Is polar bear hair fiber optic?

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New direct measurement of high optical attenuation rates in polar bear hairs—2–8 dB/mm in the visible—and reanalysis of the data of Tributsch et al. [Sol. Energy Mater. 21, 219 (1990)] seem to rule out the UV waveguiding proposed by Grojean et al. [Appl. Opt. 19, 339 (1980)]. The case against fiber-optic polar bear hairs is summarized, and four conditions are given that any variation of the model of Grojean et al. would have to satisfy. © 1998 Optical Society of America

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1. Introduction

While developing a remote-sensing technique for counting harp seal (Pagophilus groenlandicus) populations, Lavigne and Øritsland found that the pelts of harp seal pups and polar bears (Ursus maritimus) reflect UV light poorly, despite their white appearance to the human eye.1,2 In trying to explain this phenomenon, Grojean et al. proposed that the UV was transmitted through the transparent hairs3 to the skin, as in an optical fiber.4 Ten years later, Tributsch et al., at the Hahn-Meitner Institute (HMI) in Berlin, found that optical transmission in a single hair dropped dramatically in the UV, and they proposed a modified model in which incident UV light induces fluorescence, which is then waveguided in the hair.5

Bohren and Sardie,6 and later, Lavigne,7 insisted that the appearance of the pelts is readily explained by absorption of UV light by hair protein. Despite this much simpler explanation, the legend of fiber-optic polar bear hairs has made its way, largely unchallenged, into the popular scientific literature,8,9 despite a complete lack of direct evidence in its support. A regional environmental museum in the United States has even advertised that, at the museum, patrons can “understand the fiber-optic quality of polar bear fur.”9

I measured the fiber-optic transmission in polar bear hairs and reanalyzed the HMI data to determine whether there is any evidence to support a theory of fiber-optic polar bear hairs.

2. Experiment

Hair from a seven-year old male polar bear was obtained from the Seneca Park Zoo in Rochester, N.Y. Light was coupled axially into individual hairs with a 0.66 NA 45° microscope objective. The coupling end of each hair was clipped with scissors to improve coupling, although the sharpness of this clipped end was not critical to coupling efficiency. My first experiment was to couple white light into the hair and observe the light transmitted axially through the hair as I cut the hair, leaving the coupling end undisturbed. For total hair lengths of 15, 10, and 7 mm, the output light was a dull orange, a brighter gold, and an even brighter yellow, respectively. This is qualitatively consistent with the HMI group’s observation of monotonically decreasing transmission for decreasing wavelengths in the visible and UV.

Next, monochromatic or nearly monochromatic light from each of four sources—a 650-nm diode laser, a green-filtered mercury lamp, a sodium lamp, and a commercial fluorescent black-light tube containing a strong 450-nm component—was coupled into a hair. Light scattered perpendicular to the hair was taken as an indirect measure of transmission along its length. A photomultiplier attached to a stereoscopic microscope measured the light gathered in a 1.5-mm-diameter field and the background was subtracted. The field of view was shifted by half-millimeter steps down the length of the hair across 3–5 mm, over which the intensity of the scattered light fell off by between 1 and 2 orders of magnitude. These measurements showed an exponential decay of 2, 3, 5, and 8 dB/mm at 650, 589, 545, and 450 nm, respectively, which is consistent with the keratin data of Bendit and Ross10 cited by Bohren and Sardie.6

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Loss at 650 nm was nearly identical for a section of hair containing a core and a section of hair containing no core, suggesting that most of the loss in the hair is a result of absorption in the shaft, not scattering in the core.

To test whether the scattered light measured in this experiment was in fact proportional to the transmitted light in the hair and that it did not simply represent unguided modes leaving the hair, I measured the transmitted intensity of 650-nm light in hair of approximately 15-mm length as I cut the output end of the hair by a 2-mm length without disturbing the coupling end. Direct transmission measurement by use of a broadband light source and spectrometer11 confirms a loss value of 2 dB/mm near 650 nm, which increases for shorter wavelengths.

These measured losses, if sustained throughout the hair, would result in a loss of over 10 orders of magnitude throughout the visible spectrum for a typical 10-cm hair and over 100 orders of magnitude in the UV.

3. Data Analysis

The HMI group measured the transmission of light through polar bear hair for three different geometries: (a) transverse transmission, in which light is incident transverse to each hair in a tuft of hair and transmitted light is gathered by an integrating sphere; (b) reflection, in which light is incident transverse to each hair in a tuft and scattered light is gathered by an integrating sphere; and (c) axial transmission (fiber-optic coupling), in which light is coupled axially into the outer shaft of a single hair and light transmitted along a length of that hair is measured. The HMI group compared these data and the scattering by a polar bear pelt, reported by Grojean et al.,4 as shown in Fig. 1.

The HMI group normalized each set of data to 100% at 700 nm, apparently by multiplying each set by some constant. As can be seen in Fig. 1, this causes the three sets of data in which incident light is perpendicular to the axis of the hair (the three black curves) to fall nearly on the same line, with lower short-wavelength attenuation than when light is launched axially (fiber-optic coupling, gray curve). However, because the optical path for fiber-optic coupling is probably longer than for the other curves—the authors do not report the length of these samples—this is a misleading comparison. If the source of attenuation were the same for all curves, loss per length would be equivalent, even if transmission were not. Loss is calculated as

$$\text{loss} = -10 \log(I/I_0),$$

where the loss is measured in decibels, $I_0$ is the intensity of the incident light, and $I$ is the transmitted light.

I calculated loss from the data in Fig. 1 after renormalizing each set of data. I used the original reflection data from Ref. 4, before they were normalized by the HMI group. I renormalized the other curves by choosing a transmission at 700 nm that was consistent with the loss per length curves that were most nearly identical. The results, plotted in Fig. 2, show that one can interpret the data as showing loss to be independent of the direction of the propagation of light. I compared the fiber-optic coupling data with the data of both this paper and that of Bendit and Ross10 by converting loss per length to loss in a 2.3-mm hair, a length that gives good agreement among the various sets of data. This allows us finally to fix the magnitude of the attenuation that the HMI group reports as being of the order of 10 dB/mm and more in the UV, or over 20 orders of magnitude for a typical 2-cm hair.

4. Summary

The experimental data of this research and the reanalysis of the HMI data5 show that light launched fiber optically into a single polar bear hair suffers loss of several decibels per millimeter, which increases as one goes from the red to the violet portion of the
spectrum. Although neither set of data extends into the UV, for which Grojean et al. invoked fiber optics to explain the low reflectance of polar bear pelts, both sets of data clearly show that fiber optics cannot explain the decrease in pelt reflectances (80% near 600 nm to 50% at 450 nm) from the red to the violet, which then continues smoothly into the UV. Nevertheless, it might be possible to modify Grojean et al.’s fiber-optic hypothesis to bring it into compliance with the experimental evidence. However, such a theory would have to satisfy the following criteria:

1. Such a theory would have to explain how light can survive a trip down the hair despite losses of over 2 dB/mm in the visible and approximately 10 dB/mm in the UV—over 20 orders of magnitude for an average length of hair—apparently as a result of absorption in the outer shaft of the hair.

2. If such a theory avoids these large attenuations by proposing fiber-optic transmission in the infrared, the waveguided portion of the spectrum would account for no more than 20% of the incident light—the fraction of light absorbed by polar bear pelts at wavelengths above approximately 700 nm—and require losses over 10 orders of magnitude lower than those in the visible.

3. If such large attenuations could be avoided by proposing waveguiding in the inner core of the hair, the theory would have to explain how such a medium, in which dandrufflike material of approximately 1.56 refractive index alternates with air on length scales of approximately 30 μm (Ref. 4), could be much less lossy than 1 dB/mm.

4. If such large attenuations could be avoided by invoking fluorescence, such a theory would have to explain how the mostly blue and violet fluorescence could travel any more freely down the shaft than incident light of the same wavelength.

The theory of fiber-optic polar bear hair is an attractive theory. It is often seen as explaining and connecting a wide collection of facts about the polar bear—the pelt’s low UV reflection, the skin’s blackness, the hair’s transparency in the visible, even the bear’s ability to maintain its body temperature in a harsh climate. However, there is no direct evidence to support this theory. The low UV reflection of the pelt—the reason for which the theory was first invoked—is more simply explained by a mechanism for which there is ample direct evidence: absorption by the hairs.

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