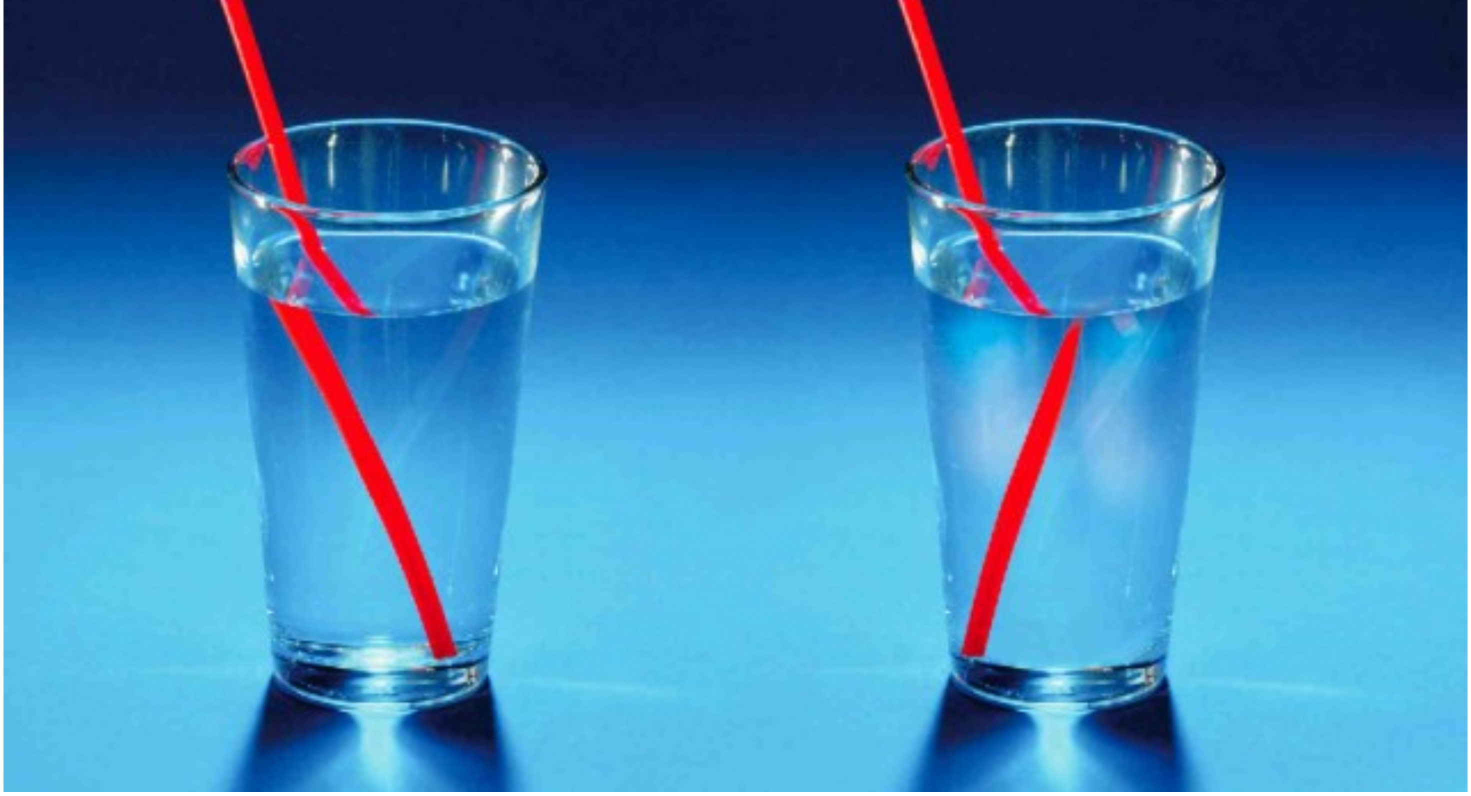

UCSB Art and Technology

Ordinary materials refract light, making the straw appear bent or broken as in the left image. Some special materials have negative refraction, which bends light in the opposite direction, as depicted on the right.

When it comes to light, certain types of fabricated materials behave in a radically different manner from ordinary materials like water and glass: they have negative refractive indices, so that light will travel in the opposite direction expected in normal materials. These negatively refracting materials can focus light effectively, even when the wavelength of the light is much larger than the device, allowing microscopic control of optical devices.

A new experiment has achieved extraordinarily large negative refractive indices for radio frequency light. Hosang Yoon, Kitty Y. M. Yeung, Vladimir Umansky, and Donhee Ham constructed a special material which, at very cold temperatures, bent light much more strongly than has been accomplished before. In the process, it provides a new understanding of the interaction between light and electrons.

The researchers achieved high negative refraction through a specially designed semiconductor device. This consisted of a set of thin strips of aluminum gallium arsenide (AlGaAs) on top of a substrate of gallium arsenide (GaAs). The construction produced a two-dimensional electron gas (2DEG), where the electrons' motion was confined to the interface between the strips and the substrate. The authors pointed out that if only one strip was used, the device didn't exhibit negative refraction. This is because the strips acted in the same way that atoms do in a crystal lattice, forcing the electrons into a set of behaviors—it's just that, in this case,

Refraction—the bending of the path of light when it passes from one medium to another—is a familiar phenomenon. If you place a drinking straw into a glass of water, the straw will appear bent, with the part in the water appearing to extend at a steeper angle than the part in air. However, the straw will not "bend" in the opposite direction from its insertion in ordinary materials: if you imagine a vertical line at the point where the straw enters the water, the refracted image will always be on the opposite e refraction created materials with indices as large as -3. By contrast, the current study obtained an index of refraction of about -700, a dramatically larger effect. As with normal materials, the index depended on the frequency of the light (which is how prisms split visible light into its component colors). In this case, the highest index of refraction was achieved for frequencies around 10GHz, well within the radio portion of the electromagnetic spectrum.

The authors' model to explain the phenomenon is quasi-Newtonian: the light waves accelerate the electrons, which produce a new electromagnetic wave perpendicular to the original one. In combination, these two sets of waves produce the negative refraction. This model is supported by evidence that the device works mainly at very low temperatures (approximately 4 Kelvin—4°C above absolute zero) where the electrons don't disperse, and fails at higher temperatures where thermal effects dominate.

(Arguably, the model is not purely Newtonian, since electrons in materials don't have the same properties as their free cousins: their effective masses are generally different. In fact, the charge carriers in materials like graphene may be effectively massless, even though, as the authors suggested, graphene has similar 2DEG to the metamaterial they used).

Ordinarily radio waves are hard to steer: they are not amenable to lenses (as visible light is) and focusing requires large reflectors, like the ones used in radio telescopes. Using metamaterials to focus radio waves represents a significant advance in the control of light for microscopic devices.

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