THE EXTRA-TRANSMISSION OF ELECTRIC WAVES.

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LAST Christmas I presented at the New York meeting of the American Association for the Advancement of Science a paper, having for its title "The Optical Analogue of Certain Electrical Experiments." In it I tried to account for a phenomenon observed by Messrs. Blake and Fountain,[1] and mentioned in a paper they have recently published, in an entirely different way from what they did. Since then a paper by Mr. Schaefer[2] has appeared, in which he tries to show that it is unlikely that the phenomenon exists at all. For this reason I have undertaken in the present paper to discuss the experiments of Blake and Fountain from a somewhat different standpoint than theirs. It seems to me that the results obtained by these two experimenters are not only not unreasonable, but they are precisely what one ought to have expected.

In their experiments Blake and Fountain allowed electric waves to fall upon sheets of glass upon which tin-foil strips had been pasted, and also upon sheets of bare glass, and found that when the tin-foil covered sheets of glass were used, under some circumstances there was less energy reflected, and more transmitted than was the case with bare glass. This they account for by assuming that glass covered with tin-foil strips constitutes a medium having a different index of refraction than that of glass. To me it seems more plausible to suppose that since the total energy reflected by bare glass is the vector sum of the amounts reflected by the front and back surfaces of the glass, and since the change of phase produced at a surface on which there are tin-foil strips is different from that produced at a bare glass surface, it might well happen that the tin-foil strips would cause the difference of phase between the energy reflected at the two surfaces to be more favorable to destructive in-

[1] F. C. Blake and C. R. Fountain, PHYS. REV., XXIII., p. 257, 1906.
[2] C. Schaefer, PHYS. REV., XXIV., p. 421, 1907.

terference, and that there would be a consequent diminution in the reflected intensity and an increase in the transmitted. That such a change of phase is produced by screens of resonators is more than likely, especially in view of the fact that gratings produce a change of phase, as has recently been shown experimentally by Messrs. Schaefer and Laugwitz.[1]

If the above explanation of the phenomenon of extra-transmission be correct, it ought to be possible to obtain the same effect with ordinary light. All that is necessary is a sufficiently thin film of one substance and upon this a very much thinner film of some other substance, to produce the necessary phase change. Now the phase change produced at the surface of a transparent substance is either zero or π while that produced by sufficiently opaque substances like the metals or certain dyes is different from either zero or π. The phase change produced by a thin film of metal depends upon its thickness as well as upon the optical contents of the metal. As the thickness of a thin film of metal diminishes the change of phase and the intensity of the reflected light will both diminish, but while with diminishing thickness the intensity approaches zero as its limit, the change of phase approaches a certain finite constant value, which is practically the same for all thicknesses less than one thousandth of a wave-length. This value is in the case of silver and gold about six tenths of the value of the phase change produced by thick plates, as has been shown by G. T. Walker[2] and by Maclaurin.[3] One ought therefore to be able to realize this effect of extra-transmission by taking a film of some substance thin enough to show interference colors, and depositing upon it a mere suspicion of silver. This coating of silver would produce the necessary phase change, while being perfectly transparent. I tried to obtain the effect by silvering pieces of blown glass which showed interference colors, but did not meet with much success. This was no doubt due to the low reflectivity of the glass which is only about 4 per cent. With substances like selenium or the aniline dyes whose reflectivity is as high as 25 per cent. or 30 per cent. for some colors, one might

[1] C. Schaefer and M. Laugwitz, Ann. der Physik., XXI., p. 587, 1906.

[2] G. T. Walker, Ann. der Physik, X., p. 194, 1903.

[3] R. C. Maclaurin, Proc. Roy. Soc., 1906. Series A, Vol. LXXVIII, p. 302.

obtain much more noticeable effects. I therefore silvered lightly a film of selenium which had been deposited on glass by cathode discharge. The result was that the film of selenium which was previously of an orange color, changed to purple. This would show that there was less purple light reflected after silvering and hence more transmitted. The film of silver was very thin — it had only required fifteen seconds to deposit it by cathode discharge — and where it fell on bare glass it was impossible to detect it by the eye. Part of the plate had been protected from cathode discharge, and the only way in which it was possible to tell where the silver had fallen was by the difference in color of the two parts of the selenium film. In another case a film of selenium too thin to show interference colors was deposited upon a glass plate and this gave the glass a light brown color. Upon part of it an extremely thin coating of silver was deposited. By transmitted light the unsilvered part appeared darker than the silvered.

Experiments were also tried with compound films of fuchsine and silver. Half of one side of a glass plate was lightly silvered with the intention of afterwards depositing fuchsine upon it. I was unable to tell which side was silvered try as I might, but I thought I remembered that I had exposed to cathode discharge the side of the glass plate which was least scratched, and so proceeded to deposit from an alcoholic solution a film of dye upon what was thought to be the silvered side. The dye showed plainly that this side had been silvered, because where the dye film crossed the silver film, it was plainly more transparent than it was where it covered bare glass. The increase in transparency was still more marked when the silver was deposited on the fuchsine instead of being between the fuchsine and the glass. Indeed a thin wash of fuchsine on glass vanished from sight almost entirely by being silvered. This I do not believe to have been due to an annihilation of the dye caused by the bombardment by the silver cathode particles because the dye reappeared when the plate was washed with alcohol: that is to say, the alcohol became colored with the dye that was on the plate.

In the discussion of my paper at the meeting of the American Association, it was suggested that possibly the films had been chemically acted upon by the silver so as to produce a change of color or an increase of transparency. That this was not so in the case of selenium at least, was proved by a wedge shaped deposit of selenium, which showed interference colors, something like Newton's rings. On lightly silvering a part of this the interference bands of the silvered part were displaced relatively to those of the unsilvered part.

Let us now return to the experiments of Blake and Fountain. They allowed not light, but electric waves of wave-length 9.9 cm. to fall on glass plates about a meter square. One of the plates was 5 mm. thick and the others were 3 mm. thick. They found that the thick plate reflected 38 per cent. and transmitted 60 per cent. of the incident radiation, while those of 3 mm. thickness reflected 17 per cent. and transmitted 80 per cent. The fact that the sum of the reflected and transmitted radiation is nearly unity in both cases, is a very good check on the work. Furthermore, from their data we can compute the index of refraction of the glass by Airy's formula.

$$I = \frac{4a^2b^2 \sin^2 \frac{1}{2}\delta}{(1 - b^2)^2 + 4b^2 \sin^2 \frac{1}{2}\delta}$$

in which a^2 is the intensity of the incident radiation; b^2 is the reflection coefficient, which is connected with the index of refraction as follows:

$$b^2 = \left(\frac{n - 1}{n + 1}\right)^2.$$

$$\delta = \frac{4\pi ne \cos r}{\lambda},$$

e is the thickness of the plate, λ the wave-length in air, and r the angle of refraction.

Using these formulæ one gets the same value for the index of refraction of the thin pieces and the thick piece of glass, viz.: 2.41, which would make the dielectric constant about 5.8. These results are evident from the curves shown in Figs. 8 and 9[1] of their paper.

In the curve of Fig. 8, one may notice that the addition of the resonators causes the reflected intensity to increase. This increase

[1] Ibid., p. 269.

becomes greater as the resonators are made longer, until a resonator length of 2.7 cm. is reached after which increasing the resonator length diminishes the reflected intensity. This is not because the energy reflected at the tin-foil covered surface is a maximum for a resonator length of 2.7 cm., but because the vector sum of the energy of the rays from the front and back surfaces of the plate is a maximum at this point. If the glass had been left bare and the phase relations between the rays from the front and back surfaces had been changed by varying the thickness of the plate, the maximum of the reflected intensity would have occurred at a thickness

$$e = \frac{\lambda}{2\pi n \cos r} = .65 \text{ cm.}$$

and this maximum would not have been greater than about 49 per cent. With the resonators on the plate the maximum reflected intensity was 53 per cent., which goes to show that the resonators increased the reflectivity of the surface upon which they were pasted, as well as changing the phase of the reflected energy, and the figure also shows that they introduced some real absorption, as might have been expected.

In Fig. 8 one sees that the intensity of the reflected energy never reaches the highest possible value, but attains its maximum at a resonator length of 3 cm. where the phase change is a maximum. The intensity having its maximum at the same point as the maximum phase change, causes the curve to be rather symmetrical about a center line, which is not the case in Fig. 9.

All of the foregoing considerations, it seems to me, tend to make the results published by Blake and Fountain very plausible, though I do not think this kind of reasoning should be pushed too far. There are other effects coming in due to the fact that the thickness of the glass is of the same order of magnitude as the resonator widths and lengths. The different absorptions as shown by the dotted lines of Figs. 8 and 9, and no doubt the phase changes, are also affected to some extent by the nearness of the second surface of the glass. If, however, Mr. Schaefer had only given in his paper the results which he obtained when he tried to verify Blake and Fountain's experiments, his evidence would have had more weight.

We do not know whether his glass was thick or thin, whether it had a high or low index of refraction, nor what the reflection and transmission of the bare glass was. From his curves of reflection and transmission for different lengths of resonators, together with the same data for bare glass, it ought to be possible to decide whether or not an increased transmission should be expected in his case. In obtaining an increased transmission of light through thin films by silvering them, I had no success for a long while, because I silvered the films a little too much, so that what was gained by phase change, was lost by the absorption of the silver film. Some such thing may have prevented Mr. Schaefer from obtaining increased transmission, or it may be that the index of refaction of the glass plates that he used was too low. The index of refraction of the glass Blake and Fountain used was high — the reflection coefficient was 17.1 per cent. — while some glass is known to have a very low dielectric constant, and no doubt has a correspondingly low reflection coefficient. If the dielectric constant of Mr. Schaefer's glass was 3, a by no means improbable value, the index of refraction would probably be 1.73 and this would give 7.2 per cent. for the reflection coefficient. It is evident that with such a low reflectivity the effect of extra-transmission would be difficult to observe.

Finally I wish to say that I am not in a position to judge as to the reasonableness of the criticisms Mr. Schaefer makes of the adjustments of Blake and Fountain's apparatus. Their results seem to be good. Even if Mr. Schaefer can show that Blake and Fountain's results are wrong, which I doubt very much, it ought still to be possible for some one to obtain a true extra-transmission.

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