APPARATUS AND DEMONSTRATION NOTES

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A low-cost polarimeter for an undergraduate laboratory to study the polarization pattern of skylight

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A simple, low-cost, fully automated polarimeter, which demonstrates fundamental properties of skylight scattering and polarization for undergraduate physics students, is described. The polarimeter includes a microprocessor-based control unit, a Sun tracker, an elevation-azimuth mount with two degrees of freedom, and a polarization sensor unit equipped with a light-dependent resistor for measuring light intensity. Results obtained in the principal plane of the Sun using the polarimeter on a relatively clear day, together with the theoretically expected results for a molecular atmosphere, are presented. A root-mean-square error comparison indicates fairly good agreement between theory and experiment. Construction and experimentation with the polarimeter will provide students with insight into important physical concepts involved in skylight scattering and polarization as well as improve their instrumentation capabilities.
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I. INTRODUCTION

Polarization of light is an important fundamental undergraduate-physics concept that is useful in understanding various natural phenomena and applications.[1] For example, some insects utilize polarized light for navigation, and the polarization pattern of skylight is employed in atmospheric optics techniques.[2–8] In order to consolidate their understanding of polarization effects, students need to possess a good understanding of the underlying principles as well as acquire hands-on experience. Although the former objective can be achieved through theory courses in optics, students do not generally get an opportunity to verify polarization theory experimentally as the polarimeters employed for such purposes are rather expensive. This paper describes a low-cost polarimeter, designed for the above-described educational purpose. This polarimeter is appropriate for an undergraduate student's senior-year project and can be employed to demonstrate most of the fundamental properties of the polarization pattern of skylight.

For over two centuries, experimental investigations on the polarization of skylight have been carried out by various scientists, including Rayleigh, Brewster, and Babinet.[2,6] Initially, visual polarimeters equipped with dichroic polarizers were employed to investigate the polarization pattern of skylight. With advances in physics and electronics, visual polarimeters were replaced by units with photomultiplier and electronic detectors, which have the advantage of giving quantitative data with a higher accuracy.[6,9–11] All of these early polarimeters were used to scan the sky, particularly concentrating on the *principal plane* of the Sun, which is the vertical plane at the observation site that passes through the Sun.[12] Present-day studies on skylight polarization are carried out using full-sky imaging video polarimeters equipped with digital sensors and fish-eye lenses, which can take a picture of the whole sky at any given instant. The resulting recorded data can be analyzed using image processing techniques to find the polarization pattern of the entire sky hemisphere.[5,13] These state-of-the-art polarimeters have the advantage of obtaining a snapshot of the entire sky in a single image so that the variation of the solar position with time does not affect the conclusions drawn using these data. In contrast, data obtained using the previously employed method of scanning the sky are acquired over (at least) a few minutes, during which time the Sun's position changes. However, given the high cost of state-of-the-art polarimeters,