Refraction and Standing Waves

Lab #7

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Objective

Measure the wavelength of a microwave by creating a standing wave and calculate the index of refraction of a material using Snell's law.

1 Introduction

1.1 Standing waves

A standing wave is a wave whose energy density at every point remains constant, or a wave that does not propagate. The points at which the energy density is zero are called the nodes of the wave, and the points where the energy density is a maximum are called the antinodes.

A standing wave is generated by resonance when a traveling plane wave of wavelength λ reflects back on itself from a wall that is some integer multiple of $\lambda/2$ away from the source and interferes with itself. The horns of the microwave receiver reflect some radiation, so the transmitter and receiver can be placed facing each other at a distance $n\lambda/2$ apart (for any natural number n) to create a standing wave. When this happens, the intensity reading will be at a maximum.

1.2 Refraction

An electromagnetic wave is refracted, or bent, when it passes from one medium to another medium with a different index of refraction. Snell's law, named after Dutch astronomer Willebrord Snellius, relates the indices of refraction of the materials the light passes through and the angles at which it enters and leaves the boundary. If θ_1 is the angle between the direction of the light before crossing and the surface normal of the boundary, θ_2 is the angle between the direction after crossing and the surface normal, and n_1 are the indices of refraction of the first and second materials the light passes through, then

$$n_1 \sin\theta_1 = n_2 \sin\theta_2. \tag{1}$$

The index of refraction of air is approximately 1.

2 Procedures and Results

2.1 Standing waves

We set up the microwave system so that the transmitter and receiver diodes were approximately 70 cm and then slid them a few centimeters farther apart to get a maximum intensity reading. Then, we slid them farther apart, counting the times that the intensity reading hit a local minimum, stopping at a local maximum. We recorded the initial and final positions of the units and the number of minima passed.

Table 1: Standing wave measurements

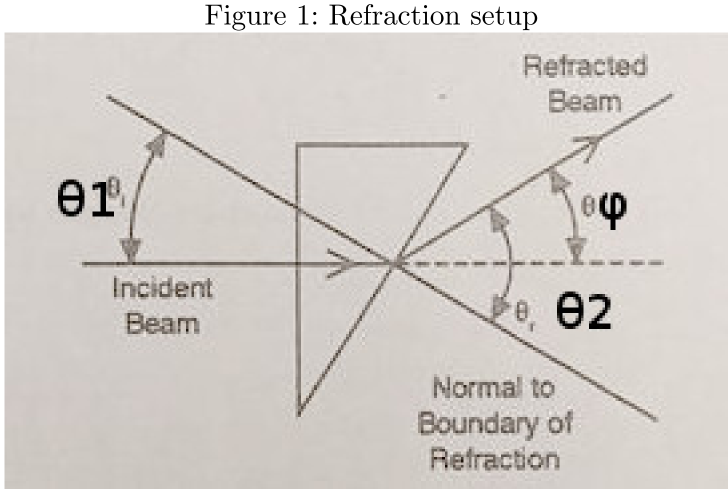
Initial position (r_i)	Number of minima passed (n)	Final position (r_f)
74.9 cm	10	90 cm
73.3 cm	11	88.3 cm

2.2 Refraction

We set up the microwave system with a right triangular ethafoam (polyethylene foam) prism mold on the center of the goniometer, then filled the prism mold with polystyrene pellets. We aligned the prism mold so that its longer leg was facing perpendicular to the transmitter arm of the goniometer, then turned the transmitter on. Next, we moved the receiver arm until the intensity reading was a maximum and recorded the angle φ between the refracted ray and the incident ray.

Because the prism mold is a right triangle, the angle of incidence θ_1 is equal to the angle adjacent to the leg facing the transmitter. We measured this angle using a protractor. The angle of refraction $\theta_2 = \theta_1 + \varphi$.

Figure 1: Refraction setup



$$\begin{aligned}\theta_1 &= 48^\circ\\ \varphi &= 12^\circ\\ \theta_2 &= \theta_1 + \varphi = 60^\circ\end{aligned}$$

3 Discussion

3.1 Standing waves

Using the data in Table 1, we can calculate the wavelength λ. A sample calculation is shown for the first entry:

$$\begin{aligned} n\lambda/2 &= r_f - r_i \\ 10\lambda/2 &= 90\,\mathrm{cm} - 74.9\,\mathrm{cm} \\ 5\lambda &= 15.1\,\mathrm{cm} \\ \lambda &= 3.02\,\mathrm{cm} \end{aligned}$$

Using the second row of data we obtain $\lambda = 2.73\,\mathrm{cm}$.
The percent difference between these two values is approximately 10%.

3.2 Refraction

When light enters a right triangular prism through a leg of the triangle, it is not refracted because it enters perpendicular to the surface. However, when it leaves the prism, it is refracted according to Snell's law.

$$\begin{aligned} n_1 \sin\theta_1 &= n_2 \sin\theta_2 \\ n_1 \sin 48^\circ &= 1.0 \sin 60^\circ \\ n_1 &= 1.0\,\frac{\sin 60^\circ}{\sin 48^\circ} \\ n_1 &\approx 1.17 \end{aligned}$$

The index of refraction of the prism mold is $n_1 \approx 1.17$.

4 Conclusion

We can use the properties of standing waves to determine the wavelength of a wave, and we can use Snell's law to find the index of refraction of a material.