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THE EPHEMERAL BLUISH NECKLACE OF THE CERULEAN WARBLER

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According to Roger Tory Peterson the male Cerulean Warbler (*Dendroica cerulea*) usually forages so high that the "narrow black ring crossing the upper breast is the best mark" for identification of the species (Peterson 1947). Earlier, Chapman recorded the color of the breast band as bluish black (Chapman 1896); more recent publications describe it as dusky or bluish (Stevenson 1960) and black (Dunn and Garrett 1997). The streaking along this warbler's sides similarly has been described as being bluish or black.

I photographed the same individual in different postures at St. George Island, Franklin County, Florida on 17 April 1999, and the photos reveal a black pectoral band when it is partly in the bird's shadow, but a bluish black band when the bird is perched in a more upright position Figure 1.

I examined six male Cerulean Warbler specimens at Tall Timbers Research Station, Tallahassee, Florida using a Leica 10-X zoom dissecting microscope with a lateral overhead "Daylight" source. Individual pectoral band contour feathers were one centimeter in length and occupied several rows. Each feather had a white rachis. The barbs were mostly black with white tips and the accompanying barbules had similar color distribu-

Figure 1. Male Cerulean Warbler photographed on St. George Island, Franklin County, Florida, 17 April 1999. The slender, but prominent, breast band when viewed from this angle appeared to be bluish black.

Figure 2. Sketch using a Leica 10-X dissecting microscope of a pectoral band contour feather (right side only) of a male Cerulean Warbler, revealing tip and base composed of white barbs and barbules, while intermediate barbs and barbules are black.

tion (Fig. 2). When these white tips closely overlapped the black portions of underlying pectoral band contour feathers, the white tips glowed with a blue-gray color when subjected to light. In bright sunshine the band appeared black when the specimens were held with the breast held horizontally (facing downward) and bluish when the specimens were held with the breast held vertically (tail down, similar to the bird in Fig. 1).

Colored light wavelengths are measured peak to peak (as in ocean waves) and blue waves are the shortest at 0.45 microns (Greenewalt 1960). According to Prum et al. (2003) the "colors of avian plumage are produced by chemical pigments, or by nanometer-scale biological structures that differentially scatter, or reflect wavelengths of light." The spongy medullary layer of feather barbs is composed of a matrix of keratin (protein) rods and air vacuoles of varying shapes and sizes (Prum et al. 1999). The barbules of hummingbird gorgets contain complex well-ordered matrices of thin keratin layers called "films" which encase tiny air bubbles (Greenewalt 1960). In both cases a myriad of keratin-air interfaces are present which produce structural colors by refraction (bending) and reflectance. Constructive interference occurs when two light waves of the same color reflect off keratin-air interfaces in close approximation and unite in phase (coinciding peaks) thus doubling the intensity of the color (Greenewalt 1960). In Greenewalt's stacked barbule "films" the number of rebounding in-phase united waves is increased sufficiently to produce the brilliance of iridescence with its unique ability to change hue with the angle of observation. When Greenewalt was studying the phenomena, iridescence was thought to be synonymous with coherent scattering, or interference (Prum and Torres 2003).

Until recently the blue plumage of most birds was thought to be related to Tyndall or Rayleigh random (incoherent) scattering of blue light waves from small particles (slightly larger than blue waves) in the barbs and this phenomenon was also thought to be responsible for the blue color of the sky (Welty 1975). Prum et al. (1999) used two-dimensional Fourier analysis to demonstrate that structural colors of feather barbs are "produced by constructive interference of coherently scattered light waves from the optically heterogeneous matrix of keratin and air in the spongy medullary layer." Thus, both iridescent and non-iridescent structural colors can be produced by coherent scattering (Prum and Torres 2003).

The blue color of the Cerulean Warbler results from constructive interference and is structural in nature. The blue-gray glow of the pectoral band appears to be localized to the white tips of the black barbs in the band and is dependent on direct incident light. It does not change hue with the angle of observation. The white tips may act as a vehicle to illuminate blue waves reflected off underlying black barbs. Nevertheless, apart from the white tips, the pectoral band is actually black.

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