APPARATUS AND DEMONSTRATION NOTES

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This department welcomes brief communications reporting new demonstrations, laboratory equipment, techniques, or materials of interest to teachers of physics. Notes on new applications of older apparatus, measurements supplementing data supplied by manufacturers, information which, while not new, is not generally known, procurement information, and news about apparatus under development may be suitable for publication in this section. Neither the *American Journal of Physics* nor the Editors assume responsibility for the correctness of the information presented. Submit materials to James L. Hunt, *Editor.*

Microwave demonstration of the spatial shift due to the evanescent wave

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Optical systems have been increasing in importance for information processing. They have rapidly decreased in size and we now have optical waveguides, integrated optics, and fiber-optic communication systems. For these systems, total internal reflection is widely used to control the light path. The number of reflections may be very large so it becomes necessary to understand carefully what happens to the amplitude and phase of the light beam at each reflection. These effects can often be best demonstrated in the microwave part of the spectrum. Our apparatus quickly and easily allows the demonstration and measurement of one of these effects.

As shown in Fig. 1, when a bounded light beam experiences total internal reflection a sideways displacement of the beam results due to the evanescent wave. This displacement is known as the Goos–Haenchen shift, first experimentally demonstrated by Goos and Haenchen[1] in 1947.

The Goos–Haenchen shift is quite small, usually of the order of a fraction of the wavelength of the radiation used. Using visible light, multiple reflections (number of reflections > 100) are needed to demonstrate the effect. Using X-band microwave with 3-cm wavelength, the Goos–Haenchen shift can be easily demonstrated with a single reflection only.

Figure 2 shows a typical experimental arrangement in which polarized microwaves are fed into a 45°–90°–45° prism made of low-loss plastic with index of refraction of 1.6 at the X-band microwaves. The incident angle ϕ of 45° which is larger than the critical angle ϕ_c of 38.6° assures the valid condition of total reflection. A metal sheet is first placed against the base of the prism and the reflected waves are received by a microwave detector. In this case no Goos–Haenchen shift is expected because the microwaves are reflected from a solid metal surface rather than a dielectric interface. Then the metal plate is removed and the shift is measured. Both the microwave source and detector are placed on elevated stands with rotating supports to reduce reflection from the table top and to study the shift dependence on the state of polarizations.

Almost all physics laboratories have available a suitable klystron source and detector with attached microwave horns; ours were obtained from Sargent–Welch Scientific Company (Catalog Numbers 2643A and 2643B). The plastic prism is part of the Klinger Blackboard Optics set.

The old klystron microwave sources work well for this experiment, but the modern solid-state Gunn diode transmitters and Schottky diode receivers are more reliable and do not need a warmup time. For more precise work, a Digital multimeter may be used with the receiver instead of its analog meter. These microwave optics systems are available from Pasco Scientific (Catalog No. WA-9314) and Daedalon Corporation (Catalog Nos. EG-20 and EG-22) as well as others.

The Goos–Haenchen shift has been found important in the theory of optical waveguides,[2] integrated optics,[3,4] and fiber-optic communications.[5,6] It is felt that this experi-

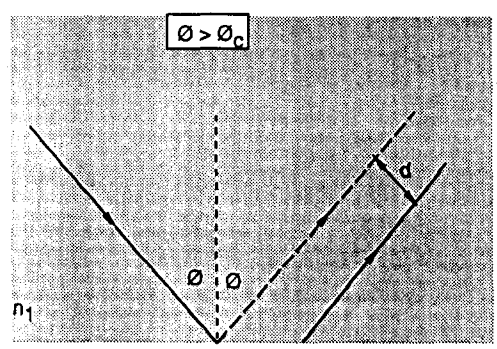

Fig. 1. The Goos–Haenchen effect.

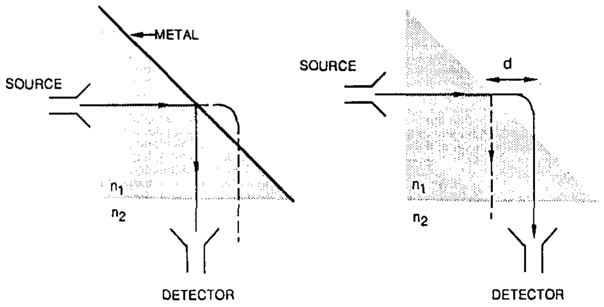

Fig. 2. The experimental arrangement to measure the Goos–Haenchen shift.

ment would be a valuable addition to most science and engineering curricula.

[1]F. Goos and H. Haenchen, "Ein neuer und fundamentaler Versuch zur Totalreflexion," Ann. Phys. **1**, 333–336 (1947).
[2]M. Adams, *An Introduction to Optical Waveguides* (Wiley, New York, 1981), p. 16.
[3]*Integrated Optics*, edited by T. Tamir (Springer-Verlag, Berlin, 1979).
[4]D. Lee, *Electromagnetic Principles of Integrated Optics* (Wiley, New York, 1986), p. 66.
[5]J. Midwinter, *Optical Fibers for Transmission* (Wiley, New York, 1979), p. 33.
[6]S. Zhu, A. Yu. D. Hawley, and R. Roy "Frustrated total internal reflection: A demonstration and review," Am. J. Phys. **54**, 601–607 (1986).

KELVIN ON THE IMPORTANCE OF MEASUREMENT

I often say that when you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *science*, whatever the matter may be.

Lord Kelvin (William Thomson), from Electrical Units of Measurement, A Lecture delivered at the Institution of Civil Engineers on May 3, 1883; being one of a series of Six Lectures on "The Practical Applications of Electricity." Reprinted in Sir William Thomson, *Popular Lectures and Addresses* (MacMillan, London, 1889), Vol. I.

AND A REJOINDER BY JACOB VINER

When you *can* measure it, when you can express it in numbers, your knowledge is *still* of a meagre and unsatisfactory kind.

Attributed to Princeton economist Jacob Viner. See Robert K. Merton, David L. Sills, and Stephen M. Stigler, "The Kelvin Dictum and Social Science: An Excursion into the History of an Idea," Hist. Behav. Sci. **20**, 319–331 (1984).