LM-75-01

Goniophotometer Types and Photometric Coordinates

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Prepared by: Prepared by the Subcommittee on Photometry of Outdoor Luminaires of the IESNA Testing Procedures Committee

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INTRODUCTION

A goniophotometer is a device used to measure the directional light distribution characteristics of sources, luminaires, media, and surfaces.[1] A goniophotometer measures data at a series of spherical photometric coordinates in order to define a web of photometric data surrounding the light source. Goniophotometer and coordinate types are normally divided into three categories: Types A, B, and C. Originally, the different goniophotometer types were designed to match the type of source being measured. Data were measured and reported in corresponding photometric coordinates. With the advent of position sensitive lamps, certain sources could no longer be tested on the traditional goniophotometer type; however, data still needed to be reported in the traditional photometric coordinate type. Fortunately, though a goniophotometer type is often thought of as generating a specific coordinate type, in actuality, any goniophotometer can be used to generate any coordinate system, with varying degrees of difficulty.

This document will define the three photometric coordinate systems and explain when each is used. The operating principles behind each of the three types of goniophotometers will also be addressed.

BACKGROUND

The information presented here grew out of a need to further describe the types of goniophotometers available for photometric testing, as well as the coordinate systems used to describe photometric data. These terms are fundamental to the study of photometry, but their explanation has often been left to oral tradition. For example, it is convenient and traditional to describe coordinate systems in the vernacular of horizontal and vertical because this is the common mode of use. Coordinate systems fundamentally do not relate to the horizontal and vertical. Rather, they relate to a plane and a normal to that plane. Many current IESNA documents mention goniophotometers and coordinate systems, but none of them, including the *IESNA Lighting Handbook, Ninth Edition and LM-35-1989*,[1,2] offer a complete explanation or provide harmonious definitions. This document provides a solution and is in agreement with CIE 102 and 121.[3,4]

1.0 SPHERICAL COORDINATES

The three coordinate systems used in photometry are variations on the standard spherical coordinate system used in mathematics. A point in space is described by the following coordinates:

$$(\rho, \theta, \phi)$$

The first coordinate ρ (rho) denotes a point's distance from the origin. When describing points on a sphere, as in photometry, ρ is constant; therefore, this coordinate will not be considered further.

The two remaining coordinates are defined as they pertain to common photometric terminology:

Half plane of data – The data points described by rotating from pole to pole within a half plane (180 degrees of rotation). The half plane does not extend beyond the polar axis. (See **Figure 1**.) The coordinate θ (theta) is the angle between the polar axis and the data point.

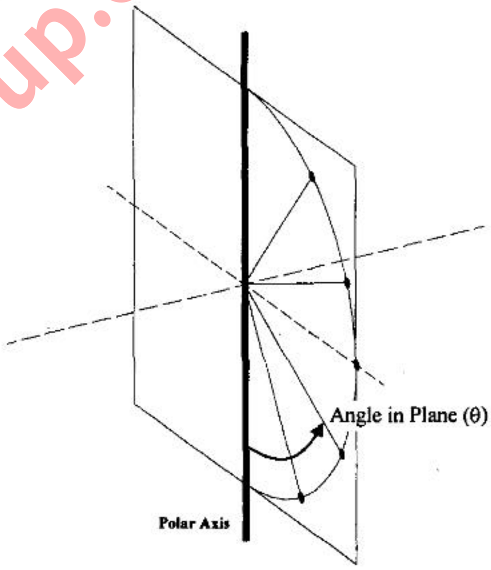

Figure 1. Half Plane of Data

Angle to plane – The angular rotation about the polar axis required to locate each plane of data. (See **Figure 2**.) This is the coordinate ϕ (phi) in mathematical notation.

Reference plane – The half plane that identifies the starting point for measuring the angle to the plane. (See **Figure 2**.) For the reference plane, the coordinate ϕ (phi) is equal to zero. The location of the reference plane is dependent upon the application and should always be clearly defined.

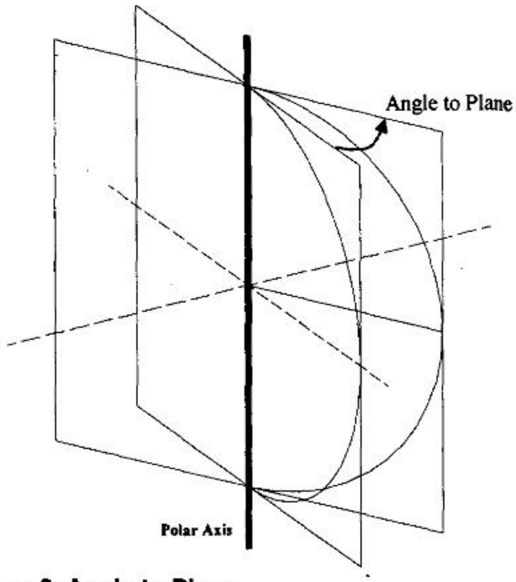

Figure 2. Angle to Plane

Polar axis – The line about which rotation occurs to locate the half planes.

Spherical coordinates may seem like an unfamiliar concept, but in reality they may be more familiar than one realizes. Latitude and longitude, another form of spherical coordinates, are used to identify the location of a point on Earth. The angles measured in the vertical half planes are the angles of latitude and range from 90°s to 0° to 90°n. The horizontal angles to the plane are the angles of longitude and progress from 180°w to 0° to 180°e. To clarify the explanation of the three photometric coordinate systems, examples in the following text relate back to the coordinates of places on Earth. The map of the earth, shown in **Figure 3**, marks several locations, which will be referenced again in the discussion of photometric coordinates. In geographic terminology, Greenwich, England is located at (51°n, 0°e). The South American city of Quito, Ecuador has a geographic location of (0°s, 78°w). On the remote Pacific Isle of Fiji, the town of Suva is situated at (16°s, 180°e). The geographic origin (0°n, 0°e) lies off the African coast deep in the waters of the Gulf of Guinea. On the frozen continent of Antarctica, the geographic South Pole is designated as (90°s, 0°e).

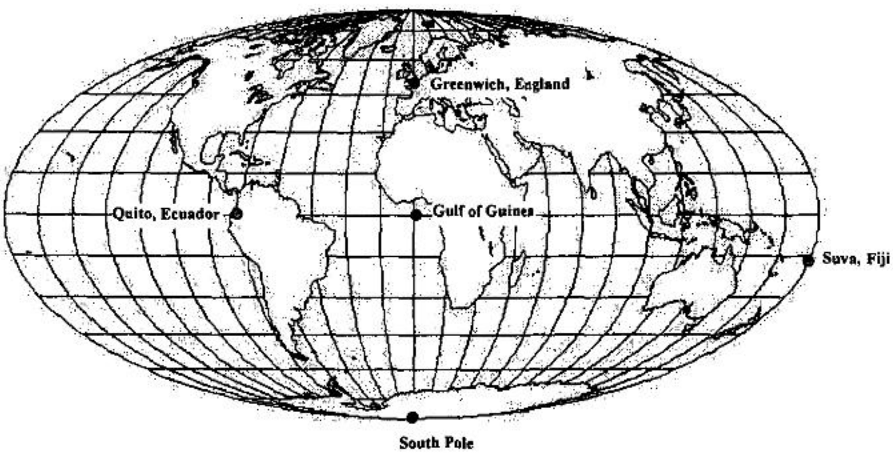

Figure 3. Geographic Coordinates

2.0 COORDINATE SYSTEMS

2.1 Type A Coordinates

In the Type A coordinate system the polar axis is vertical, as shown in **Figure 4**. The angles measured in the vertical half planes are labeled Y angles, while the horizontal angles to the half planes are called X angles. Locations on the sphere are denoted by their (Y, X) coordinate pair. Point (0,0) is located on the equator of the sphere. In photometry, the luminaire is generally aimed at (0Y, 0X), such that the 0°X plane is perpendicular to the light opening of the luminaire. The vertical Y angles range from –90° (nadir) to 90° (zenith). The horizontal X angles range in value from -180° to 180°, as shown in **Figure 4.** Automotive lighting and optical systems testing are presented in Type A coordinates.

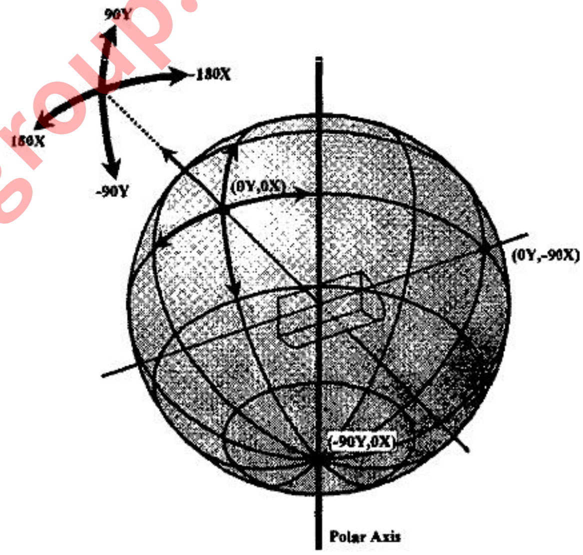

Figure 4. Type A Coordinates. Arrows indicate photometric angles.

Using the Type A coordinate system to describe locations on Earth, Greenwich, England is located at (51Y, 0X), Quito, Ecuador is at (0Y,78X), and Suva, Fiji's coordinates would be (-16Y, 180X). That point in the Gulf of Guinea would have Type A coordinates of (0Y, 0X), while the location of the geographic South Pole is (-90Y, 0X).

2.2 Type B Coordinates

The Type B coordinate system is illustrated in **Figure 5.** The polar axis is horizontally oriented. This coordinate system looks much like a Type A coordinate system that has been turned on its side. The angles measured in the horizontal half planes of data are called Horizontal angles, and the vertical angles to the half planes are Vertical angles. Locations on the sphere are denoted by their (H, V) coordinate pair. 0°H is on the equator of the sphere. Point (0,0) is normally the aiming point of a luminaire, and the 0°V plane is perpendicular to the luminaire light opening. The H angles range from -90° to 90°, as shown in **Figure 5.** The vertical V angles range in value from –180° to 180°, where -90° would be at nadir and 90° at zenith. Floodlight photometric data is traditionally presented in Type B coordinates.

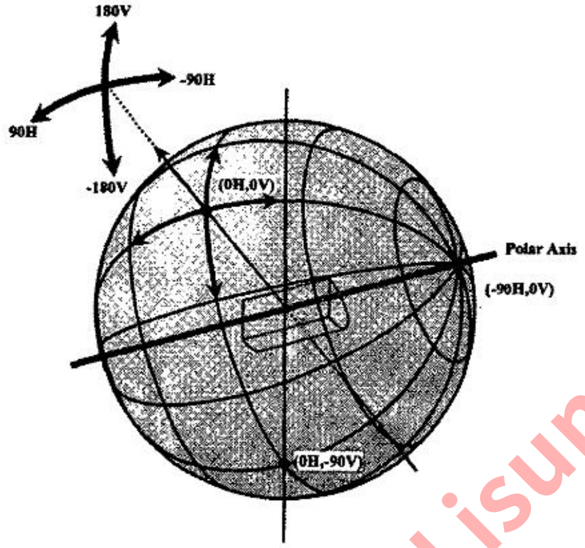

Figure 5. Type B Coordinates. Arrows indicate photometric angles.

Were the locations on the Earth to be described in Type B coordinates, Greenwich would be at (0H, 51V), Quito at (78H, 0V), and Suva, Fiji at (0H, -164V). Point (0H, 0V) would still be located in the Gulf of Guinea, while the South Pole would be designated by (0H, -90V).

2.3 Type C Coordinates

With the Type C coordinate system, the polar axis is vertical, as shown in **Figure 6.** The Type C coordinate system varies little from the Type A system. The angles measured in the vertical half planes of data are called Vertical angles, and the angles to the horizontal half planes are called Lateral angles. The Type C coordinate pair (0V, 0L), where the luminaire is normally aimed, is located at nadir. The vertical V angles range in value from 0° (nadir) to 180° (zenith). The lateral L planes range in value from 0° to 360°, as shown in **Figure 6.** In photometry, the 0°L reference plane is normally positioned parallel to the primary axis of the luminaire. Type C photometric data is the most popular and widely recognized. The majority of photometric data, including data for indoor and roadway luminaires, is presented in Type C format.

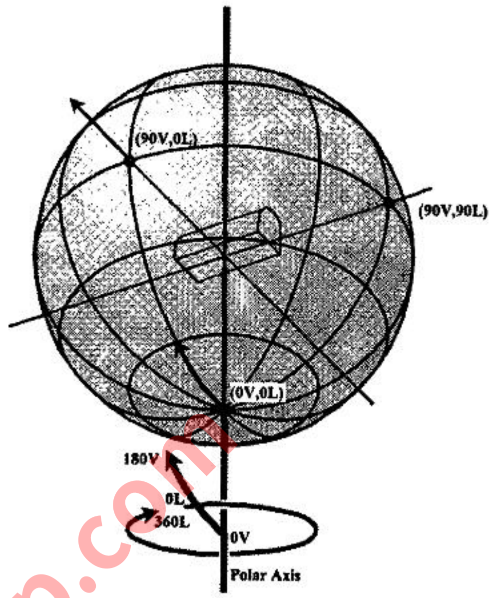

Figure 6. Type C Coordinates. Arrows indicate photometric angles.

Were the locations on the Earth to be described in Type C coordinates, Greenwich would be at (141V, 0L), Quito at (90V, 282L), and Suva, Fiji at (74V, 180L). That point in the Gulf of Guinea would be at (90V, 0L). The South Pole would have coordinates of (0V, 0L).

3.0 GONIOPHOTOMETERS

3.1 Horizontal Axis (Type A)

With this goniophotometer system, the photodetector is fixed while the luminaire is rotated about the X and Y-axes, as shown in **Figure 7.** When this type of goniophotometer is used to create a Type A web of data (**Figure 4**), the luminaire is normally aimed at the equator (0Y, 0X). To create data in Type A coordinates with a Type A goniophotometer, the luminaire is first rotated about the x-axis to the desired X coordinate. The luminaire is then rotated about the y-axis, through the full range of Y coordinates, until a full plane of data has been gathered. This process is repeated until the luminaire has been positioned at all X coordinates. Because the Type A goniophotometer relies on tilting the luminaire in order to take measurements, its use has become more restricted with the advent of position sensitive lamps.

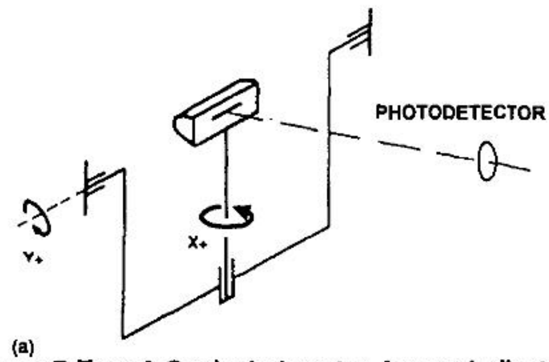

Figure 7. Type A Goniophotometer. Arrows indicate direction of luminaire rotation.

3.2 Vertical Axis (Type B)

The photodetector is also fixed with the Type B goniophotometer (**Figure 8**). The luminaire is rotated about the V and H axes. When this type of goniophotometer is used to create a Type B web of data (**Figure 5**), the luminaire is normally aimed at the equator. When using a Type B goniophotometer to gather data in Type B coordinates, the luminaire is first rotated about the V axis to the target V coordinate. The luminaire is then rotated about the H axis, through the full range of H coordinates, until a full plane of data has been measured. This process is repeated until the luminaire has been positioned at each V coordinate. Like the Type A goniophotometer, the Type B goniophotometer tilts the luminaire in order to take measurements; therefore, its use with position sensitive lamps is restricted.

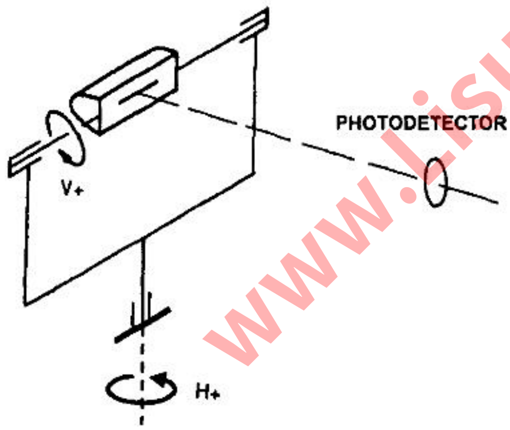

Figure 8. Type B Goniophotometer. Arrows indicate direction of luminaire rotation.

3.3 Moving Detector or Mirror Goniophotometer (Type C)

A Type C goniophotometer is shown in **Figure 9**. It is characterized by having the luminaire suspended in a fixed orientation in space, movable only around a vertical L-axis. Either the photodetector or a mirror is rotated around the luminaire (around the V-axis) in a vertical plane. The elimination of the tilting of the luminaire makes the Type C goniophotometer ideal for measuring the light output of position sensitive lamps.

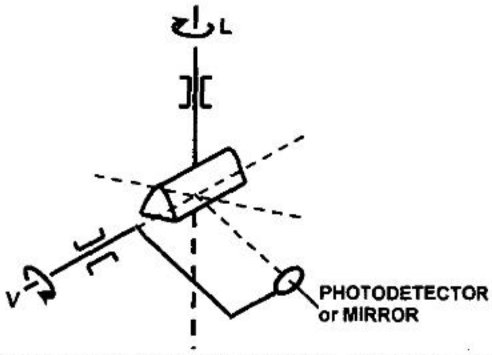

Figure 9. Type C Goniophotometer. Arrows indicate direction of luminaire rotation.

When this type of goniophotometer is used to create the Type C web of data (**Figure 6**), the luminaire is normally aimed at nadir. The luminaire is rotated about the L axis to the desired Lateral angle, then the mirror or photodetector is rotated about the horizontal V-axis to obtain a plane of Vertical data. This process is repeated until all data have been gathered at all desired Lateral planes. When this type of goniophotometer is used to create the Type A web of data (**Figure 4**), the procedure is the same except that the luminaire is normally aimed at the equator.

3.3.1 Moving Detector Goniophotometer. This device consists of a photodetector that moves vertically on a rotating boom or arc shaped track, where the light source is positioned at the center of the arc traced by the detector. Readings are collected with the detector positioned at the desired angular settings. Sometimes multiple detectors on an arc replace the rotating boom. (See **Figure 10**.)

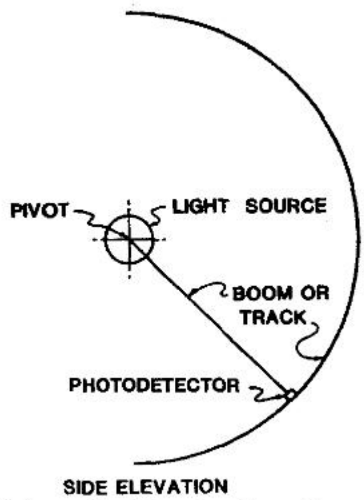

Figure 10. Schematic side elevation of a moving detector photometer

3.3.2 Moving Mirror Goniophotometer. In this type of goniophotometer, the mirror rotates vertically around the light source, reflecting the luminous flux to a single detector. Readings are taken at each desired angle as the mirror moves to that location. This is the most common goniophotometer type in use today. (See **Figure 11**.)

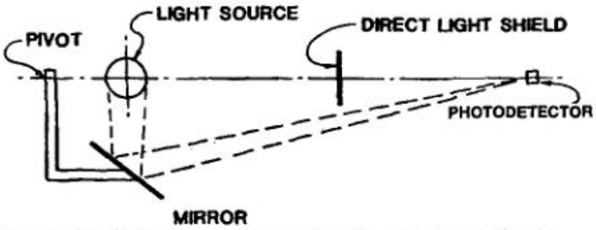

Figure 11. Schematic diagram of a moving mirror photometer

References:

1. *IESNA Lighting Handbook, Ninth Edition*, New York: Illuminating Engineering Society of North America, 2000, Chapter 2.

2. IESNA Committee on Testing Procedures, *IESNA Approved Method for Photometric Testing of Floodlights Using High Intensity Discharge or Incandescent Filament Lamps*, IESNA LM-35-1989, New York: Illuminating Engineering Society of American, 1989.

2. International Commission on Illumination, *Recommended File Format for Electronic Transfer of Luminaire Photometric Data*, CIE 102, 1993. Vienna, Austria: Commission Internationale de L'Eclairage, 1993.

4. International Commission on Illumination, *The Photometry and Goniophotometry of Luminaires*, CIE 121, 1996. Vienna, Austria: Commission Internationale de l'Eclairage, 1996.

ANNEX A
COORDINATE SYSTEM CONVERSION

Sometimes it is necessary to convert data from one coordinate system to another. The following equations demonstrate how to convert Type A and Type B coordinates to their Type C equivalent.

A1.0 Type A to Type C Conversion

To determine the Type C coordinate (V,L) equivalent of any Type A coordinate (Y,X), use the following set of equations:

$$V = Y + 90$$

$L = -X$	for $-180 < X < 0$
$L = 360 - X$	for $0 < X < 180$
$L = 0$ or $L=360$	for $X = 0$

For the Type A coordinate system, the 180X and –180X planes describe the same points and are only described once in the Type C coordinate system as 180L. Conversely, in Type C coordinates, the 0L and 360L planes describe the same points and are only described once in the Type A coordinate system as 0X.

A2.0 Type B to Type C Conversion[1]

To determine the Type C coordinate (V,L) equivalent of any Type B coordinate (H,V), use the following set of equations:

Let

$m = \sin H$

$n = \cos H \cos V_B$

$p = \cos H \sin V_B$

Then

$L = \arctan(-m/n)$	for $m < 0, n > 0$
$L = 360 - \arctan(m/n)$	for $m > 0, n > 0$
$L = 0$ or $L=360$	for $m=0, n>0$
$L = 180 - \arctan(m/n)$	for $n < 0$
$L = 270$	for $m > 0, n = 0$
$L = 0$	for $m = 0, n = 0$
$L = 90$	for $m < 0, n = 0$

$V_C = \arctan(-(m^2 + n^2)^{0.5} / p)$	for $p < 0$
$V_C = 180 - \arctan((m^2 + n^2)^{0.5} / p)$	for $p > 0$
$V_C = 90$	for $p = 0$

where subscripts have been added to the V coordinate of each coordinate system for clarification purposes.

For the Type B coordinate system, the 180V and –180V planes describe the same points and are only described once in the Type C coordinate system as 90V (for $90 \leq L \leq 270$). Conversely, in Type C coordinates, the 0L and 360L planes describe the same points and are only described once in the Type B coordinate system as 0H (for $-90 \leq V \leq 90$).

Reference:

1. William E. Brackett and Bryan L. Mydosh, "Subtleties in Floodlight Photometry", *J. Illum. Eng. Soc.*, Vol. 14 No. 1, p. 347, Oct. 1984.

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