PHYSICS DEPARTMENT COLLOQUIUM

"Electrodynamics of Left-Handed Materials"

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About 35 years ago Russian physicist Veselago considered theoretically propagation of the electromagnetic waves (EMW) in a hypothetical medium where both electric permittivity ε and magnetic permeability μ are negative in some frequency range and both of them have small imaginary parts. He found out that such a medium would have very unusual optical properties within this frequency range. It is well known that the light velocity $c^2 = 1/\varepsilon\mu$, so if, $\varepsilon<0$, $\mu>0$, the EMW does not propagate at all. For example, this is the case of a metal below plasma frequency. However, if $\varepsilon<0$, $\mu<0$, one gets $c^2>0$, and the wave equation has a propagating solution.

Veselago has shown that the EMW at $\varepsilon<0$, $\mu<0$ are not the same as for a regular medium (RM), where $\varepsilon>0$, $\mu>0$. It follows from the first order Maxwell's equations that in the second (regular) case the vectors **k, E, H** form a right-handed set , while in the Veselago case they form a left-handed set. Therefore, the medium with $\varepsilon<0$, $\mu<0$ is called the left-handed medium (LHM) and EMW in this medium are called backward waves, because the change of sign ε,μ is mathematically the same as the change of the sign of time. Thus, these waves are kind of going back in time.

All unusual properties of the LHM originate from the fact that in the isotropic medium the energy flux given by Poynting vector $\mathbf{S}=\mathbf{E}\times\mathbf{H}$ is anti-parallel to the wave vector **k. (**F The negative refraction of EMW at the interface of LHM and regular material, the negative Doppler effect and the negative light pressure are among the most drastic theoretically predicted manifestations of the LHM.

The interest to the negative refraction is connected with the possibility of creation of the unique lens first predicted by Veselago which is just an infinite slab of the LHM with $\varepsilon' = -\varepsilon$ and $\mu' = -\mu$, where "prime" stands for the slab of the LHM, embedded into a normal medium with $\varepsilon>0$, $\mu>0$. The reflected wave is completely absent because wave impedances of both media coincide. Such an instrument should be very important because it images stigmatically any three-dimensional object inside three-dimensional domain. Note that this result is obtained using geometrical optics while holographic imaging assumes complicated interference of the rays.

We have proposed to use spectrum of the photonic crystal in the vicinity of the Γ-point of the second Brillouin zone of the two-dimensional photonic crystal, where one mode has isotropic and negative group velocity. Our recent calculations demonstrate the possibility of creation of Veselago type LHM with $\varepsilon<0$, $\mu<0$ based upon two-dimensional
dielectric photonic crystal.

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