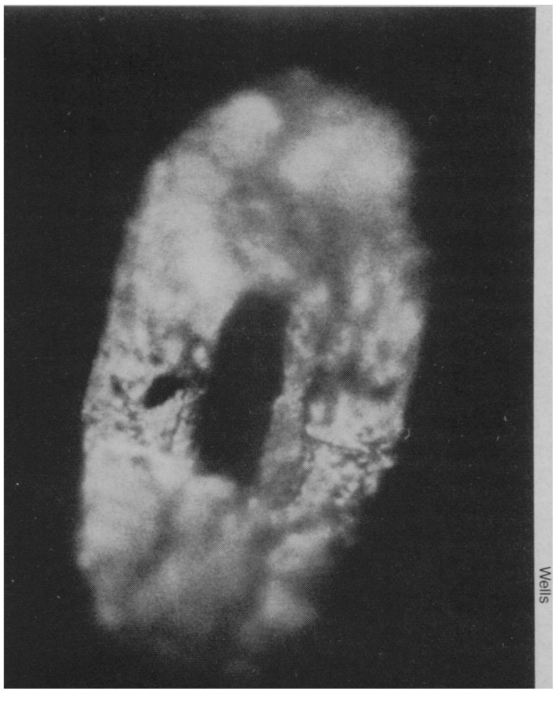
# The Natural Roots of Fiber Optics

## You needn't go far to find them

By IVAN AMATO

Optical fibers will one day thread through most household telephone systems, but they won't be the first light-pipes in your home. You're using millions of fiber-optic elements right now to read this sentence. And if your hair is gray, a recent chance observation suggests you may have thousands more optical fibers on top of your head.

Some scientists describe the retina's 130 million or so light-gathering cells — called rods and cones — as biological waveguides, or natural optical fibers. "Photoreceptors act as classical waveguides or fiber-optic elements, [comparable to those] used, for example, by telecommunication systems," write biophysicists Jay M. Enoch and Vasudevan Lakshminarayanan of the University of California, Berkeley, in *Vision and Visual Dysfunction* (in press, Macmillan, W.N. Charman, Ed.). In 1961, Enoch first reported evidence that vertebrate photoreceptor cells function as natural optical waveguides.



Wells

*Section of gray hair mounted on a microscope and illuminated from below. Light emits from regions around center.*

To guide light along a particular axis, a material has to be reasonably transparent. In addition, its index of refraction — the degree to which light passing through it bends upon exiting into a surrounding medium — must be greater than that of the surrounding medium. The glass cores of optical fibers for telephonic and other communication technologies, for instance, are denser and more refractive than the glass surrounding them. When light traveling along the core veers slightly off-center and hits the boundary between the two types of glass, it reflects inward rather than passing outward through the boundary. Thus the light remains in the core without leaking out of the fiber's sides.

It now seems rods and cones aren't the only parts of animal anatomy that pipe light around. In a two-paragraph letter published in the March 2 NATURE, John Wells of Berkeley Nuclear Laboratories in Gloucestershire, England, reported discovering that sections of his own hairs — which had begun graying about two years earlier — could shunt light along their shafts.

That short letter made Enoch wonder if Wells' observation might relate to the fiber-optic behavior of retinal photoreceptors. In an equally brief follow-up letter in the July 20 NATURE, he and Lakshminarayanan suggest an intriguing connection between the two types of natural optical fibers, citing cilia as the link.

Cilia, an 18th-century word for eyelashes, now refers most often to tiny hair-like structures that nudge substances along through internal organs, help sensory cells gather environmental signals, or "row" tiny creatures through watery environments.

Enoch and Lakshminarayanan note in their letter that "many vertebrate sensory systems incorporate cilia in their structure, including the hair cells of the cochlea [in the inner ear] . . . and the photoreceptor cells of the retina."

In an embryo, they point out, the photoreceptor-lined retina develops from surface (ectoderm) cells, some of which also form the subsurface skin layer from which body and head hair sprout. "The infolding and incorporation of surface tissue within the embryo accounts for the presence of ciliated cells within nervous tissue," they write.

Unlike retinal photoreceptors, which use modified cilia to gather and process light, hair might seem an unlikely candidate for an optical fiber. Its more obvious roles, such as conserving body heat, overshadow such seemingly farfetched functions as piping light around. Indeed, Wells wasn't expecting any revelations when he first plucked a hair from his crown, snipped it about a quarter-inch from the root, mounted the segment through a piece of cardboard and put the assembly under a microscope.

"Just out of interest, I wondered what would happen if I shined light into the [hair] specimen directly," Wells told SCIENCE NEWS. To be sure, this experiment didn't come totally out of the blue. For several years, Wells has been looking into ways of using plucked hairs as a biological radiation dosimeter. Fluorescent dyes, microscopes and various kinds of illumination — the sorts of things that could help him satisfy his curiosity — represent integral parts of his daily routine.

"I just turned on the lights underneath the [microscope] stage, rather than the fluorescence light that normally hits the specimen from above," he recalls. "Light just shot out the end of the hair."

No light came through its core, Wells says. Rather, it poured out of the region just surrounding the core but below the hair's surface layer. Very little light leaked out through the sides of the hair shaft.

Having observed the phenomenon in gray hair, Wells then tried brown hair, which contains plenty of light-absorbing pigment called melanin. Little or no light came through. Other hair colors, he says, have yet to be studied.

In his initial observations, Wells shined light into the segment of gray hair from the root and saw light coming out of the opposite end. This made him wonder whether light shining in from the other direction would end up in the root, which normally lies beneath the skin surface. It did.

"So you certainly have a way of getting white light right down to the base of the bulb of the [gray] hair, in other words to the base of the dermis in the skin," he says. And this, he speculates, could answer some medical questions.

For one, it hints at a connection between gray hair's ability to carry light and the incidence of a type of skin cancer, he says. The cells in the skin's dermal layer, where hair bulbs lie buried, sometimes become cancerous. Wells observes that the melanin in brown hair and in the scalp can deflect much of the solar ultraviolet radiation that causes this condition, known as basal cell carcinoma. Graying hair represents a reduction or disappearance of pigment, he says. So the question becomes: Does gray hair actually pipe in cancer-causing ultraviolet light to the basal layer, enabling the light to bypass the damage-deflecting mechanisms of the scalp? The question awaits investigation, he says.

That speculation, if confirmed, might be a boon to the hair dye industry. "If you have a cosmetic product that may have a medical side to it as well, in that it cuts down light transmission through hair, then it could become an even better money spinner," Wells predicts, though his letters to several cosmetic companies have so far gone unanswered.

A student visiting Wells' laboratory helped to uncover another possible example of biological fiber optics, this time in plants. The student wanted to try applying a certain fluorescent staining technique, which Wells originally developed for looking at the cells of human hair bulbs, to the hairs on plant stems. When the two illuminated the dyed plant specimen, which glowed yellow, they found that most of the light emerged from the hairs and not from the nearby cells on the stem, Wells told SCIENCE NEWS.

Though he says he is fascinated by such experiments, the pursuit of natural optical fibers falls outside the scope of his official research program. He doesn't expect to spend much more time on them, especially now that a sizable grant for his biological dosimetry work has been renewed. But he hopes his observations will spark others to investigate the phenomenon.

For Enoch, who has been studying retinal cells for decades, the idea of biological fiber optics is a logical one. "I have surmised that we've had multiple evolutions of waveguides in animal species," he says. "If you look at the hair cells of the cochlea or in the vestibular system [the balance center in the inner ear], they all are cilia modified in different ways. But the ones in the retina turn out to be lightguides in the vertebrate and also have the usual fine tubule structure of a typical hair."

Does this mean that retinal photoreceptors and head hair might be evolutionarily linked in their waveguide function? At first blush, the answer would appear negative, given Wells' speculation that gray hair's fiber-optic properties could threaten an individual's survival. But it's still too early to say whether the light-shunting is merely an incidental effect of pigment depletion, or whether a full head of waveguides might also confer some unknown benefit. That, Enoch says, is a question he'll save for a retirement project. □


Lakshminarayan/Enoch

*The outer segments of human retinal photoreceptors can guide light in a number of patterns. Shown are commonly observed waveguiding modes.*

---

Continued from p.410

are very close to a three-dimensional, anatomical model of how the fibers are laid out. We're now looking for better ways of visualizing it."

Peskin is particularly interested in the problem of reducing the fiber geometry to sets of numbers a computer can use efficiently for its calculations. Especially challenging is the additional problem of displaying a three-dimensional structure in motion while showing the fluid flow that occurs inside it.

"We can look at our results now, but at the moment the pictures are pretty crude, and we want to improve them," Peskin says. "My hope is that the tools the project is developing will turn out to be useful for this."

When sufficiently refined, Peskin's heart model could allow researchers to study how a normal or diseased heart functions and to use the simulation as a test chamber for experimental devices, such as newly designed artificial valves to regulate blood flow.

While addressing participants' specific mathematical problems, the Geometry Supercomputer Project tackles broader issues as well. "Part of our mission is to develop a graphics programming environment for mathematics," Marden says. Developing computer programs, graphics techniques and tools for other mathematicians to use means establishing compatibility standards so that researchers can readily share software and communicate results. And the search for such standards raises a host of questions concerning how best to represent and manipulate two- and three-dimensional shapes in a computer.

It also means writing computer programs that work on a variety of different machines. "We're trying to save people from having to learn the idiosyncrasies of each new device," Dobkin says.

Adds Charles Gunn, director of the project's graphics laboratory, "Part of the dream is to bring graphics tools to the people who can benefit from them. We're just beginning to see how graphics can be used and how it's going to change the way we do mathematics."

The main uncertainty at present is whether the project, now nearing the end of its second year, will continue beyond its three-year mandate. Currently funded by the National Science Foundation (NSF) with additional support from other sources, the project represents a significant drain on the funds available to mathematicians for research. Some critics grumble that NSF should distribute its scarce resources among a greater number of individual mathematicians rather than providing an expensive, flashy playground for some of the world's top geometers.

Project participants, who regard their effort as a highly successful experiment, hope to extend the project's lifetime by transforming it into an NSF science and technology center devoted to the computation and visualization of geometric structures. Their proposal calls for a budget of nearly $25 million spread over five years.

Group members also envision an important educational role for the tools they're developing. "Computer visualization offers an ideal approach to the teaching of mathematics," they state in their NSF proposal. "Not only the images, but also thinking how to produce the images, are powerful aids to understanding."

Moreover, novel graphics techniques and large-scale computation allow mathematicians to tackle problems they would otherwise find impossible to solve or even consider. "They increase the playing field in which your ideas can operate," Almgren says.

"In some sense, mathematics is the problems you look at as well as the answers you get," Taylor adds. "This approach extends the imagination and opens up many new questions." □