POSSIBILITY OF ELIMINATION OF DIFFRACTION PHENOMENA IN OPTICAL TOOLS

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The article contains the short historical review explaining the origins of light diffraction phenomena including the analysis of some well-known diffraction experiments.

We have shown the possibility of explanation of diffraction pictures without attraction of Huygens –Fresnel principle. We have also proved the existence of real sources of the secondary waves participating in formation of diffraction pictures. So the assumption has been made that in case of compensation of influence of secondary waves in optical tools we have an opportunity to get images without any diffraction.

Results of the given work can be used for the description or a prediction of the diffraction phenomena in case of light propagation through various optical systems. Besides, given results allow to assume the possibility of creation of optical systems with the characteristics surpassing parameters of existing devices.

Keywords: fundamental physics, optics

Introduction

Works /1,11/ contain the assumption that some laws of light propagation, nowadays explained in frameworks of wave optics only, can be explained from positions of the corpuscular theory of radiation. Thus the fact of rectilinear light propagation consisting of separate quanta of radiation is postulated.

It would be interesting to interpret from these positions and results of well-known diffraction experiments.

Let's remember some positions of the standard wave theory and short history of its occurrence.

In 1678 Huygens has opposed his wave theory to the Newton’s corpuscular theory of light. He has paid attention to analogy between many acoustic and optical phenomena, believing that light extends like sound waves. As the carrier of elastic light impulses he has assumed special everpresent environment - an ether.

However, despite of Huygens’ introduction of light waves concept, he didn't put in it the meaning which has been accepted later. Huygens didn't assume periodicity in the light phenomena. He specified thus: «... It is not necessary to imagine that these waves follow one after another on identical distances». Therefore Huygens himself didn't use the concept of wavelength. He postulated the law of rectilinear propagation without paying attention to the diffraction phenomena.

From all of Huygens ideas we widely use the most famous principle carrying his name: «Each point experiencing light excitation is the center of secondary waves; the surface which is bending around these waves at some moment, specifies the position of wavefront».

Once again it would be desirable to underline that Huygens perceived this principle only as an auxiliary method.

The theory of wave optics began to develop only in the beginning of the XIX-th century as during all the XVIII-th century the ascendent position was occupied with the corpuscular theory of light. To a great degree it was promoted by Newton's huge authority - the supporter of corpuscular theory.

Leading role in the subsequent development of wave optics played the works of Young and Fresnel. In 1815 Fresnel has specified the Huygens’ principle, having added the principle of interference by Young, that has allowed to consider the diffraction phenomena quantitatively. Simultaneously the rectilinear propagation of light could be explained, what couldn't be made in the frameworks of Huygens theory only.

The advanced principle of Huygens-Fresnel asserts that if a dot source of waves is mentally surrounded with any closed surface, the correct wave amplitude value behind its limits will be only after replacement of a dot source with the auxiliary sources distributed on this surface. Each point of a surface is considered as a source of waves, the amplitude and phase of which are equal to the amplitude and phase of the oscillation which have come to this point with a wave from the basic source. Wave action in any point out of a surface is defined as result of an interference of waves from all sources located on a surface. Thus all auxiliary sources are considered to be coherent. As the surface can be random, it is easy to choose the most convenient for the specific problem. At the points of the opaque barriers meeting on the way of wave, the amplitudes of auxiliary sources are considered to be equal to zero.

The given principle has found application in solving of the majority of diffraction problems and is used in solving of many other applied problems throughout already many decades.

Real sources of interfering waves

Works /1,11/ have in purpose to explain the known optical phenomena, in particular the rectilinear propagation of light, from the point of view of corpuscular theory of light. So the explanation of the diffraction phenomena applying only to the Huygens-Fresnel theory can't satisfy us (remember the Huygens' caution).

We still believe that light is a stream of the quanta propagating in the isotropic and optically homogeneous environment rectilinearly with a speed of c/n, where c is light velocity in vacuum, and n – refraction index of environment.

On the other hand, it is impossible to deny objectively the existing displays of diffraction in the form of diverse diffraction pictures. According to the principle of Huygens-Fresnel all of them grow out of interference of secondary waves which are emitted by elements of the auxiliary surfaces surrounding real light sources.

But sources on these surfaces are fictitious, and observable diffraction pictures are real. Therefore searches of real-life sources creating these pictures by mutual interference are actual.

In our case when light is considered as the directed stream of the corpuscles, it is natural to consider one of interfering rays the ray of light radiated directly by the real light source. Other part of the light participating in the interference can appear only there where optical uniformity of environment is broken because in a homogeneous environment light quantum propagates rectilinearly. It is easy to assume therefore that sources of secondary waves must be the edges of obstacles or the diaphragms involved in considered experiences, and adjacent areas.

The same as in case of Huygens-Fresnel principle application, it is possible to consider elementary squares as sources of secondary waves here again. However the basic difference is that in our case the sources of secondary waves are quite real.

In case of legitimacy of such approach the mutual interference of radiations from all real-life secondary radiators and their interference with the basic field of radiation from the primary source should give the diffraction pictures not different from the observed.

Further we consider the classical diffraction experiments which are well enough described in the educational literature.

Explanation of results of classical experiments

We have analyzed the results of a considerable quantity of well-known diffraction experiments and carried out our own experiments to be convinced of correctness of the approach offered above.

Running forward, we will notice that the results of all the experiments without any exception have been explained in such a way. An interesting law was thus found out: for the explanation of observable diffraction pictures it is necessary to consider the fact that: the secondary waves reradiated by edges of diaphragms to the area of a geometrical shade is cophased with the incident wave; the waves scattered to the area, lighted with the basic ray of radiation, differ on phase from the incident wave exactly on π.

1. We will remember at first a classical explanation of the mechanism of diffraction in case of Fraunhofer diffraction, when the diffraction picture is formed in the plane infinitely removed from sources of diffraction, or (that is equivalent) in the image plane of the convex lens.

In this case the most evident experiment is to consider diffraction on the slit from infinitely remote light source.

Let's address to the drawing 1 borrowed from / 2 / (p. 175) where we can see the results of analytical calculation of intensity of light behind the screen.

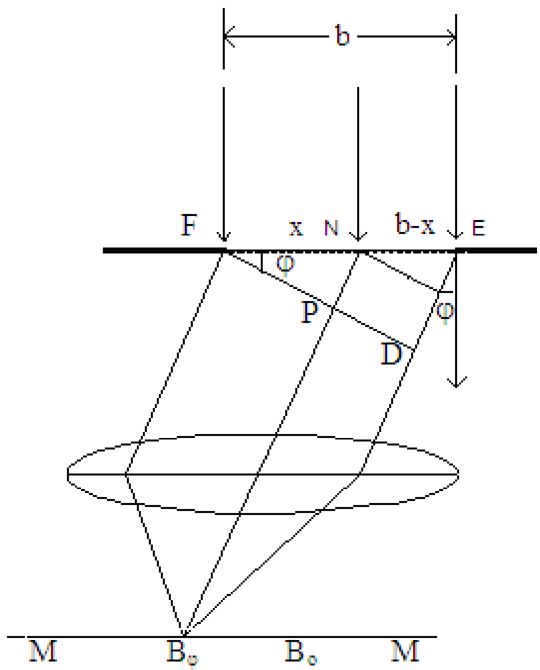

Figure 1. Diffraction on the slit.

In these calculations light disturbance ds of the slit element dx from the source of radiation with frequency ω is expressed by the relation

$$ds = (A_0/b) \cos \omega t, \quad (1)$$

where A_0 is the amplitude of the wave emitted by all slit; b – the width of slit. In order to find the impact of all the slit in this direction at an angle of φ to the initial direction it is necessary to consider the difference of phases of the waves reaching from various elements of wave front to the observation point B_φ.

Let's consider plane FD perpendicular to the chosen direction. The difference of phases corresponding to two points of plane FE can be expressed through the difference of beams' course passing through these points from plane FE to plane FD perpendicularly to the last one. For example, the course difference between waves from point F (slit edge) and from any point N which is on distance x from the edge of the slit, is equal $NP = x\sin\varphi$. Thus, the light field in point P of plane FD will be written up as

$$ds = (A_0/b) \cos(\omega t - kx\sin\varphi)dx, \quad (2)$$

where k = $2\pi/\lambda$ is a wave number. The resultant field in point B_φ is defined by integral on all values x from zero to b, that is:

$$A(t,\varphi) = \int_0^b ds = \int_0^b (A_0/b)\cos(\omega t - kx\sin\varphi)dx =$$

$$= A_0 \frac{\sin(^1/_2\, bk \sin\varphi)}{^1/_2\, bk\sin\varphi}\cos(\omega t - {}^1/_2\, kb\sin\varphi). \tag{3}$$

Hence, the resultant wave going in direction φ, has amplitude

$$A_\varphi = A_0 \frac{\sin(^1/_2\, bk\sin\varphi)}{^1/_2\, bk\sin\varphi} = A_0\frac{\sin[(b\pi/\lambda)\sin\varphi]}{(b\pi/\lambda)\sin\varphi} \tag{4}$$

As in case of one slit the diffraction picture is shown at very small angles φ, it is possible to accept that $\sin\varphi \cong \varphi$. Then it turns out that

$$A_\varphi = \frac{A_0 \sin(b\pi\varphi/\lambda)}{b\pi\varphi/\lambda} \tag{5}$$

Let's consider now a picture of diffraction which can be got without attraction of Huygens-Fresnel principle. We consider that the beams of light scattered by the edges of slit F and E participate in the interference.

1.1. For descriptive reasons at first we will consider the area where in our understanding the basic ray doesn't participate in the interference. It takes place in a case when point B_φ is in area of a geometrical shade.

Let's combine the expressions corresponding to light disturbances on the edge of the slit, believing that the sizes of area of reradiation are less than the wavelength of light. Let to point F corresponds to the disturbance $ds_F = G(\varphi)\cos\omega t$. Then to point E there corresponds the disturbance $ds_E = G(\varphi)\cos(\omega t - kb\sin\varphi \pm \pi)$. (We shall remind that correction value $\pm\pi$ has been put by us for an explanation of known diffraction pictures in the offered way). Therefore the resultant wave going in direction φ, can be represented as the sum of these expressions

$$G(t,\varphi) = G(\varphi)\cos\omega t + G(\varphi)\cos(\omega t - kb\sin\varphi \pm \pi) = G(\varphi)\cos\omega t - G(\varphi)\cos(\omega t - kb\sin\varphi) =$$

$$= -2G(\varphi)\sin[(\pi b/\lambda)\sin\varphi]\sin[\omega t - (\pi b/\lambda)\sin\varphi] \tag{6}$$

From the comparison of (3) and (6), we see that the expression $\sin(^1/_2\, bk\sin\varphi)$ not dependent on time is common for them. It sets the dependence of amplitude of a wave from angle φ. And as the diffraction picture visible to us is defined by dependence of amplitude of a light field angle φ we can do a conclusion that calculated with the above said methods pictures should coincide (at least, in positions of maxima and minima of a light field).

The divergence of the members setting dependence of amplitude from time is interesting. It is easy to see that the divergence in phases makes π/2. It is interesting because the divergence between a phase of the diffracting wave calculated with a method of Fresnel zones and a phase of a real wave in experiment (see, for example, / 2/, p. 170) is π/2. Hence, results of calculations by means of an offered method in the considered case corresponds more to the real picture of diffraction, than Fresnel zones method.

It comes out from expression (5) that amplitude A_φ turns to zero for angles φ satisfying to a condition

$$(b\pi/\lambda)\sin\varphi = n\pi \quad \text{или} \quad \sin\varphi = n\lambda/b, \qquad (7)$$

where n = 1, 2, 3... (integers).
By means of (7) directions on screen points (hence and their positions, if value b is defined) in which the amplitude is equal to zero are defined.
At certain intermediate values of angle φ the amplitude reaches the maximum and minimum values. The greatest maximum takes place, when $(b\pi/\lambda)\sin\varphi = 0$, i.e. $\varphi = 0$. (Thus it is considered that $A\varphi = A_0$ that doesn't represent the facts, because in Sommerfeld's calculations / 3 / the value of amplitude is less by $4\lambda/(b\pi^2)$).
Following maxima correspond to values φ, satisfying conditions

$$(b\pi/\lambda)\sin\varphi = 1{,}43\pi, \quad (b\pi/\lambda)\sin\varphi = 2{,}46\pi, \quad (b\pi/\lambda)\sin\varphi = 3{,}47\pi,$$

$$(b\pi/\lambda)\sin\varphi = 4{,}47\pi \text{ etc.} \qquad (8)$$

With sufficient accuracy these conditions can be written down this way

$$(b\pi/\lambda)\sin\varphi = (2m + 1)\lambda/2. \qquad (9)$$

1.2. We will consider now the area where falls both direct radiation, and reradiation from diaphragm edges

Now expression (6) due to the above will be re-written as

$$G(t,\varphi) = G(\varphi)\cos(\omega t \pm \pi) + G(\varphi)\cos(\omega t - kb\sin\varphi \pm \pi) =$$
$$= - G(\varphi)\cos \omega t - G(\varphi)\cos(\omega t - kb\sin\varphi) =$$

$$- 2G(\varphi)\cos[(\pi b/\lambda)\sin\varphi]\cos[\omega t - (\pi b/\lambda)\sin\varphi] \approx$$

$$\approx - 2G(\varphi)\cos[\omega t - (\pi b\varphi/\lambda)]\cos(\pi b\varphi/\lambda) . \qquad (6')$$

Taking into account direct radiation the resultant intensity will be written as

$$A(\varphi) = A_0\cos\omega t - 2G(\varphi)\cos[\omega t - (\pi b\varphi/\lambda)]\cos(\pi b\varphi/\lambda) . \qquad (10)$$

At $\varphi = 0$

$$A_{рез} = A_0\cos\omega t - 2G_0\cos\omega t. \qquad (11)$$

2. We will address now to the case of Fresnel diffraction. In order to get more clearness we will consider the most simple case when interact radiations of the basic light ray and one secondary source that is the area adjacent to edge of the infinite screen.
Fig. 2, taken from / 4/, shows dependence of intensity of light on distance between an observation point and the border of a geometrical shade. This dependence is received by means of the Cornu's spiral constructed for diffraction from rectilinear edge of a semiplane. At b = 1m and λ = 0,5 microns for coordinates of maxima the calculations give values: X_1 = 0,61 mm; X_2 = 1,17 mm; X_3 = 1,54 mm; X_4=1,85 mm ;… (see fig. 3).

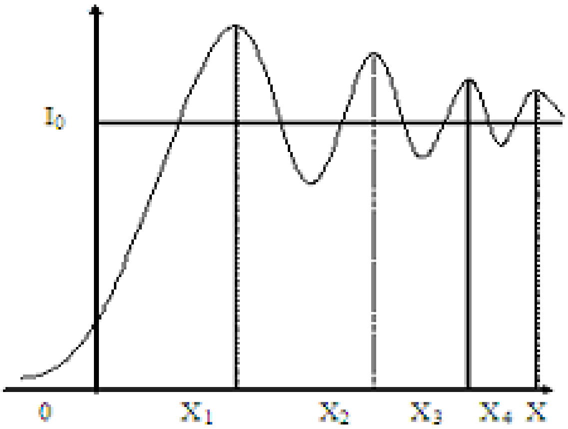

Figure 2. Dependence of light intensity after diffraction on the edge of semi-plane from the distance between observation point and the border of geometrical shade (in the observation plane)

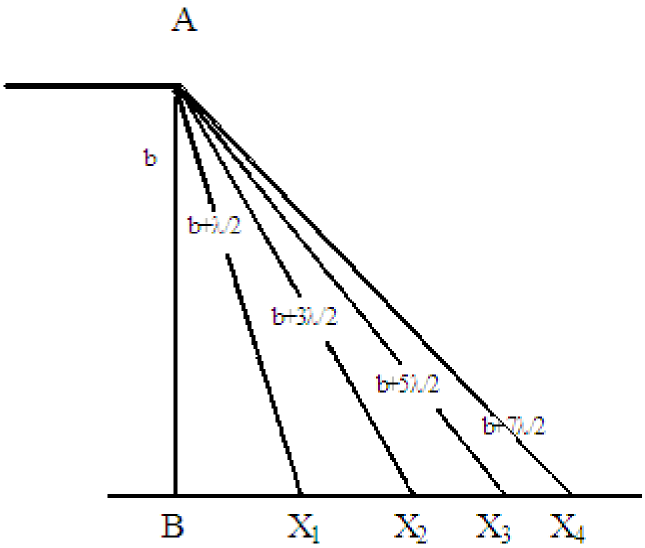

Figure 3. To the diffraction on the edge of a semi-plane.

Let's calculate now the coordinates of these maxima, proceeding from our representations about the diffraction mechanism. On fig. 3 positions of such maxima are shown, for which condition AB - $AX_n = (2n - 1)\lambda/2$ should be satisfied. Taking into account phase shift in π radian for the wave scattered in the area lighted with the basic ray, two rays meet at these points having a total difference of phases, corresponding to an integer number of waves. From the ABX_n triangle it is possible to write expression for coordinate X n.

$$X_n = \sqrt{\left[b + (2n-1)\lambda/2\right]^2 - b^2} \tag{12}$$

Calculated under the formula (12) values of coordinates of maxima are resulted in table 1 (results of calculations correspond to values b=1 m, λ=0,5 microns).

Table 1 - Calculated values of maxima

Sources	Coordinates of maxima, mm			
	X1	**X2**	**X3**	**X4**
/4/	0,61	1,17	1,54	1,85
This article	0,71	1,22	1,58	1,87

From the table data we can find the quite good conformity. Slight divergence for small values of *n* is probably caused by the fact that calculations hasn't taken the dependence of a scattered light intensity from the scattering angle into consideration. It is visible that with increase of *n* the distinction in positions of maxima decreases.

It is necessary to notice that the picture similar to the considered above, was also received by Sommerfeld /3/ when solving the problem of diffraction on infinitely thin semiplane of an ideal conductor at distances between the point of observation and the edge of a semiplane, comparable with the wavelength. In this solution it is told about phase jump on π radian on the border of a geometrical shade.

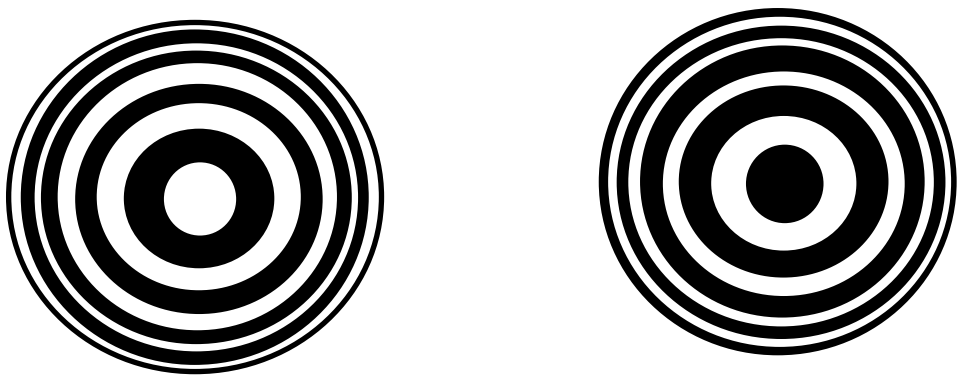

Figure 4. Zone plates.

3. We will consider one more example to illustrate the jump of phase on the border between light and shade in a diffraction picture. It will be a question of the zonal plate consisting of consistently alternating transparent and opaque rings which radiuses satisfy to a relation

$$r^2_n = n\lambda ab/(a+b) \qquad (13)$$

where *n* is a zone number; r_n - external radius of the n^{th} Fresnel zone; *a* - distance from the source to the plane of the given plate; *b* - distance from the zonal plate to the observation point.

Images of zonal plates are resulted in drawing 4. If to place a plate with an open first zone in a corresponding place of a spherical wave the plate will cover all even (odd) zones and will leave free odd (even), starting from the central. The experiment shows that the plate operates like a convex lens. A zonal plate with odd zones acts quite similarly.

We think it is not necessary to show the classical explanation of the zone plate action. It is in details described in the educational literature, being based on a Huygens-Fresnel principle.

The zone plate action is very simple to explain within the frameworks of the offered approach. In this case we consider that the scattering centers are borders between light and dark rings. One of the properties of a zonal plate is that the difference of a course for internal and external borders of any zone to a corresponding point of supervision equals λ/2. And now we pay attention to the fact that the external border of a light zone sends beams towards the lighted area during the light scattering in the direction to the observation point (which is on an optical axis). And the internal border sends beams to the area of a geometrical shade of the previous dark zone. Hence, the difference of phases between waves from internal and external borders of one zone is equal 2π (we remember that at a deviation to the lighted area the half-length of a wave is lost). Therefore in the observation point light coming from the various scattering centers, has the same phase (with accuracy up to $\pm 2\pi n$). As a result in the observation point the repeated increase of intensity of light is found out.

4. Phase jump on the border of a geometrical shade is especially obvious when considering the diffraction on two slits.

In work / 2 / (p. 192) are resulted the following positions of minima and the maxima, calculated on the basis of a Huygens-Fresnel principle:

Minima	$b \sin \varphi =$		λ		2λ		3λ
	$d \sin \varphi =$	$\lambda/2$		$3\lambda/2$		$5\lambda/2$	
Maxima	$d \sin \varphi =$	0	λ		2λ		3λ

Let's explain now on the basis of an offered principle occurrence of these maxima and minima.

Let's consider at first condition of maxima

$$d \sin \varphi = n \lambda$$

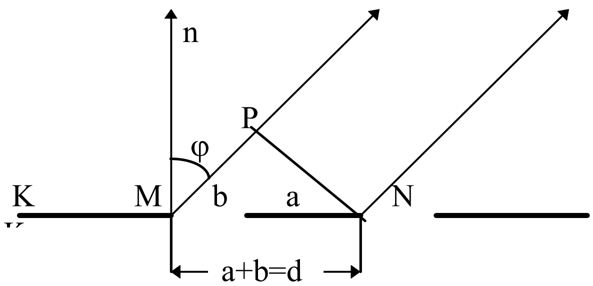

Figure 5. To the determining of main maxima and additional minima at the diffraction on two parallel slits.

We consider here an interference only from the edges of diaphragms.

Let's take the pair of secondary sources: points of M and N (fig. 5).

In the direction shown by two arrows, light scattering in both points occurs towards the area lighted with the basic ray of light. Therefore relative shift of phases between radiations from these points doesn't occur and the integer number of waves within the length MP = $d \sin \varphi$ satisfy to the maxima condition , i.e.

$$d \sin \varphi = n \lambda,$$

that conforms with the data of the resulted table.

For the same reason a minimum condition is equality

$$d \sin \varphi = (n + 1) \lambda/2,$$

at which radiations from points of M and N extinguish each other as at length MP the semiinteger of waves fits within.

Discussion of results

Consideration of classical experiments could be continued. We had not revealed any case where the diffraction picture couldn't be explained within the frameworks of the offered approach. The reader can easily prove it himself.

During the analysis and searches of publications on this theme it was found out that similar explanations of diffraction gave Young at the very beginning of the nineteenth century / 5/. We will give a passage from /6/ «If to consider the edge of a diffraction aperture (or obstacles), consisting of the points lying in a geometrical shade it seems to be shining. It was already known to Young, trying to theoretically explain diffraction before Fresnel, proceeding from the wave theory. Young believed that the incident light experiences a sort of reflection on the edge of a diffracting body and considered a diffraction picture as result of an interference of an incident wave and reflected «boundary wave». However Young's representations have been expressed only qualitatively and haven't received wide recognition». Later similar consideration has been developed theoretically by Maggi /7/. The fuller research has been carried out by Rabinovich /8/. The theory of Maggi-Rabinovich has been developed further by Miamoto and Wolf / 9/.

Besides the numerous theoretical works devoted to the «boundary wave», there are publications about experimental acknowledgement of a boundary wave "existence" / 10/.

However these representations haven't received further distribution because of seeming bulkiness of mathematical apparatus used in them / 6/.

We haven't found out ideas or offers on full compensation of influence of diaphragms edges using a «boundary wave» in the literature. It was told about in/12/.

In /13/ the idea of elimination of diffraction is experimentally realized. The experiments in which one more way of compensation of deforming consequences of diffraction is used have begun. Encouraging results that is a material of the subsequent publications are received.

Conclusion

The analysis of experiments on diffraction of light, described in the literature, and also of our own experiments with laser sources of radiation has shown that all diffraction phenomena can be explained as a result of interaction of the basic radiation field with the secondary waves emitting from the borders of screens. If we consider a diffraction picture in the area of a geometrical shade it grows out of interaction of only secondary waves. Thus there is no necessity to involve a Huygens-Fresnel principle. To such interpretation of the diffraction phenomena we were guided by the assumption that propagating light needs to be considered as consisting of separate quanta. And as in optically homogeneous environment light quanta propagate rectilinearly, it is logical to assume that the centers of quanta scattering are edges of diaphragms and adjacent areas where optical uniformity is broken.

As it is possible to understand from the short review of the literature, authors of some of the quoted works came to the same conclusion though they considered light propagation only as a wave process. Then the idea about possibility of compensation of fatal influence of secondary radiation on quality of the basic beam of radiation was probably born. One of realizations of similar compensation is widely known method of apodization.

However in the literature there is no mention of attempts to completely get rid of the influence of secondary radiation for the purpose of resolution increase of optical devices. Today limiting values of their resolution are given by the formulas deduced within the limits of the wave theory. In particular, for microscopes with visible range radiation sources the limiting resolution is estimated in 0.3 microns.

Now, when we are convinced in availability of real sources of secondary radiation, it is possible to try to find real ways of compensation of their influence on quality of the basic beam of radiation. Due to the facts stated here the works aimed on getting characteristics of optical devices better than it is permitted by the theory, shouldn't seem senseless.

We want to cite here the lines from widely known textbook / 2 / which helped many generations of physicists to study optics:« … we have already mentioned that Fresnel's postulate serving for characterizing secondary waves, interference of which explains all processes of waves propagation, was some hypothesis, a guess. Calculations on Fresnel's method and their comparison with experiments show that this hypothesis should be changed a little: we should add the factor considering the inclination of an auxiliary surface to the direction of action, to prove by additional reasonings the absence of a return wave and to change an initial phase of secondary waves on $\pi/2$. If first two additions are involved by means of more or less evident reasons, the phase advancing «is considered sometimes something mysterious» (Rayleigh, «Wave theory of light»). Certainly, as the Fresnel's postulate is a kind of recipe giving the general method of solving the problems of wave optics, it is obvious that modification of this postulate doesn't represent anything especial; Simply more careful analysis shows that it is necessary to use a bit different recipe of solving of wave problems, providing the best consent with experiment ».

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