

ELECTROMAGNETIC WAVES IN MATTER: REFLECTION AND TRANSMISSION COEFFICIENTS

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References: Griffiths, David J. (2007), Introduction to Electrodynamics, 3rd Edition; Pearson Education - Problem 9.13.

Continuing with our study of electromagnetic waves in matter, we'll carry on with the system of an incident wave travelling in the $+z$ direction (so $\hat{\mathbf{k}} = \hat{\mathbf{z}}$) and polarized in the x direction (so $\hat{\mathbf{n}} = \hat{\mathbf{x}}$). Suppose the boundary is the xy plane, with medium 1 on the left ($z < 0$) and medium 2 on the right ($z > 0$). Then the reflected and transmitted (complex) amplitudes are

$$\tilde{E}_{0R} = \pm \frac{1 - \beta}{1 + \beta} \tilde{E}_{0I} \quad (1)$$

$$\tilde{E}_{0T} = \pm \frac{2}{1 + \beta} \tilde{E}_{0I} \quad (2)$$

where \tilde{E}_{0I} is the incident amplitude and

$$\beta \equiv \frac{\mu_1 v_1}{\mu_2 v_2} = \frac{\mu_1 n_2}{\mu_2 n_1} \quad (3)$$

with v_i the speed of the wave in medium i and $n_i = c/v_i$ the index of refraction.

The intensity of a wave in a vacuum is defined as the mean (over time) of the magnitude of the Poynting vector:

$$I \equiv \langle S \rangle = \frac{1}{2} E_0^2 c \epsilon_0 \quad (4)$$

If we follow through the derivation of I for a wave in matter, we see that the only difference is that c is replaced by v and ϵ_0 by ϵ , so the intensity becomes

$$I = \frac{1}{2} \epsilon v E_0^2 \quad (5)$$

The reflection coefficient R is the ratio of reflected to incident intensity:

$$R = \frac{\frac{1}{2}\epsilon_1 v_1 E_{0R}^2}{\frac{1}{2}\epsilon_1 v_1 E_{0I}^2} \quad (6)$$

$$= \left(\frac{1 - \beta}{1 + \beta} \right)^2 \quad (7)$$

The transmission coefficient T is the ratio of transmitted to incident intensity:

$$T = \frac{\frac{1}{2}\epsilon_2 v_2 E_{0T}^2}{\frac{1}{2}\epsilon_1 v_1 E_{0I}^2} \quad (8)$$

$$= \frac{4\epsilon_2 v_2}{\epsilon_1 v_1 (1 + \beta)^2} \quad (9)$$

$$= \frac{4\beta}{(1 + \beta)^2} \quad (10)$$

where in the last line we used

$$v_i = \frac{1}{\sqrt{\epsilon_i \mu_i}} \quad (11)$$

$$\epsilon_i = \frac{1}{\mu_i v_i^2} \quad (12)$$

We can see that $R + T = 1$ which is just an expression of the conservation of energy. The larger n_2 is relative to n_1 , the larger is β which means that $R \rightarrow 1$ and $T \rightarrow 0$.

The theory here is incomplete, as in practice the index of refraction depends not only on the material but also on the wavelength of radiation. This is largely a quantum phenomenon as it depends on the distances between the atoms in the refracting medium, whereas the classical theory assumes the medium is continuous.

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