Refraction Law for Self-Collimated Light Beams at Material Interfaces

EA McCoy[1], JM Christian, and GS McDonald
Materials & Physics Research Centre, University of Salford, Greater Manchester M5 4WT, U.K.

J Sánchez-Curto and P Chamorro-Posada
Universidad de Valladolid, ETSI Telecomunicacíon, Campus Miguel Delibes s/n, 47011 Valladolid, Spain

[1] *Correspondence*: E.McCoy1@edu.salford.ac.uk

Abstract

Perhaps the most fundamental electromagnetic phenomenon is the behaviour of light at the interface between dissimilar materials. In fact, the entire field of Optics follows from this single key concept. The reflection and refraction properties of a plane wave incident on the uniform boundary between two linear dielectric materials is an elementary configuration covered in standard textbooks on electromagnetism (see, e.g. Ref. [1]). In contrast, the behaviour of a beam with a *finite transverse cross-section* is much more complicated affair, and one must often resort to wholly-numerical calculations. Relatively little is known about light-interface interactions when *nonlinear* components are thrown into the mix – for instance, where the refractive index (of one or both materials) depends in some way on incident light intensity.

The problem of fully-nonlinear interfaces was first attacked in a pair of seminal papers some two decades ago by Aceves and coworkers [2,3]. Their classic approach considered scalar spatial optical solitons (self-collimated, self-stabilizing light beams with a stationary intensity profile) incident on the boundary between two dissimilar Kerr-type media (i.e., materials whose refractive index varies proportionally with local light intensity I). While highly instructive, these early analyses were based upon a governing equation whose central tenet was that angles of incidence, reflection and refraction (with respect to the interface) must be negligibly small.

In practice, the "small angles" approximation is not entirely satisfactory. In the laboratory, one generally has complete freedom to choose any incidence angle; ideally, one would like any theoretical model to possess the same angular freedom. To this end, we have recently developed a theoretical framework that allows us to predict, *for the first time*, the refraction of soliton beams incident *at any angle* on a Kerr-type interface [4,5]. Our latest efforts have been to extend these preliminary analyses to much wider classes of power-law materials [6], whose refractive index varies with light intensity according to I^p (where $0 < p < 2$ – the Kerr nonlinearity thus corresponds to the particular case of $p = 1$). By a curious twist of fate, it turns out that the full nonlinear-beams configuration can be described by a simple generalization of the trivially-familiar Snell's law for plane waves.

References

[1] J. D. Jackson, *Classical Electrodynamics* 3rd Ed., 1999 John Wiley & Sons (New York).
[2] A. B. Aceves, J. V. Moloney, and A. C. Newell, Phys. Rev. A **39**, 1809 (1989).
[3] A. B. Aceves, J. V. Moloney, and A. C. Newell, Phys. Rev. A **39**, 1828 (1989).
[4] J. Sánchez-Curto, P. Chamorro-Posada, and G. S. McDonald, Opt. Lett. **35**, 1347 (2010).
[5] J. Sánchez-Curto, P. Chamorro-Posada, and G. S. McDonald, Opt. Lett. **32**, 1126 (2007).
[6] J. M. Christian, G.S. McDonald, R. J. Potton, and P. Chamorro-Posada, Phys. Rev. A **76**, 033834 (2007).