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RADIATIVE PROPERTIES OF POLAR BEAR HAIR

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INTRODUCTION

The polar bear's ability to survive in the harsh arctic night fascinates scientific and lay audiences alike, giving rise to anecdotal and semi-factual stories on the radiative properties of the bear's fur which permeate the popular literature, television programs, and textbooks [1-5]. One of the most interesting radiative properties of polar bear fur is that it is invisible in the infrared region. Some theories have attempted to explain this by claiming that the outer temperature of the fur is the same as that of the environment. However, this explanation is unsatisfactory because surface radiation depends on both the surface temperature *and* the surface radiative properties [6].

Although an extensive literature search revealed that most arctic fauna have highly emissive fur [7], a study on polar bears has never been conducted. In addition to this, the majority of previous research has focused on the bulk radiative properties of arctic animal fur in the ultraviolet range. Since most animal radiative heat loss occurs in the infrared range, we feel research in this area will yield useful insights into applications concerned with the effects of radiative heat loss.

METHODS

To provide an explanation of the polar bear's invisibility in the infrared, we examined the radiative properties of individual polar bear hairs donated by the San Francisco Zoological Society. The Advanced Light Source [8] synchroton infrared spectromicroscopy beamline was utilized to provide a continuous spectrum of light at a diffraction limited focused spot size of less than 10 microns. Using this facility, we designed an experimental technique to study the microscale radiative properties of biological materials (e.g. single strands of hair).

The radial radiative reflectance and transmittance properties of polar bear hairs were measured using the scanning Fourier transform infrared (FTIR) microscope available at Beamline 1.4.3 at the ALS. The reflection measurements were made using a gold slide. A 10 micron IR spot was focused at approximately the hair centerline, and a point scan (average of 32 scans taken by the computerized system) was taken at that location. The results of the reflectance versus wave number were then plotted. These reflectance values were then compared to a background scan of the gold slide and adjusted to show the percent reflection values versus wave numbers. (Therefore, the percent values are solely a function of the hair, as opposed to the hair and the slide.) Transmission measurements were made using a similar method, except that the single strands were mounted across an open aperture. In this case, the spectrum of light that exited at the bottom of the hair was collected and analyzed.

Once the percent transmissivity versus wave number plots were prepared it was possible to isolate the percent transmissivity value for an individual wavelength. In this instance, 10 microns (or 1000 wavenumbers) was chosen because this is the wavelength where blackbody radiation is the highest for mammals. Beer's law [9], seen in equation 1, was used to determine the absorptivity at 10 microns.

$$\alpha_\lambda = 1 - \tau_\lambda \tag{1}$$

Here α_λ is the absorptivity at a given wavelength and τ_λ is the transmissivity at the corresponding wavelength. From Kirchoff's law [9], the absorptivity at a specific wavelength, α_λ , is equal to the corresponding emissivity, ε_λ.

RESULTS AND DISCUSSION

The results show a measurable transmittance that can be utilized in conjunction with reflectance experiments to ultimately determine the emissivity of the hair using Beer's law. The plots generated from the experiments confirm that the values of the percent transmissivity and reflectivity drop significantly in the infrared range of light. We compared the polar bear data with data from a human hair similar in appearance and thickness, using white hairs from (BR). Figure 1 compares the transmission in the 8,500 to 650 cm^{-1} (1.1 to 15 micron) range (near infrared through mid-infrared) of two typical bear and human hairs of similar thickness. The reflectivity results (not shown) are quite low, implying that the large drops in transmissivity observed in Figure 1 are due to strong absorption. (The absorptive features centered near 3400 cm^{-1} (2.9 microns) and beyond 1650 cm^{-1} (6

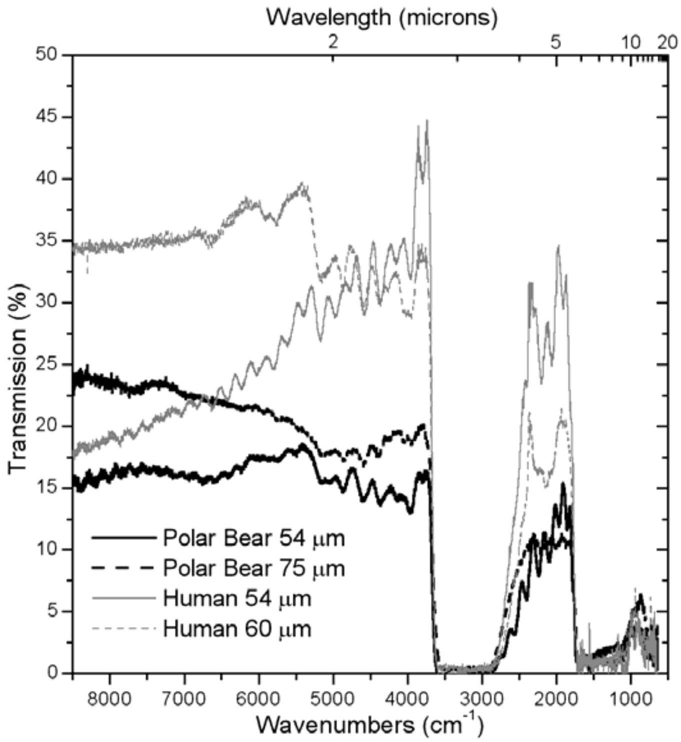

Figure 1. Percent Transmissivity Values versus Wavenumbers for Two Polar Bear Hairs and Human Hairs of Similar Thickness.

microns) are the signature of water in the hair, and are not responsible for absorption in the considered region.)

From the transmission and reflection at 10 microns, we calculated that polar bear hair and human hair have average absorptivities of 0.95 ± 0.03 and 0.91 ± 0.05 respectively. The high absorptivity of both bear and human hair in this wavelength range is significant because fur, made up of many hairs with this property, will act as a radiatively participating media, almost completely eliminating the radiative losses from a mammalian body in cold environments [6]. We are fascinated that evolution has resulted in the presence of such an excellent infrared absorber in the coverings of mammals, thus ensuring not only insulation, but also high absorptivity exactly for those wavelengths where it would yield the greatest survival value. The mammalian blackbody radiation peaks near 1000 cm^{-1} (10 microns) and the high absorptivity in this region minimizes radiative losses during a cold night for any living mammal, polar bear and hominid alike.

From Kirchoff's law we know that the emissivity of the bear fur is equal to its absorptivity, which at about 0.95 is almost identical to that of the surrounding snow, 0.96 [6,10]. This is why if the outer temperature of the bear fur is close to that of the surrounding ice and snow, the bear becomes invisible in the infrared.

CONCLUSION

Results from reflectivity and transmissivity measurements in combination with Kirchoff's law and Beer's law show that the absorptivity of polar bear hair is approximately the same as the surrounding snow. Therefore, if the outer temperature of the bear fur is close to that of the surrounding ice and snow, the bear becomes invisible in the infrared. We predict that if surveyors were to shine a beam in the near infrared, between 10,000 and 5,000 cm^{-1} (1and 2 microns), they would see polar bears in the Arctic night.

REFERENCES

1. Lavigne, D.M., 1974, "Black Polar Bears," Nature, 251, pp.218-219.
2. Grojean, R.E., Sousa, J.A., Henry, M.C., 1980, "Utilization of Solar Radiation by Polar Animals: An Optical Model for Pelts," Applied Optics, 19, n3, pp. 339-346.
3. Koon, Daniel W., 1998, "Is Polar Bear Hair Fiber Optic?" Applied Optics, 37, n15, pp. 3198-3200.
4. Rozell, Ned, 1998, "Debunking the Myth of the Polar Bear Hair," Alaska Science Forum, http://www.gi.alaska.edu/ScienceForum /ASF13/1390.html
5. Harding, Robert, 1998, "Power of the Polar Myth," New Scientist, pp.50.
6. Siegel, R., Howell, J.R., 1992, Thermal Radiation Heat Transfer, 3rd Ed., Hemisphere Publishing Corp., Washington.
7. Russel, J.E., Tumlinson, R., 1996, "Comparison of microstructure of white winter fur and brown summer fur of some arctic animals," Arca Zoologica, 77, n4, pp.279-282.
8. The Advanced Light Source is supported by the Director, Office of Science, Office of Basic Energy Sciences, Materials Sciences Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 at Lawrence Berkeley National Laboratory.
9. Incropera, F.P., DeWitt, D.P., 1996, Fundamentals of Heat and Mass Transfer, 4th Ed., John Wiley & Sons, Inc.
10. Gubareff, G.G., Janssen, J.E. and Torborg, R.H., 1960, Thermal Radiation Properties Survey, 2nd Ed., Honeywell Research Center, Minneapolis, Minnesota pp.241.