Negative refraction in chiral media

S.A. Tretyakov (News note, December 22, 2004)

It is well known that negative refraction happens at an interface between a usual isotropic medium (vacuum, for example) and a material with negative parameters (called Veselago medium, double-negative material, or backward-wave medium).

However, recent studies have shown that backward waves can propagate in materials with positive parameters provided one of the materials is *chiral*. This result has been established in papers

S. Tretyakov, I. Nefedov, A. Sihvola, S. Maslovski, C. Simovski, Waves and energy in chiral nihility, *Journal of Electromagnetic Waves and Applications,* vol. 17, no. 5, pp. 695-706, 2003

J. Pendry, A Chiral route to negative refraction, *Science,* vol. 306, pp. 1353-1955, 2004

and presented in a conference:

S. Tretyakov, I. Nefedov, A. Sihvola, S. Maslovski, C. Simovski, A metamaterial with extreme properties: The chiral nihility, *Progress in Electromagnetics Research Symposium 2003,* p. 468, Honolulu, Hawaii, USA, October 13-16, 2003.

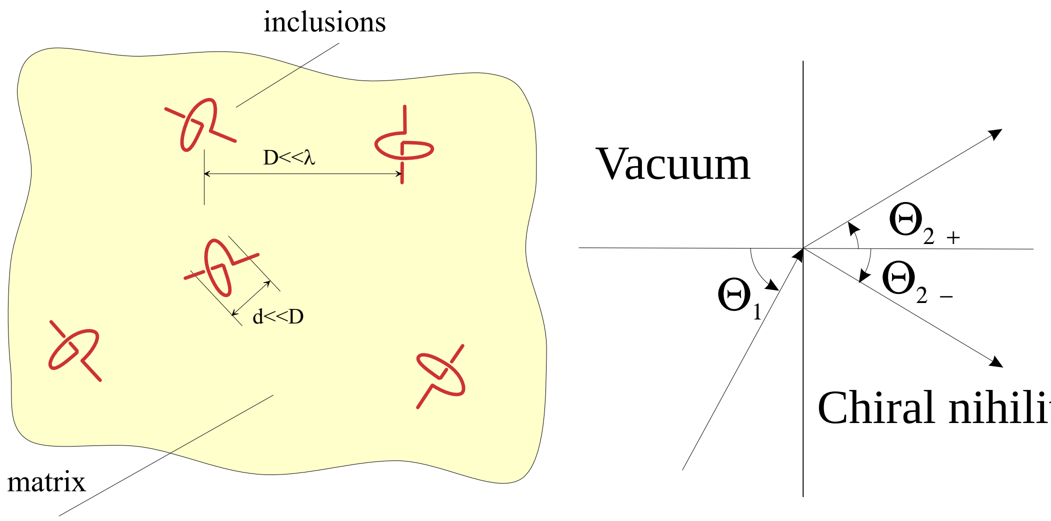

Figure 1: Typical geometry of an artificial chiral material (left) and refracted waves for a special case when $n = 0$ ("chiral nihility", right)

The physics of the effect is very simple: The propagation constants of two eigenwaves in isotropic chiral media equal $\beta = (n \pm \kappa)k_0$, where $n = \sqrt{\epsilon\mu}$ is the usual refractive index, κ is the chirality parameter, and k_0 is the free-space wavenumber (see, e.g., [1]). Near the resonance of electric or /and magnetic susceptibilities the refractive index n can become smaller than the chirality parameter κ. It means that one of the two eigenwaves is a backward wave, because its phase velocity is negative but the energy transport velocity is positive. At an interface between a usual isotropic material and such medium negative refraction takes place for this polarization (waves of the other polarization refract positively).

In chiral microwave composites this happens "naturally", because the inclusions are usually small spirals having resonant electric and magnetic polarizabilities (κ is also resonant, of course). This can be also said about optical frequencies, because chiral materials are readily available and permittivity can have resonances in the optical range.

This is a very exciting new opportunity to realize negative refraction and related effects in the optical region in effectively uniform media (the characteristic dimensions in the material can be much smaller than the wavelength).

Chiral media have been very intensively studied in the past (see references to monographs and review papers below). However, it is interesting, that this effect was not understood before. The authors of monograph [1] thought that both waves should be forward, and formulated a corresponding restriction for the material parameters! [See Eq. (2.176) on page 51].

Some references

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[2] A.N. Serdyukov, I.V. Semchenko, S.A. Tretyakov, A. Sihvola, *Electromagnetics of bi-anisotropic materials: Theory and applications,* Amsterdam: Gordon and Breach Science Publishers, 2001.
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