
min_1	1	0.8362	26.616	7.0874	0.8329	3.3
max_2	2	1.0439	34.3627	5.3124	1.043	0.9
min_2	3	1.2173	40.658	4.3681	1.2183	−1
max_3	4	1.3691	46.1	3.76	1.3708	−1.8
$I_{sh.b.}$ = 0.2695						

Based on Eq. (3), the angles of deflection of the edge rays propagated at the same distances from the screen are proportional to λ. Therefore, with the decrease of λ, the deflection of rays at the same angles occurs from a smaller area of the deflection zone. As a result, the amount of light incident on a given area decreases, and, consequently, the edge flux decreases.

Thus, the dependence of ε on λ found explains, in the natural way, the decrease of the light diffraction with the decrease of λ.

This dependence of ε on λ possibly takes place in the case of light scattering by aerosol particles.

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