Two demonstrations for a physics course

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The publication of the work of Sommerfeld[1,2] and Rubinovich[3] has led to a rehabilitation of Young's approach to diffraction problems. Young's idea was that the diffraction pattern could be explained as the superposition of direct and edge waves, i.e., waves propagating past the obstacle without change of direction and waves originating at the edges of the obstacle. This description is more physical than that given by Fresnel because the elementary sources are replaced by edge waves, the source of which are the currents induced in the edges of the obstacle. The two approaches, i.e., Young's and Fresnel's, are completely equivalent but the Young approach is more instructive[4] because it retains the local treatment of wave fields which is characteristic for geometric optics and is the foundation for the "geometric theory of diffraction."

We note that, in some cases, one of these two alternative approaches yields the required results directly, whereas the use of the other may involve the difficult calculation of phase shifts introduced by, for example, some additional obstacles.

Young's method has been rarely used in physics courses and there do not appear to be demonstrations of it. We have considered a number of experiments but none of them has demonstrated any advantages of Young's approach to diffraction as compared with the Fresnel method. The following two demonstrations are quite striking.

1. EXISTENCE OF THE EDGE WAVE

A vertically mounted metal plate (duraluminum sheet; height 1 m, width 12 cm, thickness 2 mm) intercepts radiation from the horn of a klystron oscillator producing radiation of wavelength $\lambda = 32$ mm (Fig. 1). The receiving horn is placed in the geometric center of the shadow and its output is fed into the U2-1A amplifier followed by an S1-1 oscilloscope. The recorded amplitude is then large. According to Young, this is explained by interference between the edge waves from the two vertical edges of the plate.

We now place a paraffin quarter cylinder in the way of one of the edge waves. The outer and inner radii of this cylinder satisfy the relation $(R-r)(n-1)=\lambda/2$, where n is the refractive index of paraffin. Hence, it follows that $R-r=\lambda$. Since the edge wave passes through the quarter cylinder at right-angles to its surfaces, its direction is unaffected. It is found that, when the quarter cylinder is placed in position, the received signal falls to zero and remains at this level as the quarter cylinder is displaced along the line AB. The signal is restored when an identical quarter cylinder is placed on the line AC.

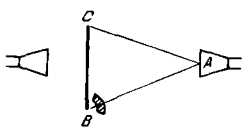

FIG. 1.

We note that the axis of the cylinder must be placed at a distance of the order of the wavelength from the edge of the plate but, in optics, this is not, of course, significant.

It is interesting to consider what will happen when the refractive index of the quarter cylinder is very high. The necessary thickness is then very small and the cylinder introduces a lag of 180° into the phase of the edge wave so that it does not affect the radiation from most of the elementary Fresnel sources. The impression is thus gained that the two equivalent descriptions lead to different results. The paradox is resolved by recalling that the small distortion of the wave front due to a very thin cylinder is rapidly smoothed out and there is no resultant effect.

2. PROPERTIES OF THE EDGE WAVE ACCORDING TO YOUNG

Sommerfeld's formulas[5] show that there should be a phase difference of π between edge wave segments radiated into the geometric shadow and into the illuminated region. This conclusion can readily be established by imposing the requirement that the solution must be continuous across the boundary between these two regions.

In fact, to the right of the line KM (Fig. 2), which separates the illuminated region from the geometric shadow, there are simultaneously two waves, namely, the direct wave producing a field of strength E_0 and the edge wave producing the field E_K whereas, to the right of this line, we have the edge wave alone. However, the field must be single-valued along the separation line KM, i.e., we must have $E_K = E_0 - E_K$, so that $E_K = E_0/2$. This and only this choice of the signs of E_K will ensure that the solutions will match on the boundary.

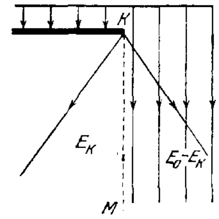

FIG. 2.

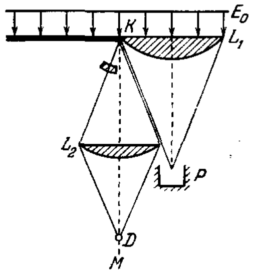

FIG. 3.

This property of the edge wave can be relatively readily and conveniently demonstrated as follows (Fig. 3). Radiation from the horn of the 32-mm klystron oscillator is directed onto the edge of a dural sheet (height 1 m, width 500 m, thickness 2 mm). The electric field in the electromagnetic wave is parallel to the edge of the sheet. The direct wave is removed by paraffin lens L_1 (focal length 50 cm), which focuses the corresponding radiation into the trap P made of graphite containing absorbing rubber. The edge wave is focused by lens L_2 onto the half-wave detector probe DK-I1 located at D and facing the edge of the screen, as shown. The detector signal is received by the U2-1A amplifier whose output is fed into an oscillograph. The signal recorded by the detector is then zero because the two halves of the front (separated by the line KM) are in antiphase.

If we now cover half the edge-wave front (right or left) with the quarter cylinder made of paraffin such that $R - r = 32$ mm, where R and r are the outer and inner radii, the detector shows a strong signal. This corresponds to zero phase difference between the two halves of the edge-wave front.

When the edge-wave front is covered by a paraffin half cylinder, which is symmetric relative to the line KM, the output signal is again zero.

We note that the axis of the quarter cylinder (and of the half cylinder) is placed 3 cm from the edge of the plate.

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