THE TRANSMISSION THEORY OF LIGHT, PART III
ABERRATION AND REFRACTION AT MOVING BOUNDARIES

Continued from pages 4353-62.

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29. Discrimination Between the Two Principles.

We shall write $c_2/c_1 = 1/n$ in case (a), assuming that in so doing not too great an error is being introduced. Our present purpose does not require close precision.

Employing the half-angle formulae of trigonometry, (28.7) reduces to

$$\tan r = \frac{\sin 2i}{(2n - 1) + \cos 2i} \qquad (29.1)$$

and on taking n = 1.333 for water, this becomes

$$\tan r = \frac{\sin 2i}{1.666 + \cos 2i} \qquad (29.2)$$

We can now observe that as $i \to 90°$ then $r \to 0$, which is a manifest contradiction of the limiting value which the angle of refraction assumes at grazing incidence for i; physics textbooks, at least, inform us that at grazing incidence, i.e., $i = 90°$, when $n > 1$, the refracted ray takes on some limiting value that is not 0° and not 90° either, but is somewhere well in between the two, dependent on n. This property is used by chemists for the critical evaluation of n for different substances in the laboratory and instruments have been devised for doing so that are based on this property. It is scarcely likely that the multitudinous measurements of this sort made during two centuries would not have turned up, by this time, an error of so fundamental a nature if one were present here. We must, therefore, at this point abandon (29.1) and its associated theory as representing natural facts.

Despite that, for its academic interest, let us still pursue the matter further, examining the discrepancies between case (a) and case (b) in more detail. The Huyghensian formula (28.13) will be rewritten in the form:

$$\tan r_H = \frac{\sin i}{\sqrt{(1.777 - \sin^2 i)}} \qquad (29.3)$$

We then proceed to compute r and r_H at 10° intervals and at 85°; the results are tabulated in Table 29.1. These are for a ray proceding out of air and going into water, with n = 1.333. The same results are presented graphically as Graph 29.1 for easy comprehension.

It is seen that r and r_H agree fairly well up to 40° but that then r turns downwards to zero while r_H goes on increasing monotonically to a finite limiting value of arcsin (1/1.333). This confirms the abandonment of case (a).

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Table 29.1

i (in degrees)	r (in radians)	r_H (in radians)	Experimental Values (in radians)
0°	0.000	0.000	0.00
10	0.131	0.131	0.14
20	0.258	0.259	0.28
30	0.380	0.385	0.38
40	0.492	0.503	0.49
50	0.583	0.612	0.62
60	0.639	0.707	0.70
70	0.620	0.782	0.73
80	0.440	0.831	0.79
85	0.248	0.845	0.84
90	0.000	0.848	The ray is too faint for a determination to be made.

For the record, and so as to do a thorough job in our investigation, we do the same for a light ray that progresses out of the water first and then goes into the air; i.e., where there is an increase of velocity of the light, supposedly, from one medium to another, rather than a decrease, as in the previous instance when it went from air into water. The same formulae apply but now the reciprocal of n must replace n in them. We have $n^{-1} = .750$, so the formulae are now, respectively:

$$\tan r = \frac{\sin 2i}{.5 + \cos 2i} \qquad (29.8)$$

and

$$\tan r_H = \frac{\sin i}{\sqrt{(.563 - \sin^2 i)}} \qquad (29.9)$$

Computed values are given in Table 29.2 and are plotted as Graph 29.2.

Table 29.2

i (in degrees)	r (in radians)	r_H (in radians)	Experimental Values (in radians)
0°	0.000	0.000	0.00
10	0.233	0.234	0.26
20	0.470	0.473	0.44
30	0.714	0.730	0.73
40	0.961	1.029	0.96
48	1.190	1.432	1.06
50	1.251	Formula turns imaginary.	1.12
60	1.571		1.25
70	$\frac{\pi}{2}$ is exceeded.		1.36
78			1.45
80			No reading.
90			

In case (a) the angle of refraction stays real for values of i > 60° and r would go on to π, which has hardly any physical meaning and must be treated as a mathematical rather than a physical consequence. In case (b) the formula turns imaginary for i > 48° approximately, which is interpreted classically that the refracted ray does not exist beyond this limit and that the incident ray is totally reflected back into the H_2O.

There is here another definite criterion to compare theory with physical fact: i.e., does the refracted ray tend to being horizontal as i ↑ 60°; does it disappear already earlier under total reflection as claimed by the textbooks, around 48°?

30. An Experiment.

Although it is clearly apparent that case (a) represents an impossible theory that does not conform to reality, yet our bitter experiences already with texbook scientific propaganda persuade us to go on and see for ourself what is this reality. Later on, it may become instructive to have pursued the matter completely, even should the textbooks perchance turn out to have been correct, for once.

A simple device for observing the angles of incidence and refraction was therefore constructed. A narrow circular ring of lucite, 17 cm in diameter, was obtained and two flat lucite sheets were bonded to its sides to form a narrow cylindrical chamber; c.f., figure 30.1. This was then filled up half way with plain tap water. A large protractor was placed behind the cylinder which could be easily viewed through the various transparent materials. A collimated light ray was shone into the chamber normal to its circular surface, both from the air into the water and from the water into the air (which last case is the one illustrated). The varous angles were then recorded.

The data is presented in the fourth colums of Tables 29.1, .2 of the previous section and is plotted with the x marks on the two graphs. The accuracy was about ±2° at the low end of the scale but decreased to ±5° near i = 90° in Table 29.1 and also in the range of 50° < i < 60° in table 29.2. This was due to the width of the ray which could not be slitted more narrowly without losing too much of its intensity, rendering it unobservable. A still better piece of apparatus might be constructed in this last regard.

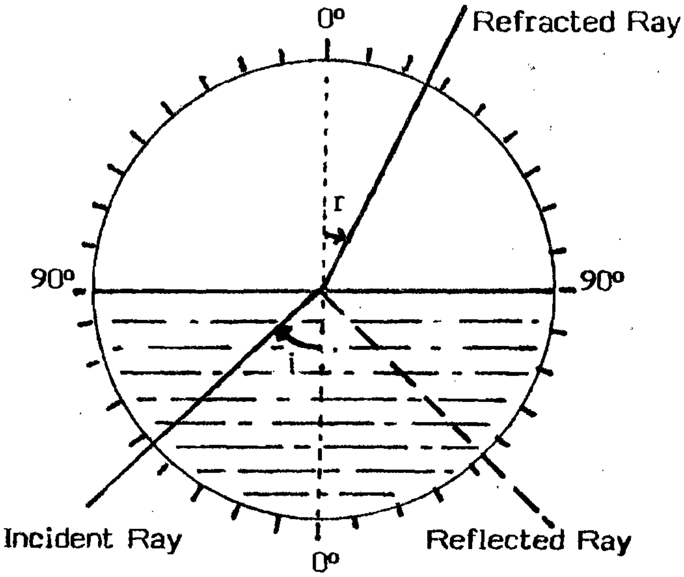
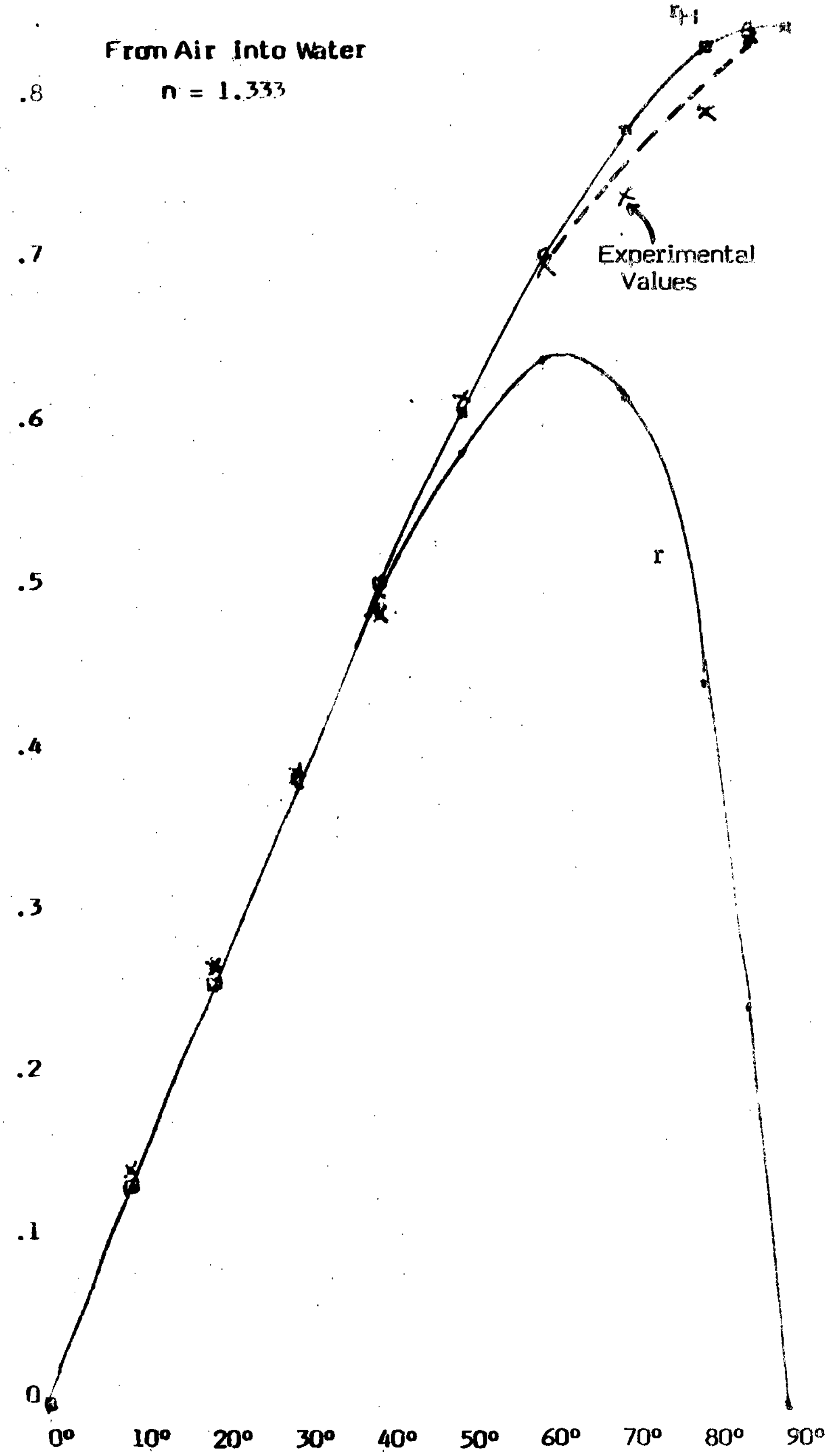
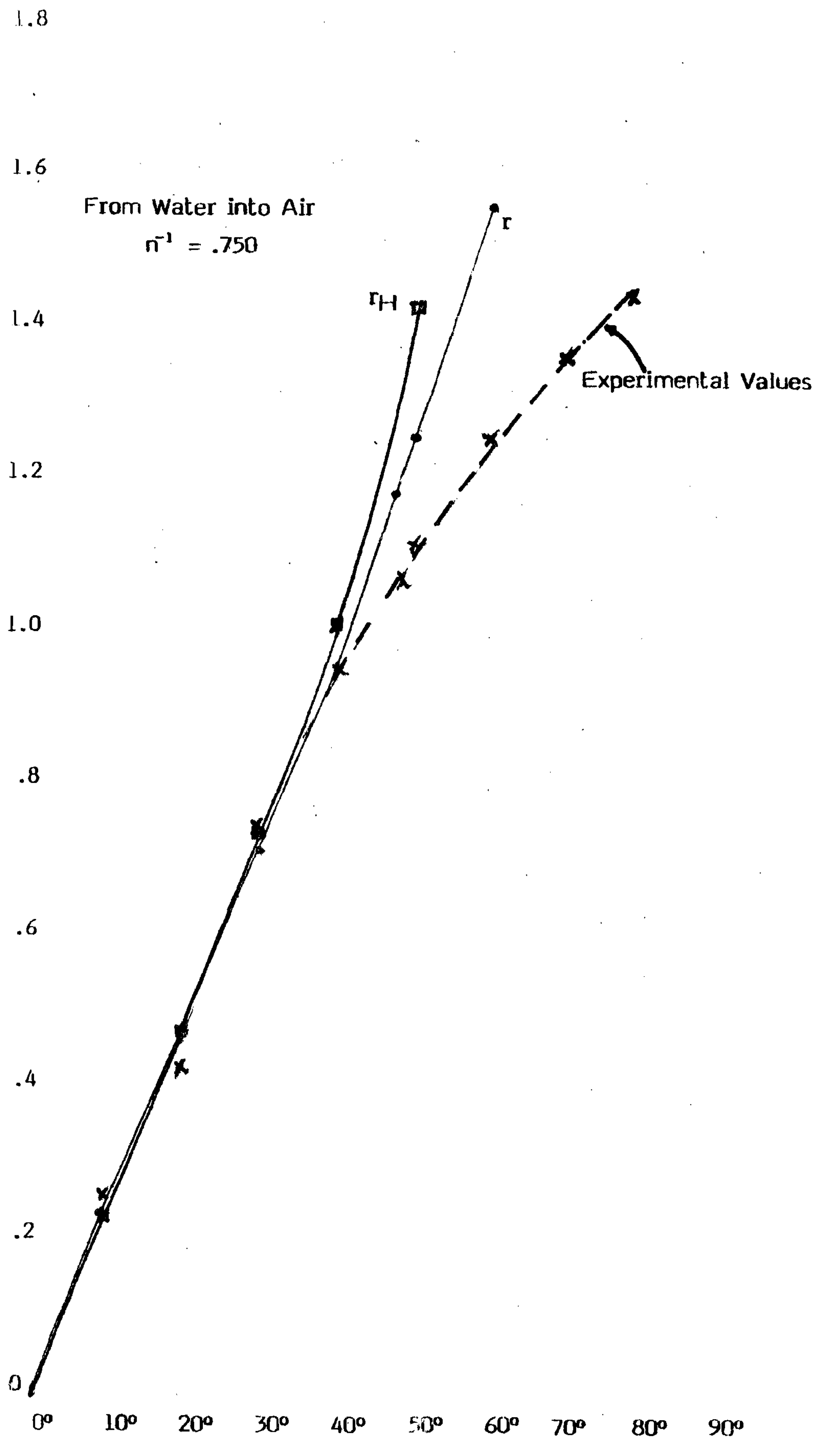


Figure 30.1.


From Air Into Water
n = 1.333
r_{11}
Experimental Values
r
.8
.7
.6
.5
.4
.3
.2
.1
0
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°

Graph 29.1.


1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
From Water into Air
n^{-1} = .750
r
r_H
Experimental Values
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°

Graph 29.2.

Table 29.1 and Graph 29.1 show that the observed data adheres closely to the Huyghensian predictions, though there is some deviation near the end of the range. This is probably due to experimental inaccuracy for the reasons mentioned already. The data definitely do not accord with the case (a) theory, which has already been rejected as aphysical.

Table 29.2 and Graph 29.2 show that the discrepancy between r and r_H is not too large up to the point of the critical angle $r_H \approx 48°$, where the Huyghensian curve stops. The curve for r goes on up to $r = \pi/2$. However, the most significant feature for this case of the light ray progressing from water into air, is that the experimental data does not agree with the predictions derived out of either of the theories. The data are subject to the large errors at the end of the range, but in despite of this, it is so that a refracted ray does exist beyond the $r_H = 48°$ critical angle.

This casts the same doubt on the Huyghensian theory that the from-air-into-water example cast on the case (a) theory. If we have not been deceived in making these observations, the Huyghensian wavelet-envelope theory is not the correct one, either. Some third, as yet undiscovered, law lies behind refraction, even in the static case. Whatever that law may turn out to be, the Huyghensian theory is an excellent approximation to it.

The result also casts considerable doubt on the reciprocity of light velocity embodied in Snell's law that the velocity of light emanating out of a medium of higher refractive index, somehow speeds up when it enters into a different medium of lower index.

If these results be correct - and they do need confirmation - a most significant discovery has rewarded patience and skepticism and our stubborn determination to see this question through to its final conclusion.