NEW EVIDENCE FOR THE OBJECTIVE REALITY OF YOUNG'S DESCRIPTION OF THE FORMATION OF A DIFFRACTION PATTERN FROM A SCREEN

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Received August 14, 1989

Additional proof of the linear dependence of the amplitude of the edge wave on the angle of deflection of the diffracted light rays is presented. The edge and incident waves in the region of the diffraction pattern on the screen are separated. New facts indicating that the energy of the edge wave is sufficient for formation of diffraction fringes with the intensity observed experimentally are examined.

It was pointed out in Ref. 1 that if the intensity of the incident light is constant over the width of the wavefront, the diffraction pattern from a screen has a very distinctive property: the ratio of the intensity of the fringes to the intensity of the incident wave J_c is constant as a function of the parameters of the diffraction scheme.

This situation can be explained starting from the linear dependence of the amplitude of the edge have on the distance h from the shadow boundary.[2] This makes it possible to prove the validity of Young's description.

To show this we shall trace the behavior of the ratio of the intensity of the first maximum of the diffraction pattern $J_{\max 1}$ to J_c as L and l change successively (Fig. 4 of Ref. 2).

For the case when L changes we employ the diagram shown in Fig. 1a, where J_{c1} and J_{b1} are the intensity of the incident cylindrical wave from the slit S and the intensity of the edge wave from the screen E_1 at the first maximum on the screen E_2; J_{c2}, J_{b2}, J'_2, and J'_{b2} are the intensities of the incident and diffracted light flowing into the first maximum on the screen E_3 in the plane of E_3 and E_2.

According to Refs. 1 and 2 $J_{c1} = A / h_1^2$; $h_1 = \sqrt{0.69\lambda(l + L_1)L_1 / l}$; $h_2 = \sqrt{0.69\lambda(l + L_2)L_2 / l}$. Since $h'_2 = h_2L_1/L_2$, we have $J'_{b2} = A / (h'_2)^2 = AL_2^2 / h_2^2L_1^2$. Dividing the expression for J'_{b2} by the expression for J_{b1} we obtain after some transformations $J'_{b2} = J_{b1}h_1^2L_2^2 / h_2^2L_1^2$. $J_{b2} = J'_{b2}L_1 / L_2 = J_{b1}h_1^2L_2 / h_2^2L_1$. Substituting the expressions for h_1 we obtain $J_{b2} = J_{b1}(l + L_1)(l + L_2)$, $J_{c2} = J'_{c2}(l + L_1)(l + L_2)$. If J_c is constant over the width of the wavefront and h_1, $h_3 \ll (l + L_1)$, then $J'_{c2} = J_{c1}$. Hence $J_{c2} = J_{c1}(l + L_1)(l + L_2)$ and $J_{b2}/J_{c2} = J_{b1}/J_{c1}$. Therefore as L increases up to L_2 the value of $J_{\max 1}/J_c$ remains unchanged.

Consider next the case when l changes (Fig. 1b). $J_{b1} = A / h_1^2$. For the same values of h the value of J_b is proportional to the intensity of the incident wave at the edge of the screen, which in its turn is inversely proportional to l. As a result of this $J_{b2} = A\frac{l_1}{l_2}\Big| h_2^2 = Al_1 / h_2^2l_2$. Since $h_1 = \sqrt{0.69\lambda L(l_1 + L_1)L / l_1}$. $h_2 = \sqrt{0.69\lambda L(l_2 + L)l_2}$, we have $J_{b2} / J_{b1} = h_1^2l_1 / h_2^2l_2 = (l_1 + L) / (l_2 + L)$, whence $J_{b2} = J_{b1}(l_1 + L)/(l_2 + L)$, $J_{c1}/J'_{c2} = (l_2 + L)/(l_1 + L)$. Since $h_2\, h'_1 \ll (l_2 + L)$, $J'_{c2} = J_{c2} = J_{c1}(l_1 + L)/(l_2 + L)$. But then $J_{b2}/J'_{c2} = J_{b1}/J'_{c1}$. Therefore changing l has no effect on $J_{\max 1}/J_c$.

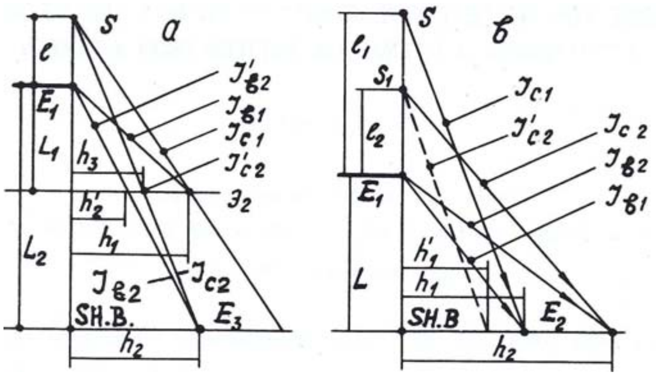

FIG. 1. Diagrams of the diffraction of light by a screen when the incident wave is cylindrical and for different values of L and l.

Figure 2 shows a diagram for analyzing the consequences of a change in L in the case when the incident wave is a plane wave.

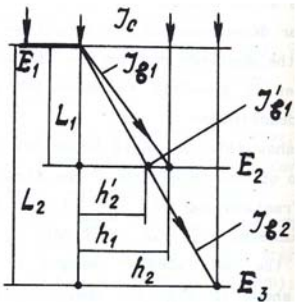

FIG. 2. Diagram of the diffraction of a plane wave of light by a screen for different values of L.

Under the given conditions

$$J_{b1} = A/h_1^2, \quad h_1 = \sqrt{0.69\lambda L_1}, \quad h_2 = \sqrt{0.69\lambda L_2}.$$

Hence

$h_2 = h_1\sqrt{L_2} / \sqrt{L_1}$, $h'_2 = h_2 L_1 / L_2 = h_1\sqrt{L_1} / \sqrt{L_2}$,

$J'_{b1} = A / (h'_2)^2 = AL_2 / L_1 h_1^2 = J_{b1}L_2 / L_1$. Since J_b is proportional to $1/L$, we have $J_{b2} = J'_{b1}L_1/L_2 = J_{b1}$, i.e., J_{max1}/J_c remains unchanged.

It is easy to see that for any other relation between J_b and h it would be impossible for J_{max1}/J_c to remain constant when l and L change. For this reason the examples presented above are an additional confirmation of the fact that the amplitude of the edge wave is a linear function of h.

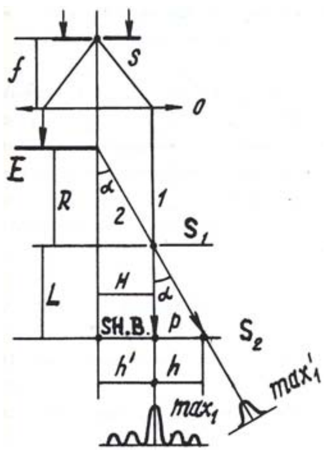

FIG. 3. Diagram of the separation of the edge and incident rays when light is diffracted by a screen.

To eliminate any further doubts about the fact that the diffraction pattern from a screen forms as a result of the interference of the edge and the incident waves we shall study experiments in which the diffracted and incident light can be separated and which show that the energy of the edge wave corresponds to the changes in the intensity of the diffraction fringes observed in practice. Figure 3 shows a diagram explaining these experiments. Here S is a slit of width $t_1 = 59$ μm; E is a thin screen with a rectilinear edge, lying on the axis of a parallel beam with $\lambda = 0.53$ μm; s_1 and s_2 are mobile slits of width $t_2 = 104$ μm and $t_3 = 200$ μm; $f = 50$ mm; $R = 49.3$ mm; and, $L = 99.5$ mm.

When one looks through s_1 as it is moved to the right from the shadow boundary one observes first a diffraction pattern formed as a result of the diffraction of the Incident rays 1 with the central maximum $\max_1$ by it. After some time a new central maximum $\max_1'$, which lies at a gradually increasing angle a relative to $\max_1$, appears on the ring of the main pattern. This maximum is seen most clearly when s_1 is located at $\min_2$ from S, at distance $H = h_{\min2} = 2\lambda f|t_1 = 0.892$ mm from the shadow boundary. In this case, because the direct light is attenuated, the secondary maxima of the main pattern become very weak and have virtually no effect on it.

For this position of s the light intensity in the plane of s is distributed in the manner shown in Fig. 4.

Measurements showed that $P/L = H/R$. Therefore $\text{шax}_1'$ is formed due to diffraction of the edge rays 2 by s_1.

Complete separation of $\max_1$ and $\max_1'$ occurs approximately for $H = PR/L = 2\, h_{\min1}\, R/L = 2\lambda R/t_2 = 0.5$ μm. As s_1 is moved into the optimal position ($H = 0.892$ mm) scintillation of the secondary fringes of the right wing of the pattern is observed (max is replaced by min and vice versa). This is easily explained by the interference of the rays forming the secondary fringes with the rays $\max_1'$ under conditions when the path difference between them changes.

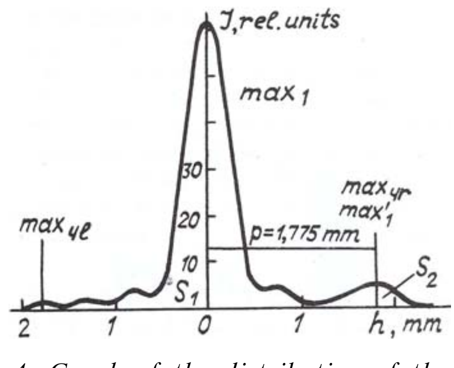

FIG. 4. Graph of the distribution of the light intensity in the diffraction pattern from, the slit s_1. The diffraction pattern is formed by the incident rays and the rays diffracted by the screen which are separated from the incident rays.

Since the intensity of the diffracted light decreases rapidly as the deflection angle increases the edge rays 2, after being diffracted by s_1, practically do not reach the region of the left wing of the pattern. For this reason scintillation of the fringes does not occur in it.

At distances corresponding to the areas S_1, and S_2 in Fig. 4 the mutual effect of the rays 1 and 2 after they are diffracted by s_1 is smaller than for the section of the pattern between $\max_1$ and $\max_2'$. We shall therefore assume that S_1 and S_2 are proportional to the intensity J_c of the direct light on s_1 and the intensity J_b of the edge waves at the same location.

According to the measurements the intensity of the incident light at the edge of the screen $J_e = 250.5$ relative units, $J_c = 3.6$ relative units, $S_1 = 401$ mm^2, and $S_2 = 30$ mm^2. Then $J_{b.exp} = J_c S_2/S_1 = 0.27$ relative units. According to (10) of Ref. 1 $J_{b.comp} = 0.02046\ \lambda R J_e/H^2 = 0.17$ relative units, i.e., 1.6 times less than $J_{b.exp}$.

If the intensity is characterized by the light flux from s_2, then under the conditions studied $J_{\max'} = 5.3$ relative units. When s_1 and s_2 lie on the axis of the beam and the screen is placed off axis, then the light flux from s_2 is $J_{c.b} = 4630$ relative units. It is evident that in the absence of noise $J_{\max'1}$ is proportional to $J_{b.exp}$ and $J_{c.b} - J_e$. But in this case $J_{\max'1comp} = 0.02046\ \lambda R J_{c.b}/H^2 = 3.1$ relative units and $J_{\max'1}/\ J_{\max'1comp} = J_{b.exp}/J_{b.comp} = 1.7$. This value is close to that indicated above. Therefore $J_{b.exp}$ was found correctly.

Since $h_{\max4} = k\lambda L |\ 2t_2 = 1.755$ mm $= P$ the fact that $J_{b.exp}$ is greater than $J_{b.comp}$ is in all probability caused by the superposition of the weak maxima $\max_{4n}$ of the main pattern on $\max_1'$ and the subsequent interference of the rays forming them.

Thus the fact that $J_{b.exp}$ is greater than $J_{b.comp}$ when $J_{\max4} \ll (J_{\max'1} + J_{\max4})$ is clearcut proof of the fact that the energy of the edge wave is sufficient for forming together with the direct rays the diffraction pattern with the same intensity of the fringes as is observed in the experiment.

REFERENCES

1. Yu.I. Terent'ev, Atmos. Opt., No. 11, 1141 (1989).

2. Yu.I. Terent'ev, Atmos. Opt., No. 11, 1147 (1989).