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A Fixture to Measure Optical Transmission of Hemispheric Domes

by

Richard A. Hollins

Linda F. Johnson

Mark Moran

Lee Cambrea

Daniel C. Harris

Research and Intelligence Department

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NAVAL AIR WARFARE CENTER WEAPONS DIVISION
CHINA LAKE, CA 93555-6100

Naval Air Warfare Center Weapons Division

FOREWORD

This report describes the construction and use of a fixture to hold a dome for measurements at different locations and different angles of incidence. Meaningful measurements of dome transmission were made with ultraviolet-visible-near infrared spectrophotometer equipped with an integrating sphere to collect refracted radiation. This work was conducted under the auspices of the U.S. Navy. This report was reviewed for technical accuracy by Robert Seaver.

Approved by
R. NISSAN, *Head*
Research and Intelligence Department

Under authority of
MARK STORCH
CAPT, U.S. Navy
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14. ABSTRACT

(U) This report describes the construction and use of a fixture to hold a dome for measurements at different locations and different angles of incidence. Meaningful measurements of dome transmission were made with ultraviolet-visible-near infrared spectrophotometer equipped with an integrating sphere to collect refracted radiation. This work was conducted under the auspices of the U.S. Navy. This report was reviewed for technical accuracy by Robert Seaver.

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1. INTRODUCTION

Transparent hemispheric domes are commonly used as protective coverings for optical sensors on missiles. Transmission specifications for a dome typically state the minimum required optical transmission at a particular wavelength or transmission averaged over a range of wavelengths. Usually, the transmission requirement applies to the entire clear aperture of the dome for a specified range of angles of incidence. Domes are often coated with an anti-reflection coating designed for specific wavelength ranges and angles of incidence.

It is not routine or trivial to verify that a dome meets its optical transmission requirements because (1) radiation refracted from the curved surface of the dome does not necessarily reach the detector of a spectrophotometer, (2) many spectrophotometers do not have a large enough sample compartment to accommodate a dome, and (3) commercial fixtures to orient a dome in a spectrophotometer are not available. For these reasons, the transmission of small, flat witness samples coated at the same time in the same chamber with the dome is often taken as a surrogate for measuring dome transmission.

This publication describes the construction and use of a fixture to hold a dome for measurements at different locations and different angles of incidence. Meaningful measurements of dome transmission were made with an ultraviolet-visible-near infrared spectrophotometer equipped with an integrating sphere to collect refracted radiation. Similar results were obtained with a Fourier transform infrared spectrophotometer designed for transmission accuracy.

2. GEOMETRY OF DOME MEASUREMENTS

The dome to be measured had an outside spherical diameter of 178.00 mm and was truncated to a base diameter of 152.40 mm (Figure 1). It was desired to measure the transmission of the dome at the apex and at several other locations with angles of incidence of 0, 21, and 50 degrees from normal.

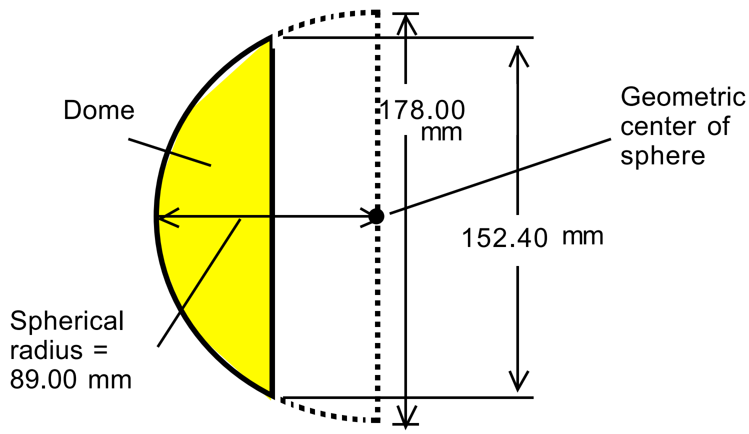


FIGURE 1. Dome Geometry.

The angle of incidence is measured from the normal to the surface. Figure 2 shows a 30 degree angle of incidence at the dome apex point A. Other points chosen for measurements were B and C, located 20 and 40 degrees from the axis of the dome. Figure 3 shows points A, B, and C viewed from the front of the dome. A fourth measurement location was point C, which is also 40 degrees away from the axis of the dome, but it is located in a different quadrant from A, B, and C when the dome is viewed from the front.

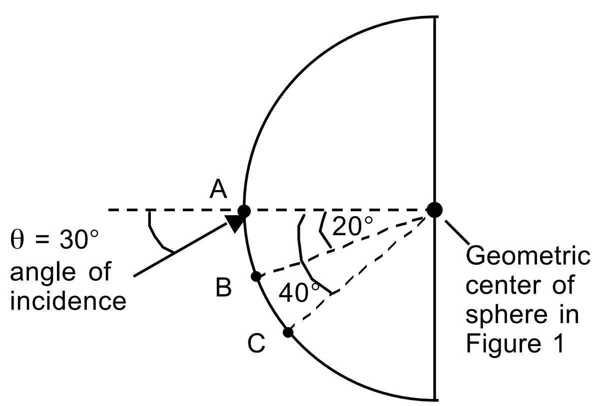


FIGURE 2. Definition of Angle of Incidence.

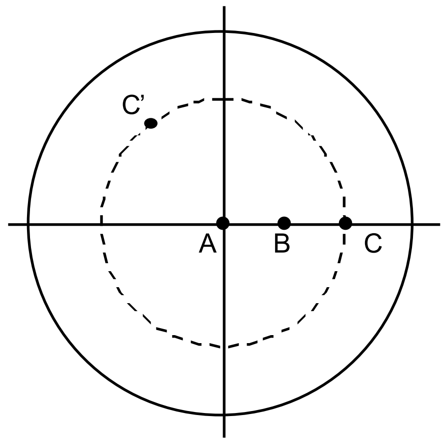


FIGURE 3. Measurement Locations.

Figure 4 shows one way to achieve an angle of incidence θ at the apex with a horizontal incident beam of light. The dome is rotated about an axis through its *geometric cente*r (not through the center of the base of the truncated dome), through angle θ, and then translated (raised) by $\Delta h = r \sin \theta$, where r is the spherical radius of the dome. Figures 5-7 show how angles of incidence of 0, 21, and 50 degrees can be achieved at points A, B, and C by rotation and translation of the dome.

NOTE
θ is the angle of incidence. ϕ is the angle of rotation of the dome about an axis through its geometric center. Δh is the height to which the dome is raised, so that the beam strikes the desired point on the dome.

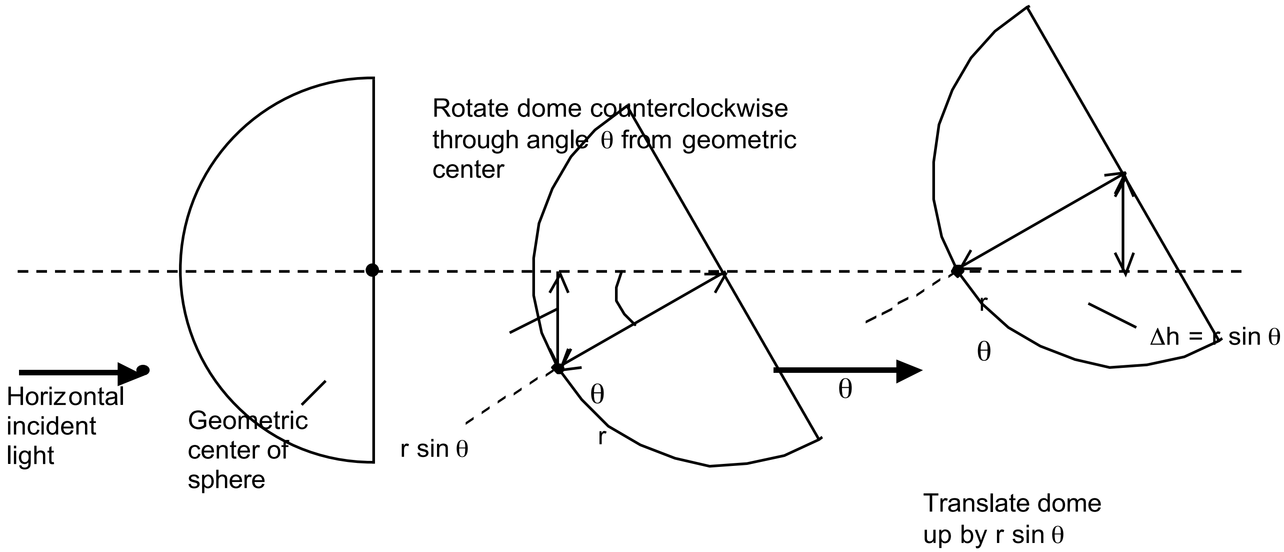


FIGURE 4. Achieving Angle of Incidence θ at Apex.

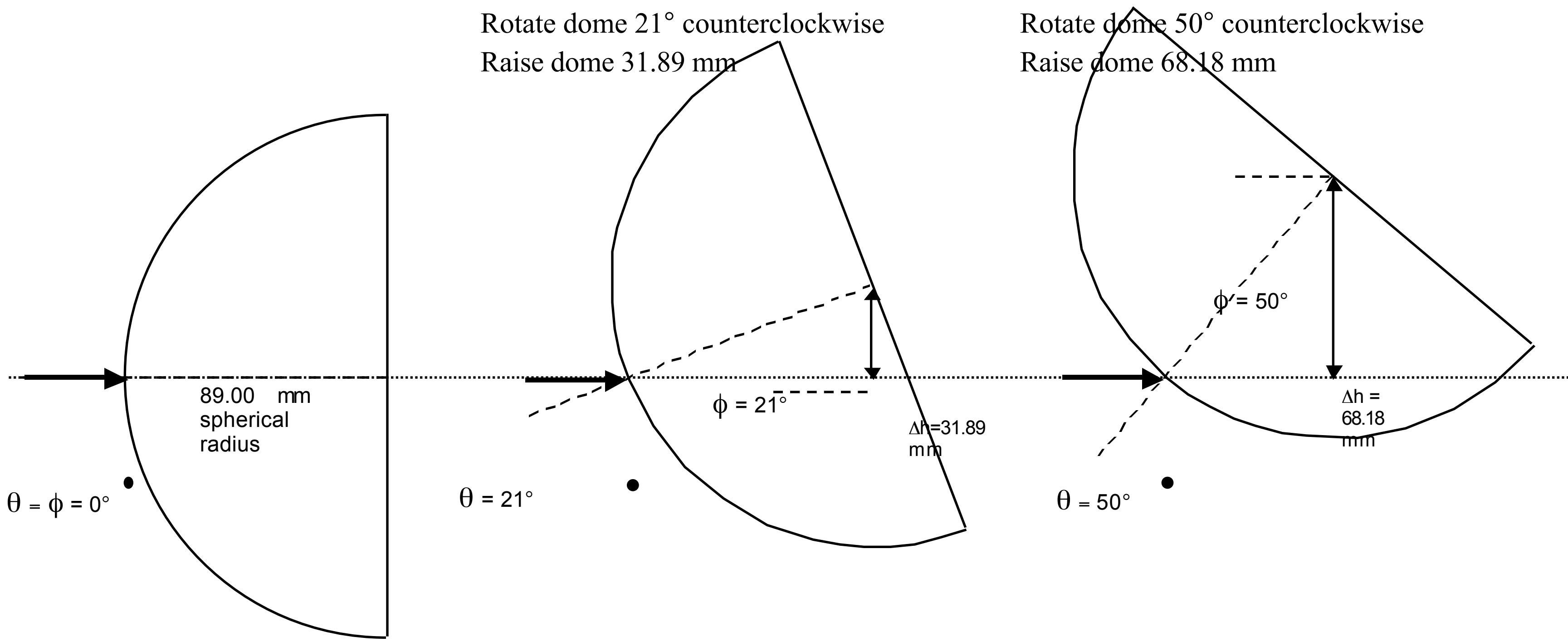


FIGURE 5. Three Angles of Incidence (0, 21, and 50 degrees) on Point A (Dome Apex)

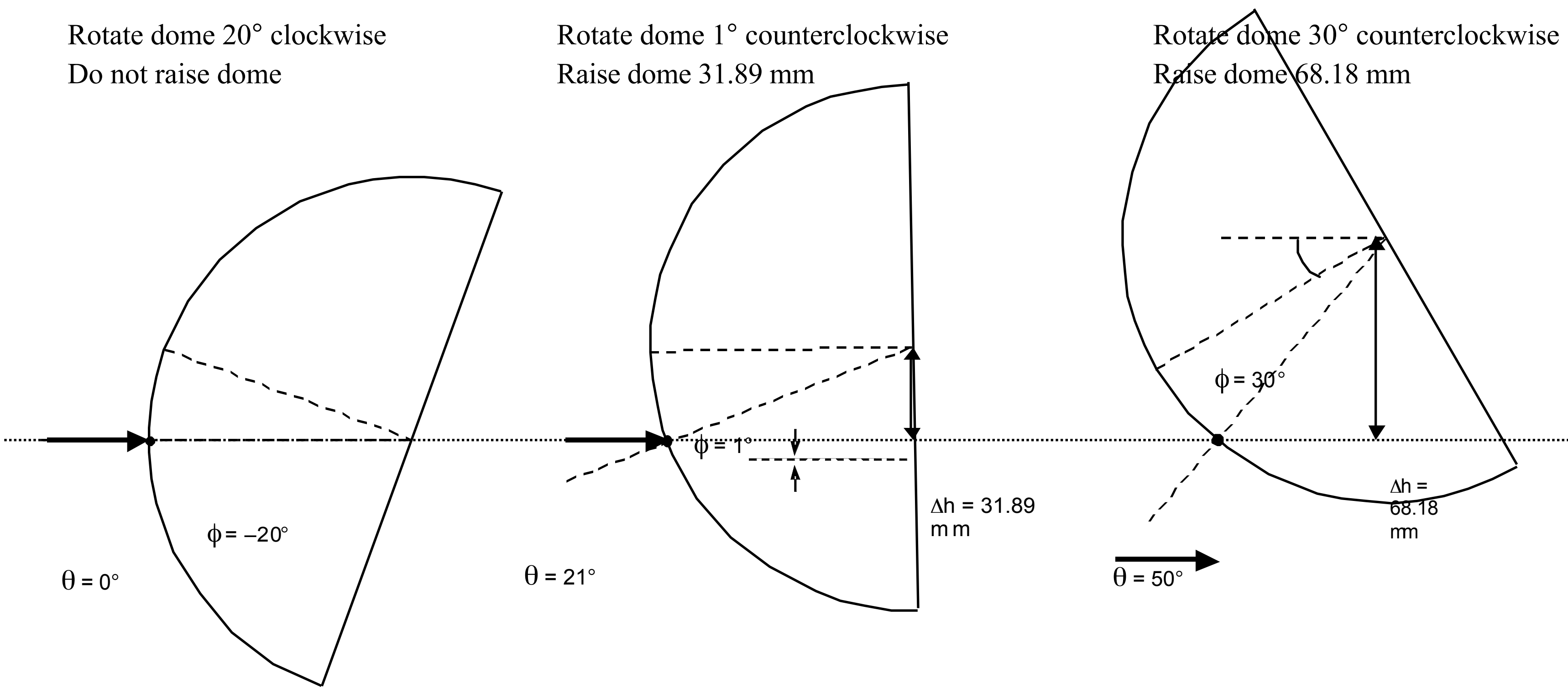


FIGURE 6. Three Angles of Incidence (0, 21, and 50 degrees) on Point B (20 degrees below dome apex).

Rotate dome 40° clockwise | Rotate dome 19° clockwise | Rotate dome 10° counterclockwise
Do not raise dome | Raise dome 31.89 mm | Raise dome 68.18 mm

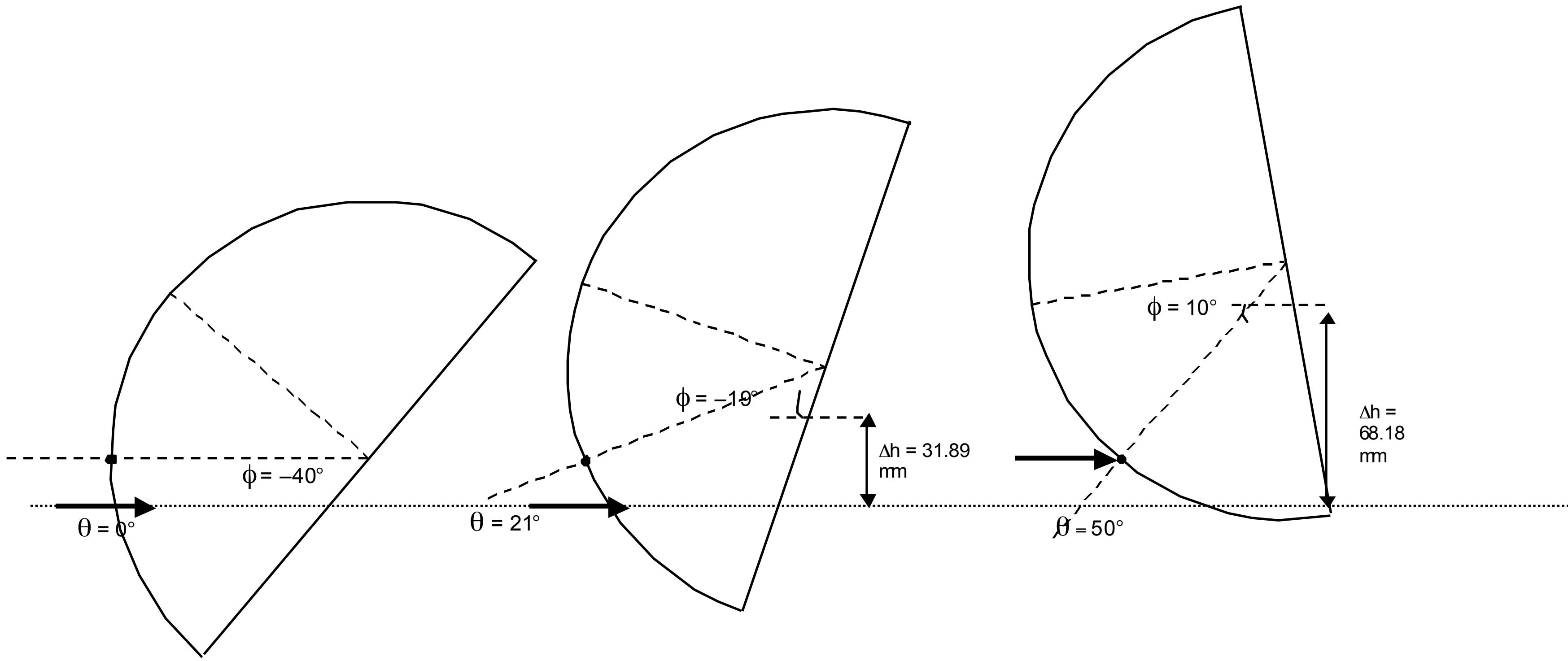


FIGURE 7. Angles of Incidence (0, 21, and 50 degrees) on Point C (40 degrees below dome apex).

3. DOME MOUNTING

Figures 8 and 9 show a fixture to hold the dome and accomplish the rotations and translations described in Figures 5 through 7. The dome is held in a Delrin® ring by three soft set screws, only one of which is shown in Figure 8. Two rigid polycarbonate plates are screwed to opposite sides of the Delrin® ring, so that the whole assembly can be rotated about an axis passing through the geometric center of the sphere.

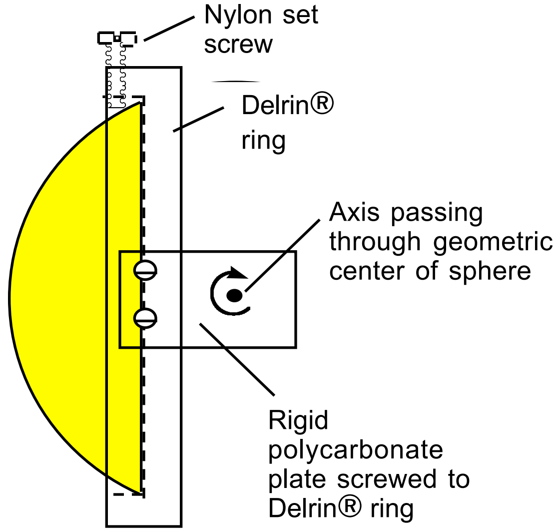
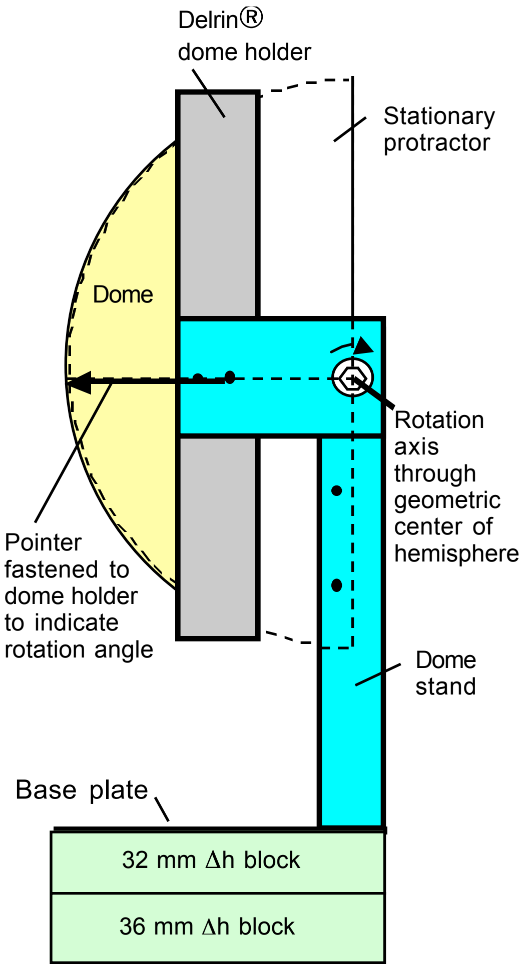
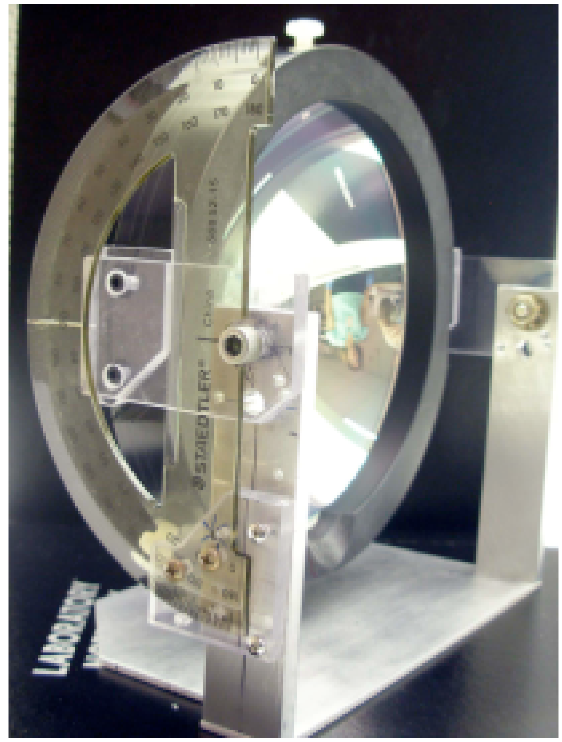


FIGURE 8. Dome Mounted in Delrin® Ring.

In Figure 9, the dome stand consists of an aluminum base plate with two vertical aluminum posts. The rotation axis of the dome is horizontal. Polycarbonate plates attached to the Delrin® ring are fastened to the aluminum posts with bolts and lock washers at the axis going through the geometric center of the sphere. The dome in its holder can be rotated and then locked into place by tightening the bolts. A stationary protractor is attached to the aluminum posts. When the dome in its Delrin® ring is rotated about the axis going through its geometric center, the angle of rotation is measured with respect to the stationary protractor. A needle fastened to the dome holder indicates the rotation angle.

Figure 10 shows the dome rotated to achieve 50 degree angles of incidence at points A and C. A metal strip mounted to the floor of the spectrophotometer sample compartment serves as a guide to orient the base plate of the fixture. The guide enables the fixture to be reproducibly oriented perpendicular to the beam in the spectrophotometer.


Delrin®
dome holder
Stationary
protractor
Dome
Rotation
axis
through
geometric
center of
hemisphere
Pointer
fastened to
dome holder
to indicate
rotation angle
Dome
stand
Base plate
32 mm Δh block
36 mm Δh block



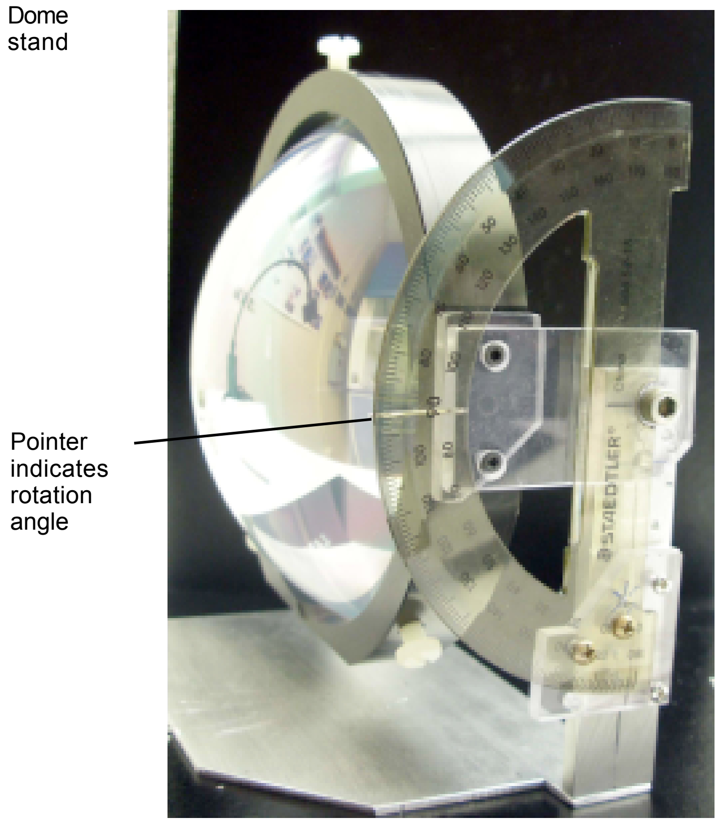
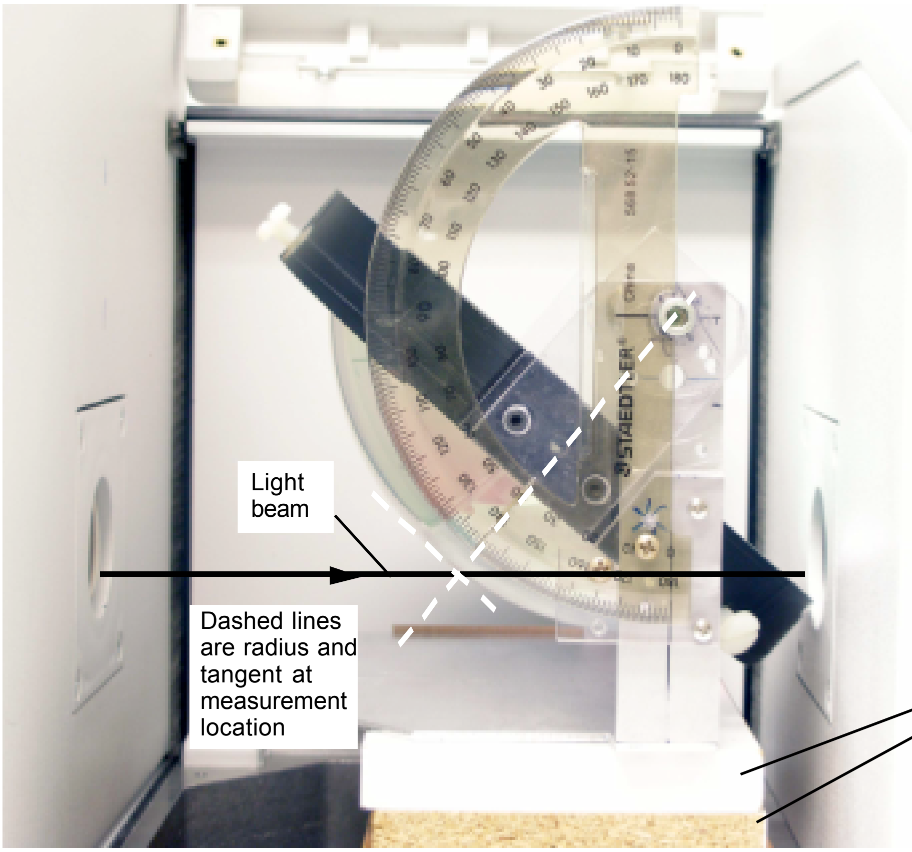

Pointer
indicates
rotation
angle

FIGURE 9. Dome Fixture.

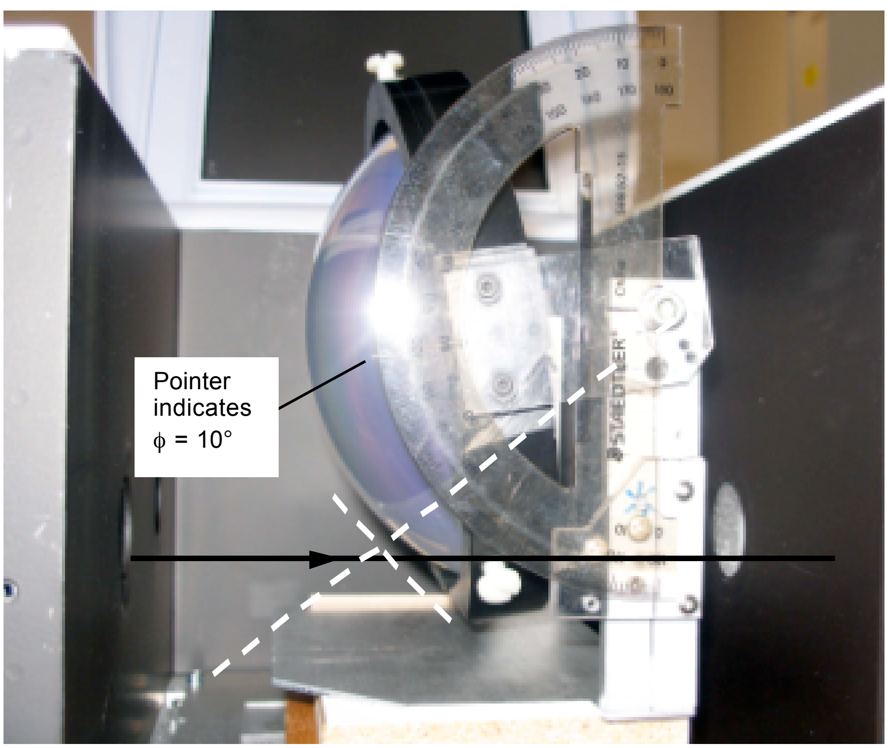


Dome positioned in infrared spectrophotometer

Point A
$\theta = 50°$ angle of incidence achieved with $\phi = 50°$ rotation angle in Figure 5

Blocks to adjust height of fixture

Stops that are not visible ensure that fixture and blocks are square in the sample compartment



Dome positioned in ultraviolet-visible spectrophotometer

Point C
$\theta = 50°$ angle of incidence achieved with $\phi = 10°$ rotation angle in

FIGURE 10. Dome Positioned in Sample Compartments.

In order to measure transmission at the positions and angles of incidence shown in Figures 5 through 7, it is necessary to rotate the dome in the fixture and to translate the whole fixture up when the dome is rotated. Wooden blocks of the desired thickness are inserted below the base of the fixture to accomplish the translation. Metal guide strips attached to one side of each wooden block allow the assembly to be stacked in a reproducible manner when blocks are inserted. Overall uncertainties estimated for the assembled fixture are ±2 to 3 degrees for rotation angle and ±1 to 2 mm for vertical translation.

4. TRANSMISSION MEASUREMENTS

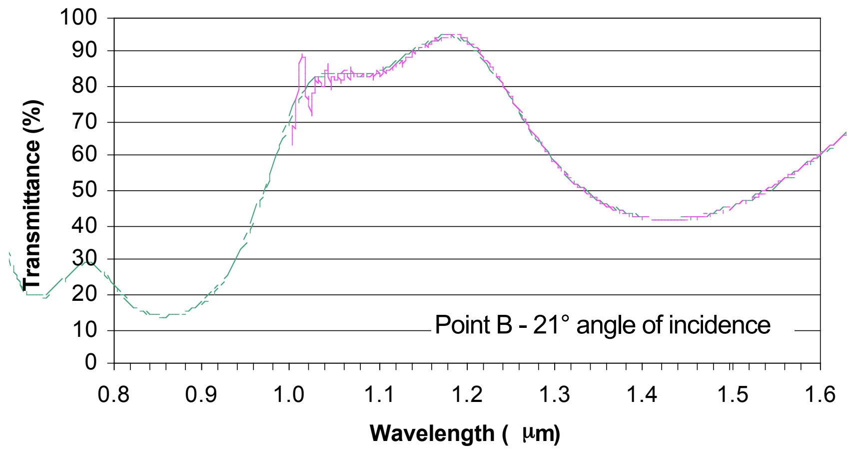
Infrared transmission was measured with a nitrogen-purged Perkin Elmer Spectrum GX Fourier transform infrared (FTIR) spectrophotometer over the wavelength range 1 to 27 μm. This instrument used a 1350K wire coil source, a deuterated triglycine sulfate (DTGS) detector, and a KBr beamsplitter. Each spectrum was an average of 32 scans with 4 cm^{-1} resolution at a wavelength of 2.5 μm. The B stop, which defines the size of the circular aperture, was set to 9.5 mm. The J stop, which defines the diameter of the beam at the center of the sample compartment, was set to 10 mm, which gave a minimally divergent beam at the expense of some wavelength resolution. Photometric accuracy was ±0.25%. The 100% transmission was measured before each sample scan. A new background was collected when the 100% transmission changed by more than ±0.25%.

Visible and near-infrared transmissions were measured with a 150-mm integrating sphere accessory on a Perkin Elmer Lambda 950 UV-VIS spectrophotometer using a tungsten lamp and lead sulfide detector for near-infrared wavelengths. The beam waist was 10-mm-tall x 3-mm-wide at its narrowest point in the center of the sample compartment. Scans were run from 2.5 to 0.2 μm wavelength at 387 nm/min with a data point every 4 nm and an integration time of 0.52 s. The variable slit was controlled by a servo mechanism which produced a resolution of 5 nm at 1.064 μm wavelength. The 0% and 100% transmittance levels were set every day before a series of measurements were made. Photometric accuracy using the integrating sphere was ±0.25%.

Figure 10 shows the dome mounted in the sample compartment of each spectrophotometer. A spectrophotometer is designed to make measurements near the center point between the apertures for the light source and the detector. Notice in Figure 10 that the measurement location is near the center of the compartment. The UV-VIS instrument incorporates an integrating sphere with the detector, so that the measured transmission is relatively insensitive to movement of the dome to the left or right in Figure 10. Transmittance measured by the FTIR instrument varied by ~1% for left-right position changes within ~ ±25 mm of the center point. Positioning the dome at the extreme left side of the compartment lowered the transmittance by 3% compared with the reading at the center of the compartment. Lateral positioning experiments were conducted at point B with an angle of incidence of 50°. The overall uncertainty in transmittance was estimated to be ±2%.

Figure 11 shows representative spectra of a coated dome with good agreement between the transmissions measured by the two instruments. The agreement attests to both the photometric accuracy of the two spectrophotometers and the ability to reproducibly position the dome with rotation and elevation in two different instruments.

Figure 11 shows experimental data, which has not been manipulated in any way. The UV-VIS spectrophotometer covers the wavelength range 0.8 to 1.6 µm, and the FTIR spectrophotometer covers the range 1.0 to 1.6 µm. In the upper spectrum, the experimental traces are superimposed. In the lower spectrum, a small displacement is observed between the two curves. The FTIR spectrum has significant noise in the interval 1.0 to 1.1 µm.



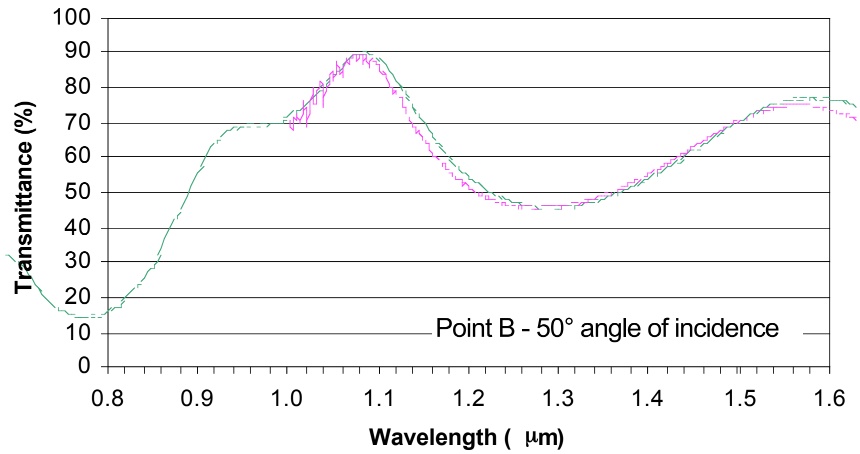


FIGURE 11. Representative Spectra of Coated Dome Showing Agreement Between Two Spectrophotometers.

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