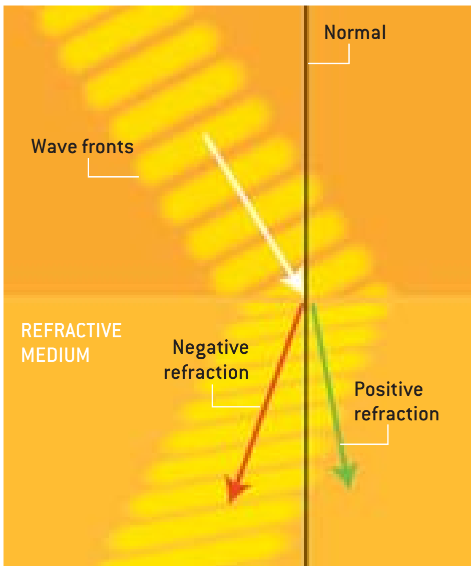
PHYSICS

Heat and Light

DOES NEGATIVE REFRACTION REALLY EXIST? BY GRAHAM P. COLLINS

Bending light through water or other media is high school science, hardly a subject that would appear to be controversial. But what happens to light in very special media that have a negative index of refraction is currently being hotly debated in leading physics journals and preprints. Ordinary materials such as glass lenses bend light so that the refracted ray is on the opposite side of the "normal," the imaginary line perpendicular to the surface of the medium. In a negative index material, also known as a left-handed material, light is refracted back on the same side of the normal. According to John Pendry of Imperial College, London, an ideal slab of such a material would act like a perfect lens, creating an image that would include details well below the stopping point for conventional lenses, called the diffraction limit. It sounds too good to be true, but for each complaint raised, proponents of negative index materials have at least a partial answer.



NEGATIVE REFRACTION bends light back to the same side of the "normal," the line perpendicular to the refractive medium. Ordinarily, light bends on the opposite side (positive refraction). Note that the modulation wave fronts in negative refraction have the same orientation expected for positive refraction.

IAN WORPOLE

The refractive index of a substance is determined by two properties known as the electrical permittivity and the magnetic permeability. In the 1960s Russian physicist Victor Veselago noted that in a material where both those quantities are negative, the refractive index will also be negative. In a negative index material (NIM), the peaks and troughs of an electromagnetic wave travel backward even though the energy of the wave continues to travel forward. This behavior leads to predictions of numerous strange phenomena, such as the reversal of the usual Doppler effect (traveling toward a wave results in a redshift instead of a blueshift).

Many materials, including plasmas and metals, have a negative permittivity, but no natural substance has a negative permeability as well. In 2001 a group led by David Smith of the University of California at San Diego demonstrated that a "metamaterial" could be built to have the requisite negative permeability and permittivity for a narrow band of microwaves. The metamaterial is made of an array of tiny copper loops and wires. The San Diego group showed that microwaves passing through a small prism of the metamaterial were refracted in the opposite direction of waves passing through a similarly shaped prism of Teflon (Teflon is to microwaves as glass is to visible light).

The negative index interpretation was soon challenged, however. Nicolas Garcia and Manuel Nieto-Vesperinas of the National Research Council of Spain in Madrid claimed that the prism was merely absorbing more microwaves at its thick end. They carried out an experiment with a thin wedge of gold and visible light to demonstrate similar results with no negative refraction. Smith counters that the gold wedge has many orders of magnitude greater absorption than his group's metamaterial and fails to reproduce the propagating refracted beam his group detects.

In a paper published last May, Prashant Valanju and his co-workers at the University of Texas at Austin disputed the basic theory of negative index materials. They pointed out that modulation wave fronts (such as those in the front of a light pulse) in a negative index material are aligned the same way as they are in a positive index material—anything else would violate basic causality and

PROBLEMS WITH PERFECT LENSES

A flat slab of a negative index material causes light from a nearby point source to converge to a focus rather than diverging. Waves with features shorter than the light's wavelength increase in amplitude inside the slab instead of attenuating. With an ideal slab, those effects would lead to perfect, sub–diffraction limit imaging but would also cause infinite energy buildup in a very thick slab—an absurdity. In a real slab, absorption losses and dispersion prevent the infinite energy buildup but might still allow superimaging. The perfect imaging occurs only at a single frequency of light—that for which the material's refractive index is exactly –1, the opposite of a vacuum. If superimaging were possible for visible light, DVDs could be made to store 100 times more data and semiconductors could be fabricated with features one tenth the size of those possible today.

require parts of the wave to travel with infinite velocity. Also, any negatively refracted wave would be rapidly smeared out in only a few wavelengths by dispersion, which Valanju maintains will always be a major problem in a negative index material.

Smith and Pendry agree that the wave fronts are aligned the way Valanju says but contend that the waves nonetheless travel in the direction of negative refraction. As for dispersion, Smith notes that NIMs are not intrinsically worse than positive index materials in that regard and that within narrow but useful bandwidths the negatively refracted waves can persist. Indeed, the U.C.S.D. team got some validation after a group at Boeing's Phantom Works, including physicist Claudio Parazzoli, repeated the prism experiment out to about 30 wavelengths—much farther than was done in the original experiment.

The question of a perfectly imaging slab remains less clear. Some papers claim that absorption and dispersion will completely spoil the effect. Others argue that although *perfect* imaging is impossible, sub–diffraction limit imaging is still feasible, provided the metamaterial meets a stringent set of conditions. Pendry's latest contribution is to suggest that slicing up the slab and alternating thin pieces of NIM with free space will greatly enhance the focusing effect and that such an arrangement will behave somewhat like a fiber-optic bundle channeling the electromagnetic waves, including the sub–diffraction limit components. Groups such as Smith's are working toward testing the superimaging effect. Judging by past form, however, even experimental results are unlikely to settle the debate quickly.

BIOPHYSICS

Shake, Waddle and Stroll

VIBRATING SHOE INSERTS FOR SURER FOOTING BY CHARLES CHOI

KEEPING BALANCED is helped by exercise—and someday perhaps by tiny vibrations underfoot.

People begin to lose their balance in their old age just as their bones get more fragile, a deadly combination that can lead to crippling or fatal falls. The elderly grow wobbly in part because their nervous systems become less sensitive to the changes in foot pressure whenever they lean one way or another. No one keeps perfect posture—everyone sways at least a little—and the brain needs the cues from the soles to stay balanced.

Foot massages could help those who have balance problems. Research led by bioengineer James J. Collins of Boston University shows that gentle stimulation of the feet helps elderly study subjects. The key is that the vibrations must be random—or, put another way, noisy. Usually, noise interferes with the main signal—think of static drowning out a television picture or attempts at conversation in a crowded room. Under the right circumstances, however, noise can actually boost weak signals. The effect is known as stochastic resonance, and it occurs in electronic circuits, global climate models and nerve cells. To see how it works, imagine a frog in a jar: by itself the amphibian might not be able to jump out, but if the jar is in a rumbling truck the frog might get the boost it needs to make it. In the same way, a faint background of random pulses could amplify weak signals sent from the feet to the brain.

The researchers built a platform with hundreds of randomly vibrating nylon rods on which volunteers stood barefoot with eyes closed and arms at their sides. When the rods were tuned so the participants said they could no longer feel their shaking, Collins and his colleagues found that the 16 senior citizens, with an average age of 72, swayed much less. In fact, they performed as well as the young volunteers, average age 23, on solid ground. When the vibrations were perceptible, no benefits were seen.

Collins's team has already developed half-inch-thick vibrating gel insoles, and when subjects stood on prototypes, they swayed even less than they did on the platform. "Within a couple of years one could have commercially viable insoles ready," Collins hopes, thereby marking the first everyday application of stochastic resonance.

Charles Choi is based in New York City.

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