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Comparison of the Photo-thermal Energy Conversion Behavior of Polar Bear Hair and Wool of Sheep

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Abstract

The unique photo-thermal energy conversion property of polar bear hairs has long been regarded as an essential element to enable this creature to survive in extremely cold conditions. However, the relevant research was ineffectual to provide sufficient evidence of its solar energy harvesting property. In this paper, the properties of polar bear hairs were analyzed and compared systematically with those of domestic sheep wool through the measurements in the aspects of photo-thermal conversion efficiency, scanning electron microscope, fluorescence spectral and transmission of UV-visible spectra. Moreover, this study was much more focused on exploring ultraviolet utilization property of polar bear hair than previous research. The research results demonstrated that the photo-thermal property of polar bear hair was superior to those of wool fiber, especially in harvesting ultraviolet part. The potential benefits of this research lie in the development of bionic solar energy collective devices, especially in artificial solar energy collection fibers and textile products.

Keywords: photo-thermal conversion efficiency, polar bear hair, sheep wool fiber, ultraviolet utilization, fluorescence spectra

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1 Introduction

In recent years, the boom of bionics has extremely increased the research attention to some special functions of wild animals in nature[1–5]. As the polar bear (*Ursus maritimus*) survives in hostile polar environments, where the temperature can be as low as −50 ˚C, it has attracted a lot of attention in the science and general media for decades[6–10]. Øritsland and Ronald[11] were the first researchers who discovered some special properties of the pelt of polar bears, such as the strong absorption ability of UV light. A number of other characteristics of polar bear hair have also been detected that the hair has a high hollow structure, the skin has a 7 cm – 11 cm thick subcutaneous layer of blubber, and the pelt retains heat so effectively that it is virtually invisible to infrared photography[12]. Nevertheless, several controversies about the properties of polar bear hair in relation light guiding and thermal protection remain unsolved[13].

Polar bear fur appears white and is composed of two layers: an outer layer of 5 cm – 15 cm long, tubular, air-filled, pigment-free transparent guard hairs and a softer layer of white down. The long transparent hollow guard hairs are responsible for gathering heat, by allowing the ultraviolet rays of sunlight to be captured by the air in the hollow hair shaft and then to be transported to the bear’s skin in the same way that warm water flows through a pipe; a process likened to fiber optics. Grojean *et al*.[14,15] hypothesized that the transported sunlight is converted into heat by the black skin, and so the animal is warmed. The reason why the bear becomes invisible in the infrared region is because the outer temperature of the bear fur is close to that of the surrounding ice and snow; it has been shown that the emissivity of polar bear fur is equal to its absorptivity[16]. Nevertheless, some research suggested that the special sunlight environment in the Arctic does not support the above ‘fiber-optic’ theory[17]. Because of the existence of the polar day and polar night, sunlight is absent when polar bears need to convert it to heat, while it is sufficient when it is not essential. In addition, polar bear hair is perhaps not unique, based on the almost identical appearance of polar bear hair comparing with that of other mammals. It

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was speculated that the polar bear's own internal metabolism is regarded as the primary heat producing mechanism, while hairs just help to keep the bear from losing heat rather than gathering heat. Therefore, the photo-thermal energy conversion property of polar bear hairs is essential to be researched systematically and compared with that of representative mammals' hairs. The sheep wool should be the most typical and common protein fiber, as its research has a rather long history[18–20]. Moreover, to the best of our knowledge, no literature has been reported regarding the direct photo-thermal energy measurement and analysis to compare these two kinds of fibers.

In this paper, the photo-thermal energy conversion properties of polar bear hair and sheep wool were measured and analyzed by a series of experiments. It was demonstrated that polar bear hairs could behave more efficiently in guiding and converting sunlight energy into thermal energy than sheep wool. Analysis and comparison of the differences in the structures and properties of polar bear hair and sheep wool not only have benefits in understanding the superiority of polar bear hair deeply, but also contribute largely to improve the properties of sheep wool in textile treatments. It should also be noted that potential benefits of this research lie in the development of bionic solar collective devices, especially in photo-thermal energy conversion textiles products.

2 Materials and methods

2.1 Hair samples

Dorsal hair samples of a polar bear (*Ursus maritimus*), age about 3 years, were obtained from the Polar Museum in Fushun, China. According to the breeder, main of the samples were picked from its backside. They were cleaned with distilled water, but not treated with any organic solvents. The sheep wool (*Ovis aries*) samples pulled from the same body part of sheep were treated in the same way. Only healthy hairs were included in the studies, as there is the evidence that fungal attack can affect their optical properties[21]. The average length of both species was 6 cm, and their diameters were approximately 10 µm – 60 µm.

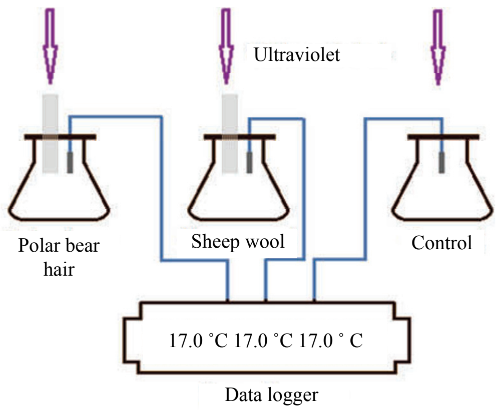

Fig. 1 The measure of photo-thermal conversion efficiency.

2.2 Photo-thermal energy conversion efficiency studies

Numerous papers indicated that polar bear hairs have special absorption properties of ultraviolet rays[22]. This experiment was aimed to test and verify the veracity of these reports. Three hundred fibers of polar bear hair and sheep wool were tied in bunches and placed into two sealed flasks, with half the fiber length inside and half outside the flask. A similar empty sealed flask was set up as a control (Fig. 1). Three thermal sensors linked to a data logger were also inserted into the flasks. After exposure to UV light irradiation (wavelength 290 nm – 400 nm) for five hours, temperature inside the flasks was recorded as a measure of the ability of polar bear hair and sheep wool to absorb ultraviolet radiation and convert it into heat. Furthermore, five more groups of repeated trials were conducted to confirm the universality and authenticity of the experiments.

2.3 Morphological structure

The morphological structures of the cross section of polar bear hair and sheep wool were examined by Scanning Electron Microscopy (SEM) (JEOL JSM-6700F SEM, Japan) and compared.

2.4 Fluorescence spectra

The different fluorescence properties of these two hair samples were measured by fluorescence spectrometer. In this experiment, the wavelength of exaction light was set as 450 nm, while the wavelength of emission light was 380 nm.

Stokes shift is a purely molecular affect as absorbed photons are emitted at lower energy, causing a spectral shift to higher wavelengths[23]. This phenomenon is presented by the wave number difference between the maximum absorption peak position and maximum emission peak position. Tributschet *et al*.[21] obtained the