# Web-Based Training for FHWA Roadway Lighting Workshop
# Module 4: Other Roadway Lighting Topics

## FHWA Safety Program

U.S. Department of Transportation
**Federal Highway Administration**

Safe Roads for a Safer Future
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# Web-Based Training for FHWA Roadway Lighting Workshop

Participant Workbook

Module 4: Other Roadway Lighting Topics

(Other modules include:
Module 1: Roadway Lighting Design Overview
Module 2: Lighting Hardware and Light Source Considerations for Roadway Lighting
Module 3: Street and Roadway Lighting Design)

May 2018

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16. Abstract

**This document serves as a participant workbook for Web-Based Training for FHWA Roadway Lighting Workshop, Module 4: Other Roadway Lighting Topics. Module 4 covers locations for lighting equipment, lighting for special locations, and the spectral effects of light. Other modules include Module 1: Roadway Lighting Design Overview, Module 2: Lighting Hardware and Light Source Considerations for Roadway Lighting, and Module 3: Street and Roadway Lighting Design.**

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**List of Acronyms and Abbreviations**

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| CCT | Correlated color temperature |
| $cd/m^2$ | Candela per square meter |
| DG | Design guide |
| FHWA | Federal Highway Administration |
| HPS | High pressure sodium |
| IES | Illuminating Engineering Society |
| K | Kelvin |
| LED | Light emitting diode |
| LRC | Lighting Research Center |
| MASH | Manual for assessing safety hardware |
| MH | Metal halide |
| NHTSA | National Highway Traffic Safety Administration |
| RDG | Roadside Design Guide |
| RP | Recommended practice |
| S/P | Scotopic/photopic |
| SPD | Spectral power distribution |

## Module 4: Other Roadway Lighting Topics

### *Other Roadway Lighting Topics*
### *Module 4, Slide 1*

This section of the Participant Workbook will help you review the content for Module 4, titled *Other Roadway Lighting Topics*. The top of each workbook slide indicates the module slide title and slide number so you can locate content within the workbook that matches content in the online modules.

***Navigating This Course***
***Module 4, Slide 2***

This slide describes how to navigate through the course module. It is similar to the instructions in this workbook.

## *Course Objectives*
## *Module 4, Slide 3*

Following completion of this module, the user will be able to accomplish the following objectives:

- Determine factors that influence the placement of lighting.
- Apply appropriate lighting placement for intersections.
- Design lighting for roundabouts, crosswalks, and other applications.
- Estimate impacts of light source spectrum on vision.

***Table of Contents***
***Module 4, Slide 4***

***Lighting Equipment Location***
***Module 4, Slide 5***

This section of the module discusses issues related to the location and placement of lighting equipment, such as poles and luminaires.

***Lighting in Clear Zones***
***Module 4, Slide 6***

*A clear zone on the side of a rural highway.*

The AASHTO Roadway Design Guide (RDG) defines a clear zone as the unobstructed, traversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles. The clear zone includes shoulders, bike lanes, and auxiliary lanes, except those auxiliary lanes that function like through lanes.

The Clear Zone is what is available for recovery. By providing a clear recovery area, roadway agencies reduce the probability of a crash or mitigate the severity of a crash.

Four factors that are considered in determining an appropriate clear zone for any particular road are speed, traffic volume, roadside slope and horizontal curvature. The clear zone should be as wide as practical, but should meet the minimums of RDG Table 3.1.

***Clear Zones***
***Module 4, Slide 7***

*Light poles placed at the end of the clear zone along a highway.*

Although an unobstructed roadside is highly desirable from a roadside safety viewpoint, some appurtenances such as light poles must be placed near the travel way. Since roadway lighting is a road safety enhancement, light poles should be placed, whenever possible, where they are least likely to be struck by errant motor vehicles. Barriers can also be considered when poles are located near travel lanes, if they are likely to reduce crash severity, according to the AASHTO Roadside Design Guide (RDG).

All new and replacement luminaire support poles should be selected from those that have been successfully crash-tested to current AASHTO MASH (manual for assessing safety hardware) criteria. Poles should not compromise the safety of the road user. Details for reducing impact severity with the use of suitable breakaway pole base design are included in the RDG.

***Lighting in Clear Zones***
***Module 4, Slide 8***

*Utility poles with attached street lighting fixtures placed with a lateral offset from the road curb.*

For lighting on the side of the roadway, the AASHTO Roadside Design Guide (RDG) recommends locating the poles as far from the shoulder or clear zone edge as practical, including the use of breakaway poles with appropriate clearance. In urban areas with curbs and gutters, place poles at the back of the sidewalks (when possible, given locations of buildings and proper sidewalk width) to reduce the potential for being struck by motor vehicles.

When poles cannot be placed behind the sidewalk, the RDG recommends that poles should be placed a minimum 1.5 feet back from the curb. This is a lateral offset and should not be confused with a clear zone. Unprotected roadway lighting poles located inside the clear zone or at the lateral offset, should be breakaway, unless conditions dictate otherwise.

***Lighting in Clear Zones (continued)***
***Module 4, Slide 9***

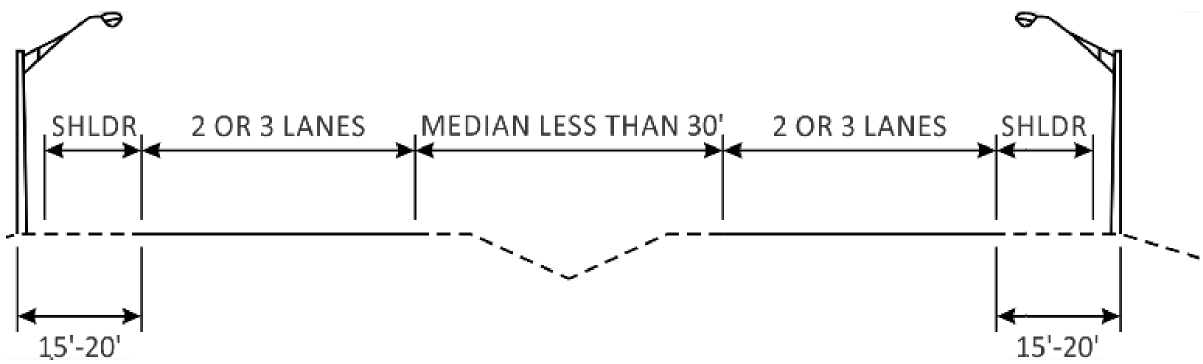
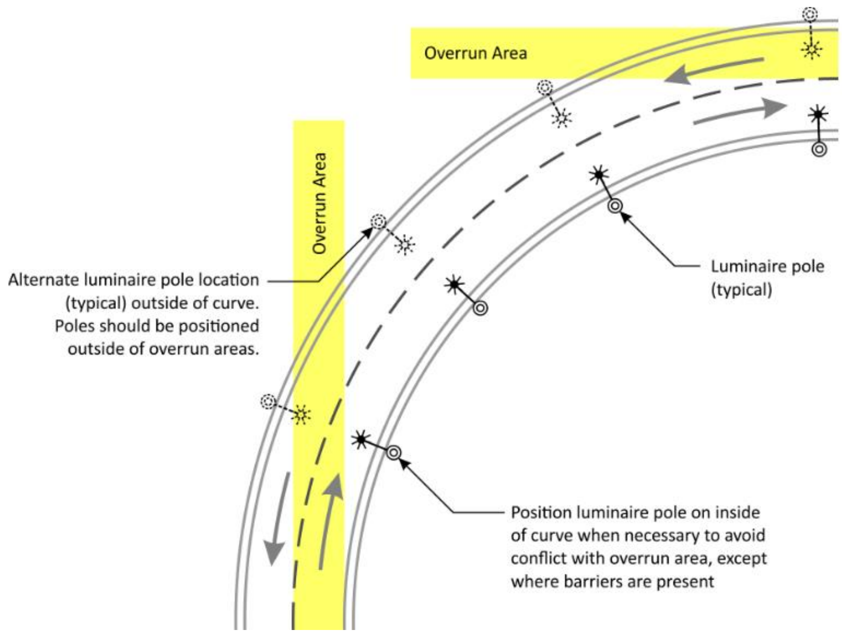



*Illustration of recommended light pole placement near clear zones.*

The AASHTO Roadway Design Guide recommends that breakaway poles be placed on the roadside of interstate highways at least 15 feet from the road edge. For highways other than interstates, also place breakaway poles on the roadside of travel lanes 15 feet from the road edge, where practical. If sufficient right-of-way does not exist for this clearance, the poles may be placed just inside the right-of-way line but not closer than 2.5 feet from the road edge.

Whenever possible, lighting poles should not be placed in medians less than 30 feet wide. If they are placed in medians less than 30 feet wide, proper protections must be installed to prevent vehicles from crashing into lighting poles. The illustration above shows typical roadside side lighting of a controlled access roadway with a median less than 30 feet wide. If the median width were 30 feet or greater, then median lighting could be used for the light poles.

***Lighting for Curves***
***Module 4, Slide 10***




*An illustration of lighting placement along curves.*

Where lighting is required on roadways with small radius horizontal curvature, poles should be positioned on the inside of the curve to reduce the potential for impacts by errant vehicles that overrun the entry to the curve.

According to the 2012 FHWA Lighting Handbook, if poles cannot be positioned on the inside of the curve, they should be located outside of the entry overrun areas as shown in the illustration above.

***Underpass Lighting***
***Module 4, Slide 11***

*A typical highway underpass that might require lighting.*

*An example of a wall-pack luminaire.*

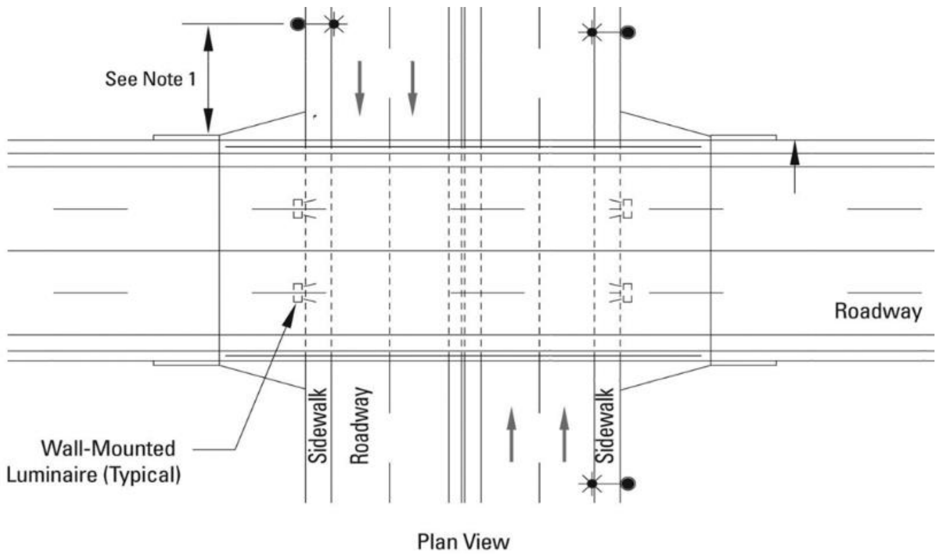
Underpass lighting generally is installed to enhance driver visibility after daylight hours. On highways that are not continuously lighted, consider providing underpass lighting where frequent nighttime pedestrian traffic exists through the underpass or where unusual or critical geometry exists within or on an approach to the underpass.

Provide underpass lighting on all highways that are continuously lighted. This can be accomplished with pole-mounted luminaires along the side of the highway (see illustration on next page) or with supplemental lighting within the underpass itself.

If lighting within the underpass is necessary, this can often be done with wall-mounted luminaires, often called wall packs, mounted on abutments and piers, or by pendant or flat luminaires, mounted over the travel lanes.

Avoid placing these luminaires below the bottom flange of girder type bridges or other types of bridges that have flush bottom surfaces so as not to interfere with necessary clearances.

***Underpass Lighting***
***Module 4, Slide 12***

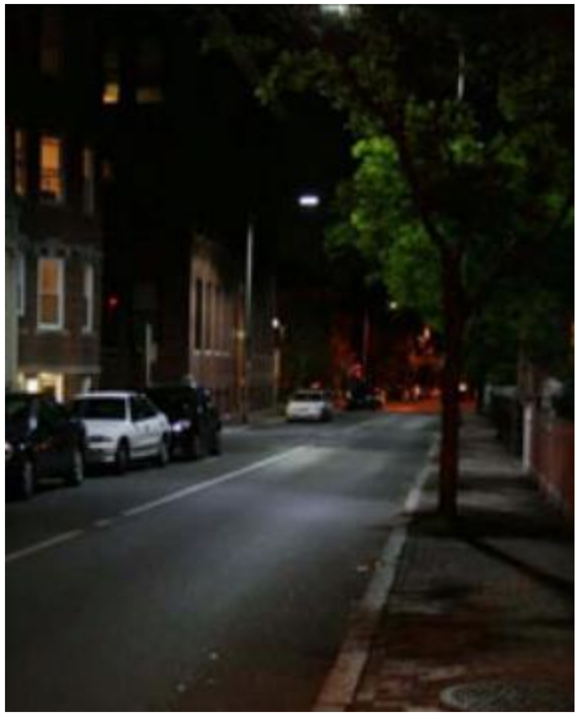



*An illustration of lighting placement within and adjacent to an underpass. Note 1: Position luminaire pole approximately one mounting height away from the structure (typically both sides).*

Favorable positioning of conventional pole-mounted highway luminaires adjacent to a relatively short underpass often can provide adequate illumination within the underpass without a need to provide supplemental lighting. If this action is considered, ensure that shadows cast by the conventional luminaires do not become a visibility problem within the underpass.

Poles adjacent to an underpass should be located at a sufficient distance away from the entrance and exit point of the underpass to allow the light from the luminaire to penetrate the underpass. This is very important at short underpasses where supplemental under bridge lighting is not required.

***Trees***
***Module 4, Slide 13***



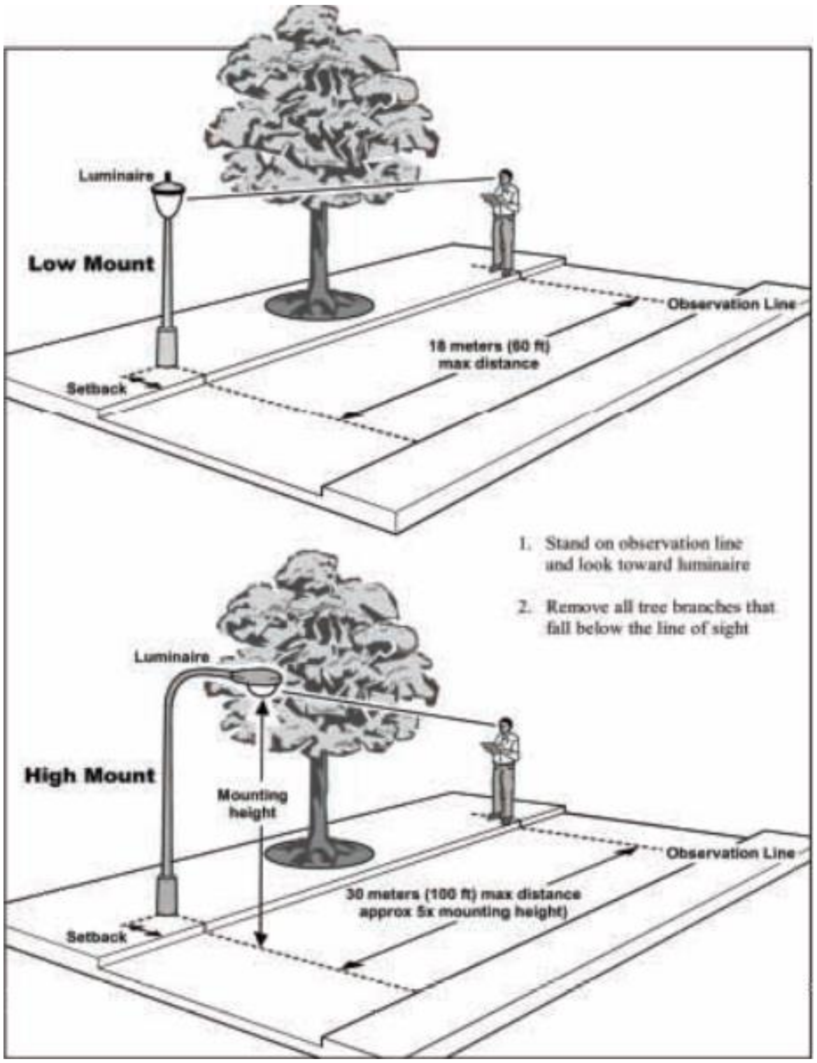
*Trees blocking light from roadway luminaires.*

Visibility on the sidewalk and streets can be reduced if trees block the light and create shadows that reduce uniformity and visibility. A study titled *Trees, Lighting and Safety in Context Sensitive Design* gave some examples of how a lighting system should be designed to allow for the presence of trees at all stages of maturity:

- The best design approach is to locate luminaires outside of the full growth lines of the species of tree along the roadway.

- When a roadway or pedestrian lighting project includes new or existing trees in close proximity to the lighting, the reduction in light reaching the road caused by the trees can be incorporated by adding an additional light loss factor. There is currently insufficient research to quantify the factor with precision, but an additional 10 – 20 percent is reasonable.

***Trees (continued)***
***Module 4, Slide 14***




*An illustration of proper luminaire placement near trees.*

It is best to locate luminaires beyond the tree canopy so that the trees do not interfere with the light distribution of the luminaire.

However, even when roadway lighting and tree installations are carefully planned, tree pruning will be required over time.

The illustration at right shows how to determine which tree branches should be trimmed. If you stand 15 meters back from a low mounted luminaire (top illustration) or 30 meters back from a high mounted luminaire, you should remove all of the tree branches below the line of sight.

This will help to ensure that the light from luminaires is not being blocked by the branches of adjacent trees.

***Knowledge Check***
***Module 4, Slide 15***

*True or False:*

If luminaire poles cannot be positioned on the inside of a curve, they should be located outside of the entry overrun areas.

□ A) True

□ B) False

*The correct answer is on the next page.*

***Knowledge Check Answer***
***Module 4, Slide 16***

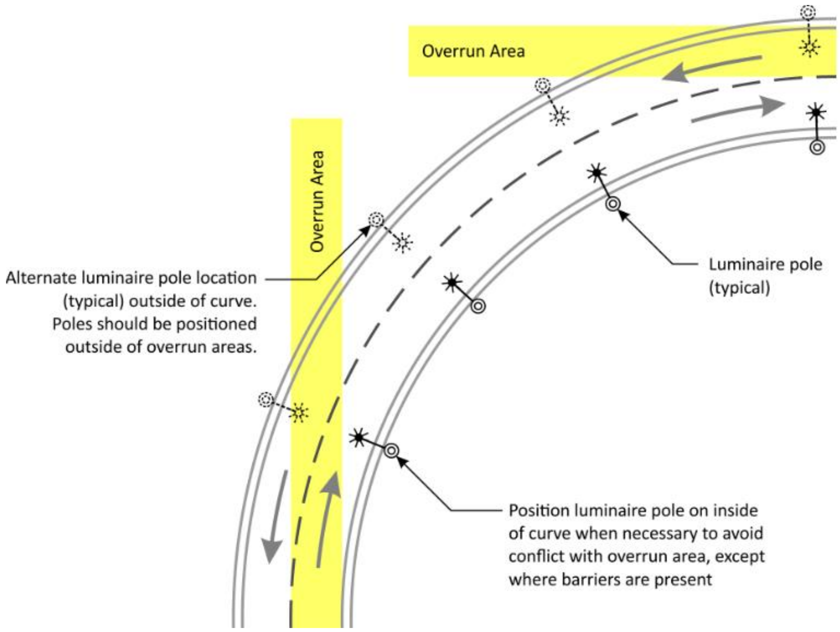



*Illustration of lighting on curves.*

The correct answer is True.

As shown in the illustration from **Module 4, Slide 10**, lighting should be positioned so as not to interfere with the overrun area.

***Lighting for Special Locations***
***Module 4, Slide 17***

This section discusses lighting for special situations such as intersections, interchanges, crosswalks, roundabouts and tunnels.

***Lighting Intersections***
***Module 4, Slide 18***

*An example of lighting at a signalized intersection.*

Unlike lighting standards for straight sections of roadways, which are written in terms of luminance (candelas per square meter); lighting for intersections is specified in terms of illuminance (lux). Lux tells us the amount of light (in lumens) that is falling on the roadway surface per a unit area, in this case, per square meter.

For example, if you measure 30 lux on the roadway surface of an intersection, you have 30 lumens per square meter on that surface.

***Lighting Intersections (continued)***
***Module 4, Slide 19***

Many vehicle-to-vehicle and vehicle-to-pedestrian conflicts occur at intersections, so even when the intersecting roadways are not lighted, lighting intersections may be warranted. In Module 1 a method for intersection lighting warranting is given. AASHTO recommends that signalized intersections always be lighted. High priority may also be given to intersection lighting when the busier road at the intersection has the traffic volume characteristics shown in the chart below. Designers may also want to consider the number of pedestrians or cyclists using the intersection.

| Roadway Type | Traffic Volume |
|---|---|
| Principal arterial | >5000 vehicles/day |
| Minor arterial | >2000 vehicles/day |
| Collector | >1000 vehicles/day |
| Local | >500 vehicles/day |

***Types of Intersection Lighting***
***Module 4, Slide 20***


*A signalized intersection that should be illuminated with full lighting.*

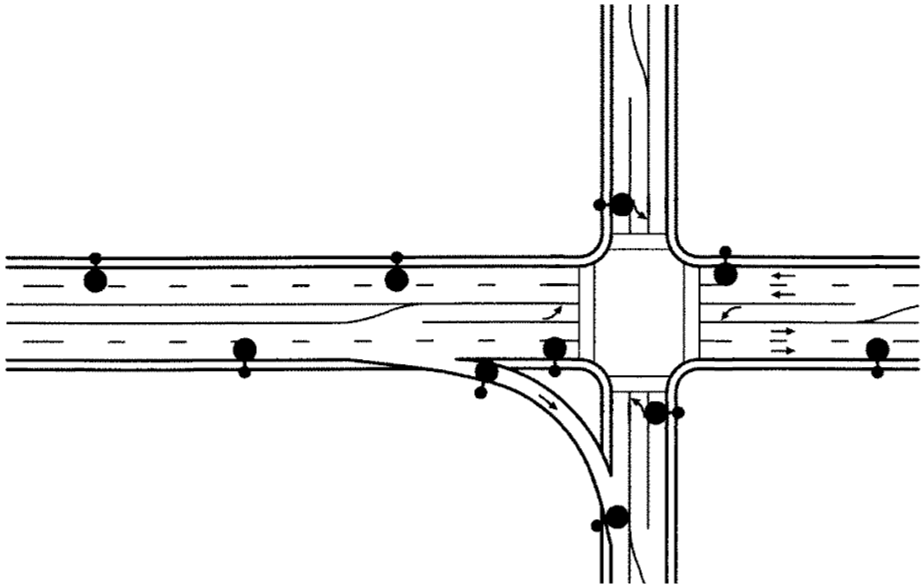
There are three primary types of lighting system that can be installed along an intersection:

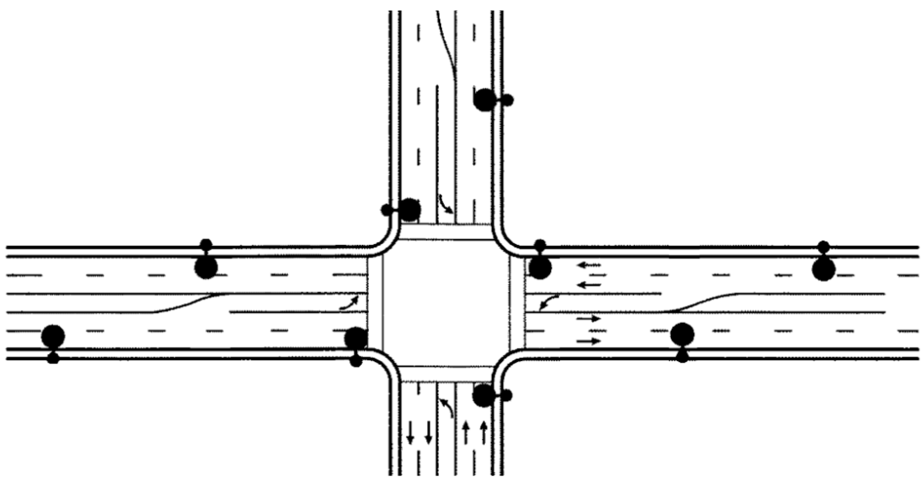
**Full lighting:** The intersection conflict areas (where the roads overlap) and approaching legs of the intersecting roads are illuminated.

**Partial lighting:** Only the primary intersection conflict areas are illuminated.

**Beacon or delineation lighting:** Only one or two luminaires are provided to demarcate the intersection location.

***Full Intersection Lighting***
***Module 4, Slide 21***

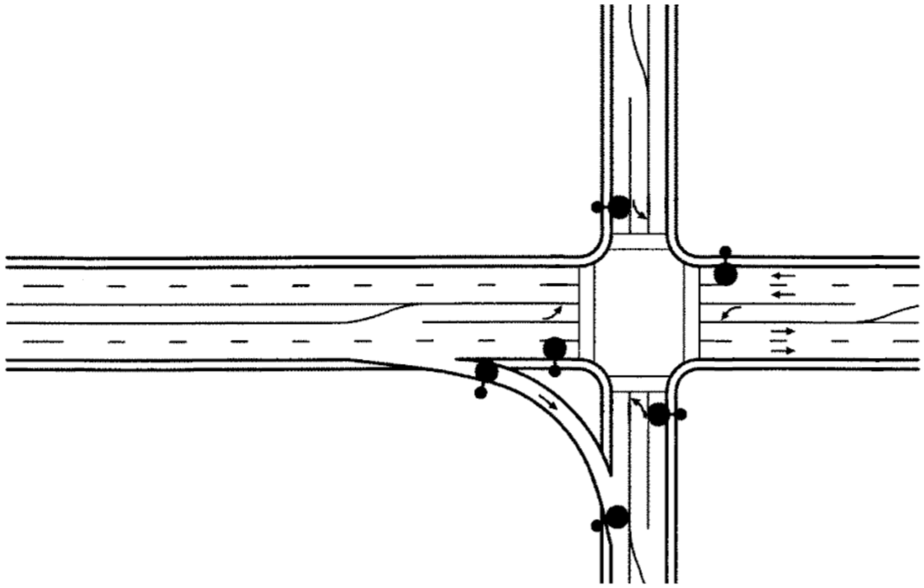


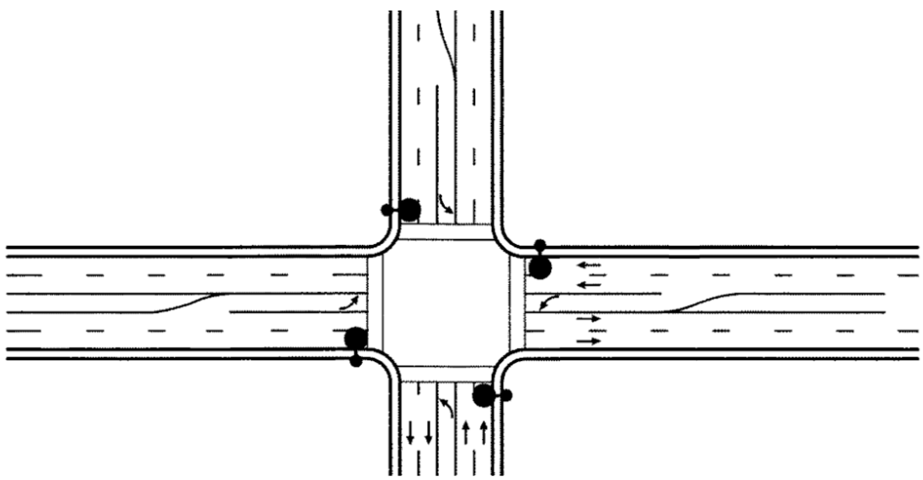


*Examples of full intersection lighting layouts. Lighting fixtures are shown in black.*

Full intersection lighting covers an intersection and related areas in a uniform manner over the traveled portion of the roadway. It is installed whenever the intersecting roads are continuously illuminated, and when the intersection is signalized. As examples, typical layouts for intersections with and without a right-turn bypass lane are shown above.

***Partial Intersection Lighting***
***Module 4, Slide 22***





*Top: Partial intersection lighting layout for an intersection with a right-turn bypass lane. Bottom: Typical partial intersection lighting layout. Lighting fixtures are shown in black.*

Partial intersection lighting illuminates key decision areas and conflict points at the intersection. As examples, typical layouts for intersections with and without a right-turn bypass lane are shown.

***Beacon Lighting for Intersections***
***Module 4, Slide 23***

*Examples of beacon lighting at rural intersections.*

Beacon lighting denotes the use of one or two luminaires at an intersection. It is sometimes installed at rural intersections, as the accompanying photographs show.

Beacon lighting helps identify the location of a potential conflict to approaching drivers. Lower light output levels are suggested to reduce the potential for glare.

***Knowledge Check***
***Module 4, Slide 24***

Full lighting at intersections is recommended when:

□ A) An intersection is unsignalized

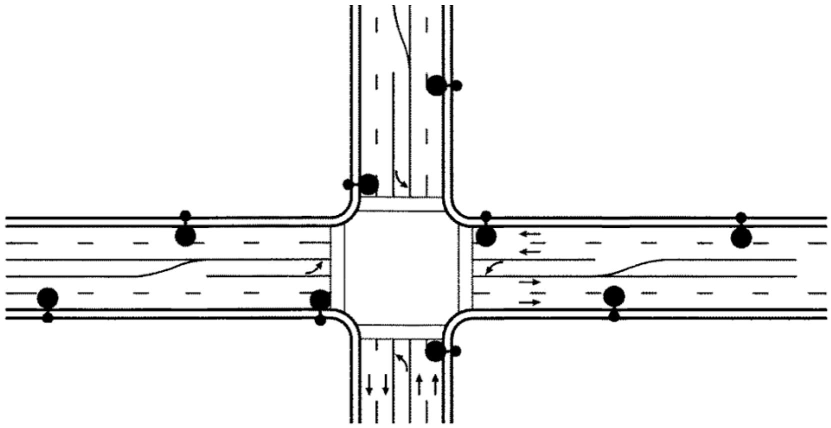
□ B) Whenever the intersecting roads are continuously illuminated

□ C) The intersection is located in a rural area

□ D) None of the above

*The correct answer is on the following page.*

***Knowledge Check Answer***
***Module 4, Slide 25***



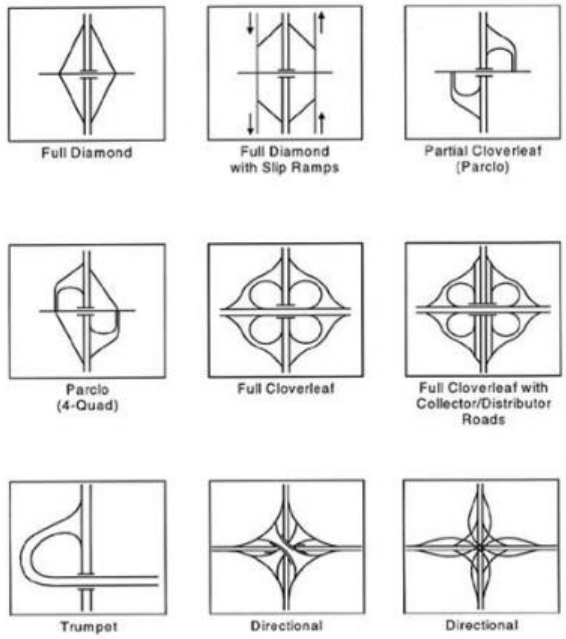
*An example of a full intersection lighting layout.*

The correct answer is B. Full lighting at intersections is installed whenever the intersecting roads are continuously illuminated. *(See Module 4, Slide 21.)*

***Lighting for Interchanges***
***Module 4, Slide 26***

This section discusses lighting techniques for highway interchanges.

***Interchange Lighting***
***Module 4, Slide 27***



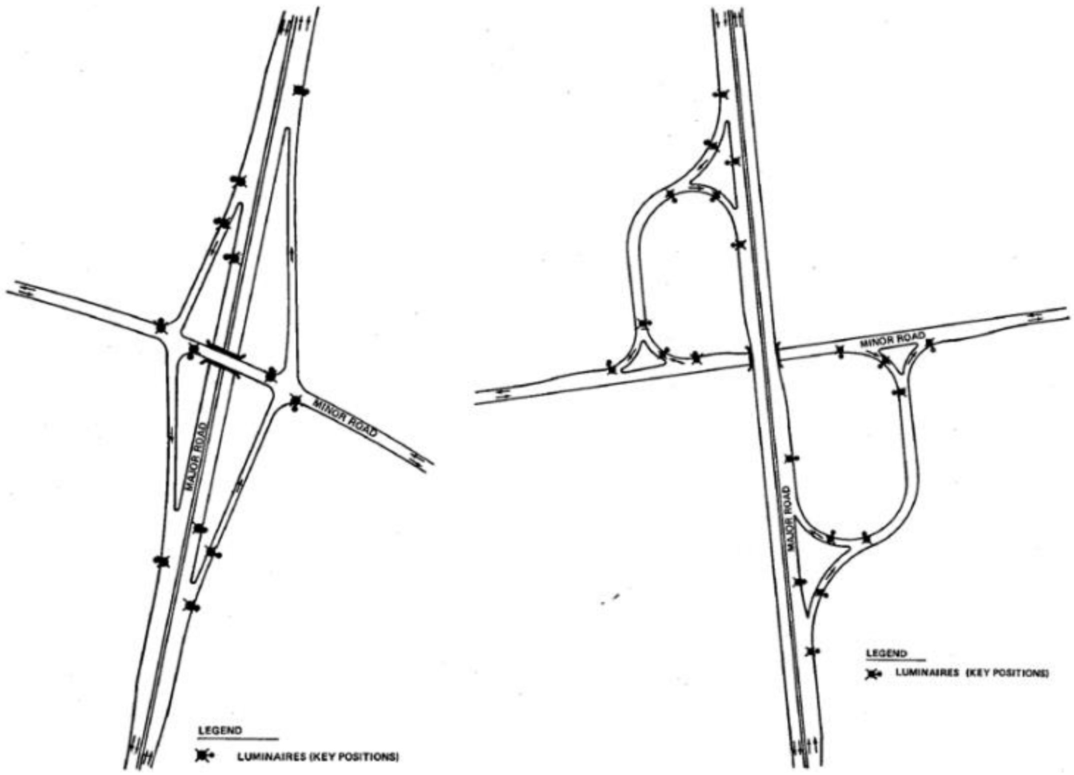

*Examples of types of freeway interchanges.*

Interchanges, where freeways intersect, can be lighted if conditions warrant it. Module 1 describes the warranting procedure for determining the type of interchange lighting needed:

**Complete interchange lighting** involves illuminating all roadways in the intersection (ramps, approaching legs) with continuous lighting.

**Partial interchange lighting** illuminates only the key decision-making locations for road users along the interchange (ramp exits/entrances, and service road intersections).

***Interchange Lighting Layouts***
***Module 4, Slide 28***

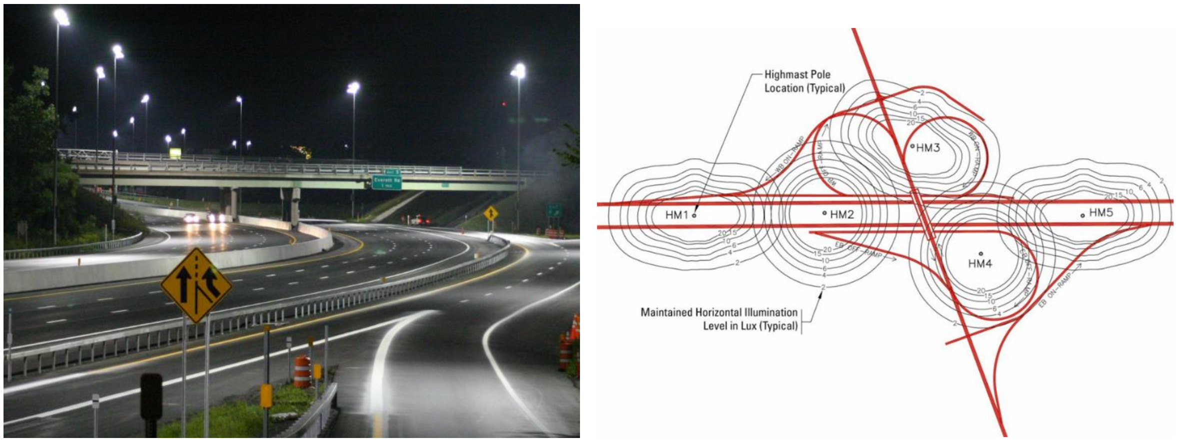



*Examples of partial lighting layouts for interchanges. Lighting fixtures are shown in black.*

Typical partial interchange lighting layouts are shown in these diagrams. Only the key decision-making locations (merging and diverging points and conflict areas) along the interchange are illuminated.

For complete interchange lighting, all ramps and connecting roads would be illuminated using regularly spaced luminaires.

***High Mast Interchange Lighting***
***Module 4, Slide 29***




*Left: A photograph of a high mast lighting installation. Right: Illuminance patterns from high mast lighting.*

Complete interchange lighting can also be provided by a smaller number of high mast lighting units. Templates showing illuminance patterns from high mast luminaires can be overlaid onto an interchange plan to identify a suitable layout as shown in the illustration above and to the right.

***Lighting for Crosswalks***
***Module 4, Slide 30***

*An example of a mid-block crosswalk.*

An important purpose of lighting at pedestrian crosswalks is to provide illumination that increases the visibility of pedestrians who may be crossing the street, or about to cross the street.

Crashes involving pedestrians on crosswalks are a common cause of road fatalities. According to the National Highway Traffic Safety Administration (NHTSA), in 2015, nearly 1000 pedestrians died when they were crossing the road at intersections.

Although there are many reasons for crashes involving pedestrians (speeding, alcohol, etc.), inadequate lighting at or adjacent to crosswalks might increase the risk to pedestrians crossing the road. The nighttime fatal vehicle/pedestrian crash rate in unlighted areas is around three times higher than the daytime rate.

***Lighting for Crosswalks (continued)***
***Module 4, Slide 31***


*An example of a mid-block crosswalk.*

Important considerations for crosswalk lighting include the vertical illumination levels on the pedestrians and the contrast between the pedestrians and the background.

In areas where it is darker at night (less ambient lighting), such as a rural roadway, vertical illumination on the pedestrian can potentially be reduced, because there will be a good contrast between the pedestrian and the darker background against which they are viewed by drivers. However, on a city street, where nighttime ambient light levels are much higher, a higher level of vertical illuminance will be needed on pedestrians in crosswalks in order to provide equivalent visibility.

A study, *Informational Report on Lighting Design for Midblock Crosswalks*, performed by the Virginia Tech Transportation Institute found that a vertical illuminance of 20 lux (about 2 footcandles) in a crosswalk, measured at 5 feet above the road surface, allowed drivers to detect pedestrians at adequate stopping distances under rural conditions. Higher vertical light levels, perhaps as much as 40 lux, might be needed for urban crosswalks.

***Mid-Block Crosswalk Lighting***
***Module 4, Slide 32***

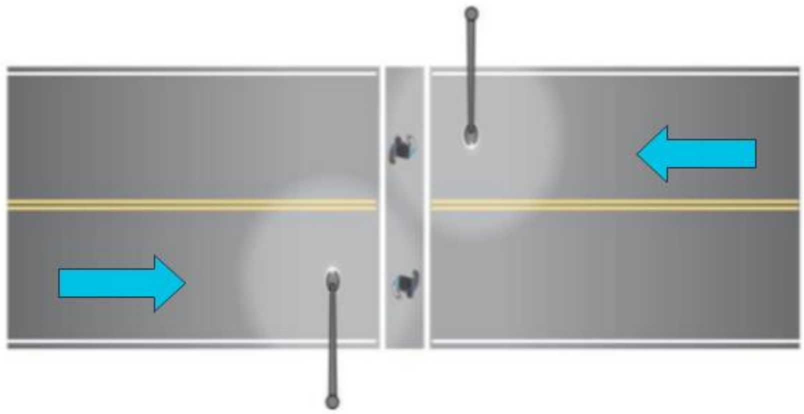


*Illustration of a recommended lighting layout for a mid-block crosswalk.*

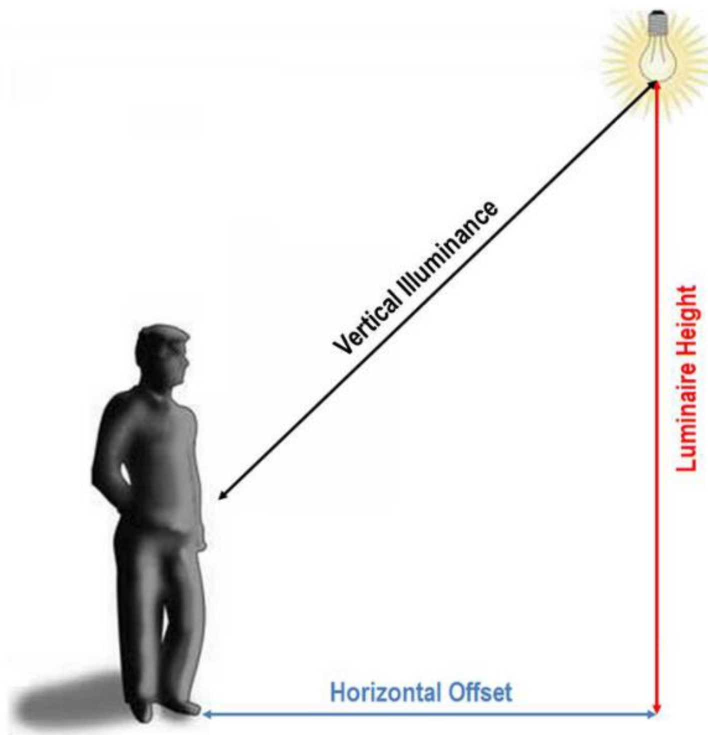
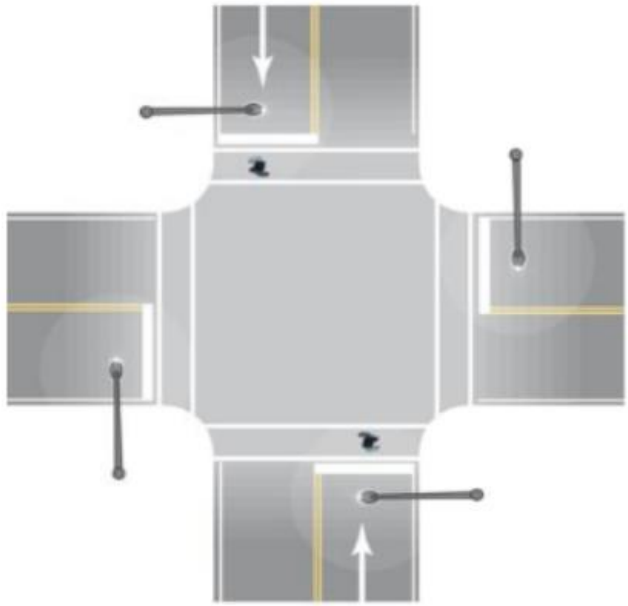



*Illustration of vertical illumination on a pedestrian.*

Crosswalks are typically lighted by overhead light fixtures mounted on poles. For mid-block crosswalks, it is recommended that lighting be placed on each side of the roadway approximately 15 feet in front of the crosswalk in each direction of vehicle travel. Placing the light fixtures in this manner provides higher vertical illuminance on pedestrians, making them more visible to drivers.

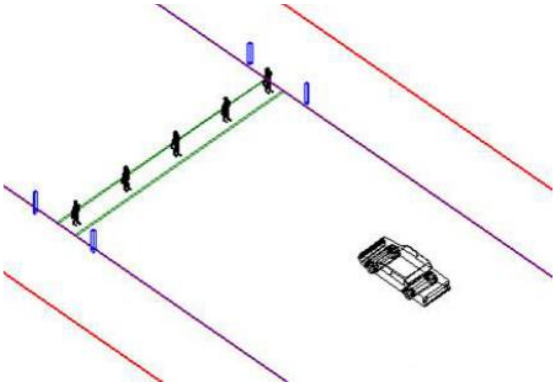
***Intersection Crosswalk Lighting***
***Module 4, Slide 33***

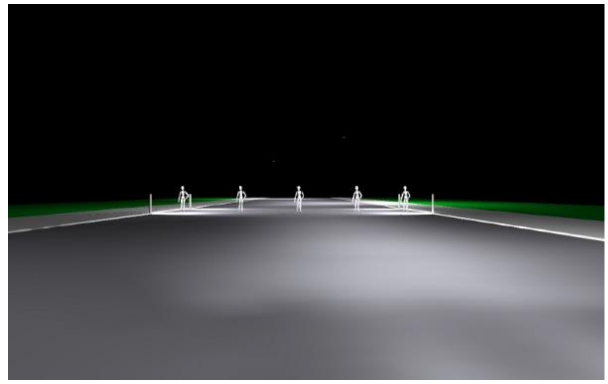


*An illustration of a lighting layout recommended for crosswalks at intersections.*

Lighting recommendations for crosswalks at intersections are similar to mid-block crosswalks in that the lighting should be placed 15 feet before the crosswalk in each direction of vehicle travel. This layout is shown in the figure above.

***Bollard-Based Crosswalk Lighting***
***Module 4, Slide 34***





*An illustration (left) and computer simulation (right) of a bollard-based crosswalk lighting system. The images show pedestrians located throughout the crosswalk in the roadway.*

Another possible way to provide lighting for crosswalks is through the use of bollard lights at each end of the crosswalk. A bollard light is a type of outdoor lighting encased in a vertical post at ground level. Such a light provides light across an intersection at the pedestrian level. This is an excellent means of providing high vertical illumination on pedestrians as they cross the street.

This technique may provide improved visibility for drivers, while using less light. This also can be a more economical solution than lighting the crosswalk from overhead light sources.

An additional benefit to the use of bollards is that they act as an architectural elements to help direct pedestrian traffic to crosswalks, especially for mid-block applications, and for delineating the location of crosswalks to drivers during both daytime and nighttime.

***Bollard-Based Crosswalk Lighting (continued)***
***Module 4, Slide 35***

*A nighttime photograph of a* ***temporary field test*** *of a bollard-based crosswalk lighting system. Bollards were placed in the roadway temporarily, only for the field test. These bollards would typically be mounted on the sidewalk, adjacent to the roadway, in a permanent installation.*

In a study (Demonstrating Urban Outdoor Lighting for Pedestrian Safety and Security) conducted by the Lighting Research Center (LRC), a bollard-based lighting system for crosswalks was judged to be promising for improving pedestrian safety.

It was also found to be practical and acceptable by transportation, transit and public safety professionals. Bollard-based lighting systems have been field tested in New Jersey, New York, and Colorado.

Optical (and temporal) control can minimize glare from bollard lights. Breakaway design (see Module 2) should be incorporated into their installation.

***Knowledge Check***
***Module 4, Slide 36***

*Select the correct answer:*

When lighting a mid-block crosswalk from overhead pole-mounted light fixtures, it is recommended that:

□ A) The light poles are placed directly in line with the crosswalk

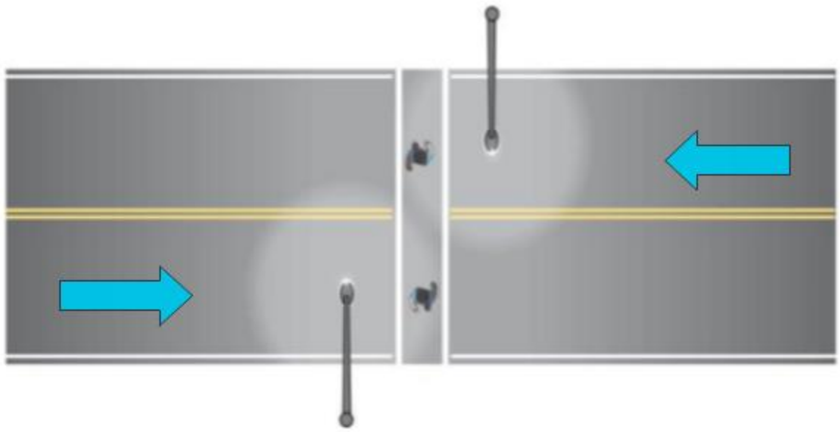
□ B) A light pole is placed on one side of the street only

□ C) Light poles are placed on each side of the street 15 feet in front of the crosswalk

□ D) The lighting provides less than 10 vertical lux across the crosswalk

*The correct answer is on the next page.*

***Knowledge Check Answer***
***Module 4, Slide 37***

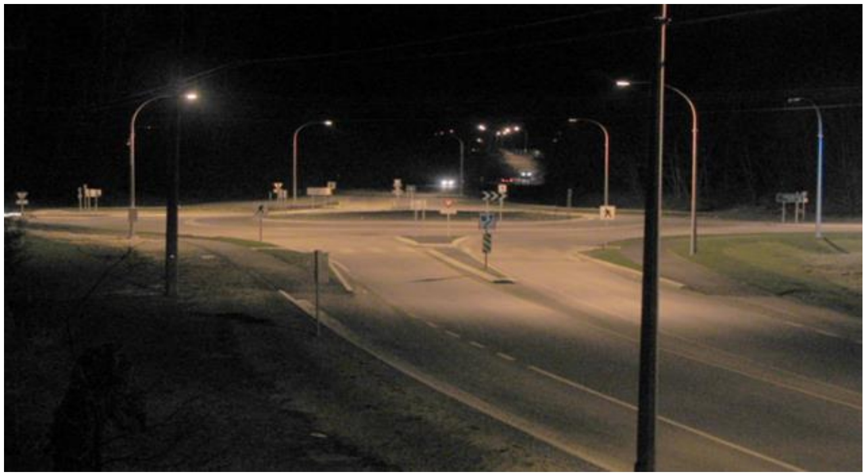


*An illustration of mid-block crosswalk lighting.*

The correct answer is C.

For mid-block crosswalks lighted from overhead, it is recommended that lighting be placed on each side of the roadway approximately 15 feet in front of the crosswalk in each direction of vehicle travel. *(See Module 4, Slide 32)*

***Roundabout Lighting***
***Module 4, Slide 38***



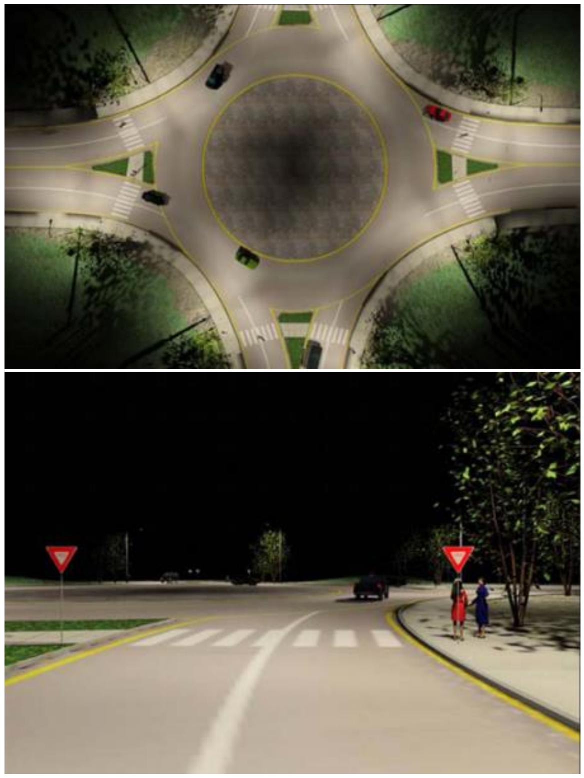
*A nighttime view of a typically lighted roundabout.*

For a roundabout to operate satisfactorily, all users—drivers, pedestrians, and cyclists—must be able to enter, navigate around, and exit the roundabout in a safe and efficient manner and pedestrians must be able to safely use crosswalks, during the day and at night.

In its lighting design guide for roundabouts (DG-19-08) the IES (Illuminating Engineering Society) provides criteria to address the visibility of the roadway, pedestrians, and hazards through a roundabout. This guide uses a combination of horizontal illuminance for the roadway areas of the roundabout and vertical illuminance in the crosswalks areas.

The latest edition of the Transportation Research Board's *Roundabouts: An Informational Guide*, reiterates the recommendation of IES DG-19-08.

***Roundabout Lighting (continued)***
***Module 4, Slide 39***



*A computer rendering of recommended roundabout lighting layout.*

Illumination is recommended for all roundabouts, including those in rural environments. The geometry of a roundabout makes headlamps ineffective in the detection of people or objects in the vehicle's path.

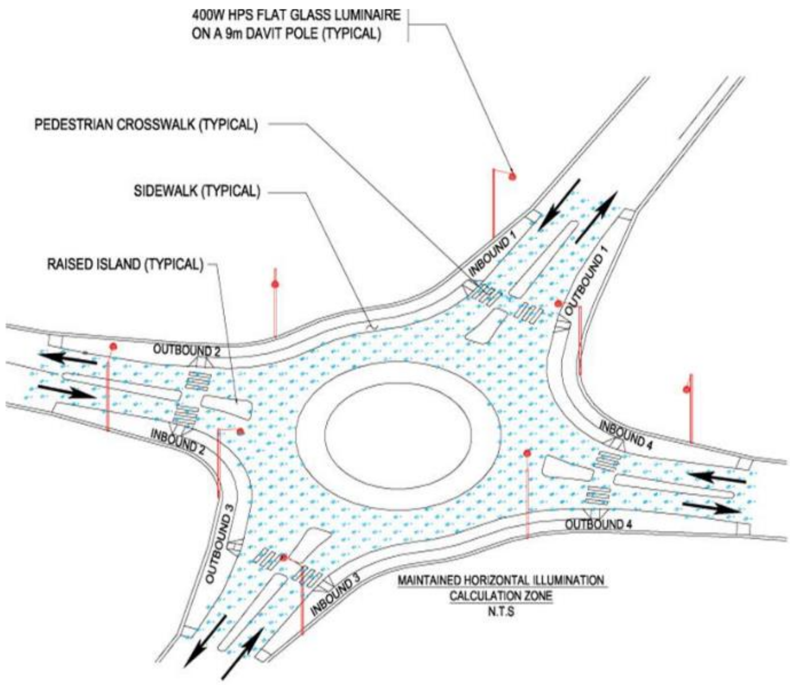
Lighting of roundabouts serves two main purposes:

1. It provides visibility from a distance for drivers approaching the roundabout.
2. It provides visibility of the key conflict areas to improve drivers' perception of the layout and visibility of other users within the roundabout.

Lighting located around the perimeter of the roundabout provides better visibility of pedestrians and obstructions than lighting located in the center.

According to IES DG-19-08, approach lighting should be used providing 20 to 40 vertical lux in crosswalks, if present, at roundabouts.

## *Roundabout Lighting (continued)*
## *Module 4, Slide 40*

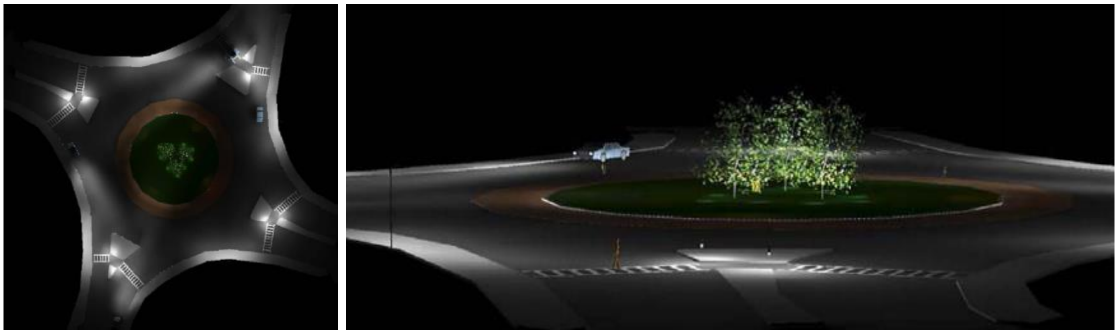



*Recommendations for placement of lighting within a roundabout. Light fixtures are shown in red.*

A roundabout may have continuous lighting on the approach roads. This lighting will help a driver adapt to the roundabout lighting. Where there is no lighting on the approach roads lighting should be added on the approach roads for a distance of approximately 80 m from the start of the roundabout.

The lighting level used in a roundabout should be equivalent to the intersection lighting level included in IES RP-8-14, Standard Practice for Roadway Lighting.

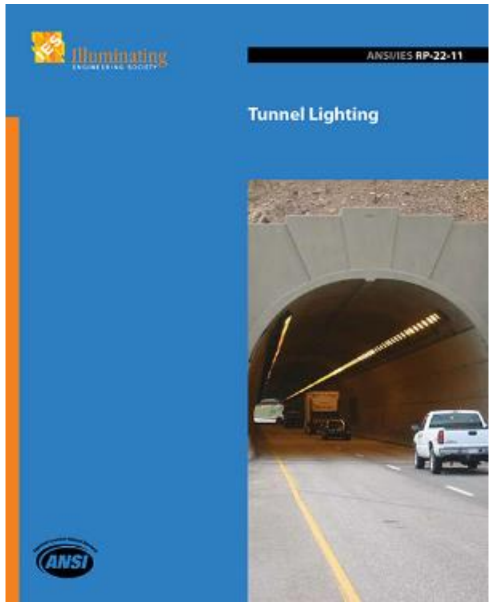
***New Approach to Roundabout Lighting***
***Module 4, Slide 41***



*Computer renderings of the Ecoluminance roundabout lighting layout.*

At roundabouts, pedestrian crosswalks appear in non-traditional locations as compared to those at intersections, and conventional overhead lighting does not enhance contrast of pedestrians. In a field study conducted by the Lighting Research Center, researchers installed bollard-based crosswalk lighting in conjunction with landscape and low-level overhead lighting. This resulted in a 75% energy use reduction. The bollard lighting enhanced visibility of pedestrians, while the landscape lighting helped to direct drivers through the roundabout. This design technique is referred to as *Ecoluminance* due to its use of lighting on existing ecological features within and around the roundabout. While not yet incorporated into national standards, this approach is being used by several transportation agencies.

***Lighting for Tunnels***
***Module 4, Slide 42***




*IES Recommended Practice for Tunnel Lighting.*

Unlike roadways, which are lighted by daylight during the day, tunnels must be lighted both during the day and at night.

The objectives of tunnel lighting are to:

1. Allow traffic to enter, pass through, and exit the enclosed section of the tunnel safely.

2. Do so without impeding the flow-through of traffic.

The IES publication RP-22-11, *Standard Practice for Tunnel Lighting*, provides recommendations for the lighting of tunnels.

***Lighting for Tunnels (continued)***
***Module 4, Slide 43***

*The entrance to a lighted tunnel.*

It is important to consider several zones when lighting a tunnel. The lighting for each zone will be different to allow drivers to enter the tunnel, adapt to the light levels within the tunnel, safely pass through the tunnel, and adapt to the light levels as they exit the tunnel.

**Approach Zone:** The external roadway area leading to the tunnel.

**Threshold Zone:** The interior area near the entrance and exit of the tunnel.

**Transition Zone:** The area between the threshold zone and the interior zone.

**Interior Zone:** The area within the tunnel where drivers eyes have adapted to the interior light levels. This is often the longest stretch of the tunnel.

***Tunnel Lighting Zones***
***Module 4, Slide 44***


*A view of the approach zone to a tunnel.*

**Approach Zone:** Due to high light levels at the approach to the tunnel during the day, the tunnel lighting system must provide enough light to allow drivers to see inside the tunnel. If it does not, the tunnel will look like a black hole, which will cause drivers to slow down.

**Threshold Zone:** A substantial amount of light must be provided in this zone to reach an acceptable reduction from the exterior to the interior luminance so that the eye can adapt.

**Transition Zone:** Light levels are reduced at a rate of no more than 3 to 1 in this zone until the interior zone light level is reached.

**Interior Zone:** The light levels for this zone will vary based on traffic volume and speed.

***Knowledge Check***
***Module 4, Slide 45***

*Select the correct answer:*

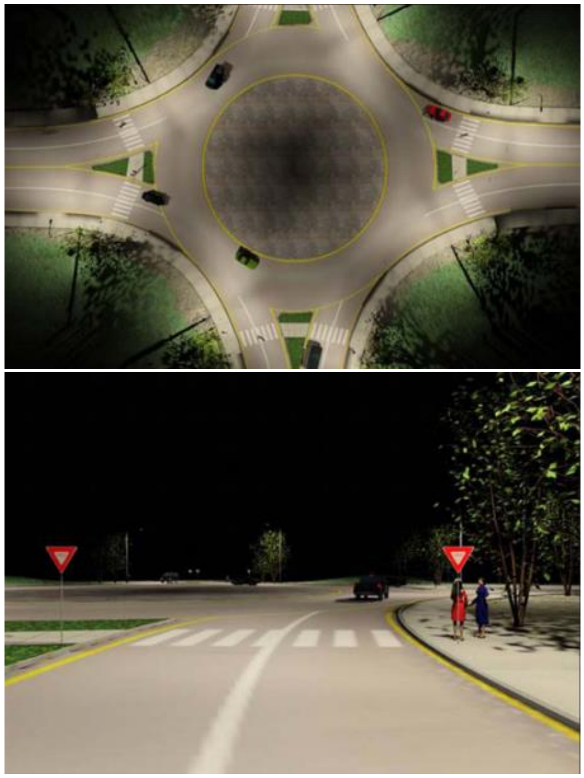
To ensure good visibility in a roundabout, is it best to provide lighting along the perimeter of the roundabout or lighting from the center of the roundabout?

□ A) It is best to light the roundabout from the center

□ B) It is best to light the roundabout from the perimeter

*The correct answer is on the following page.*

***Knowledge Check Answer***
***Module 4, Slide 46***



*A rendering of a roundabout lighted from the perimeter.*

The correct answer is B.

Lighting located around the perimeter of the roundabout provides better visibility of pedestrian and obstructions than lighting located in the center.

***Spectral Effects of Lighting at Night***
***Module 4, Slide 47***

The following section discusses impacts of light source spectral distribution in roadway lighting applications.

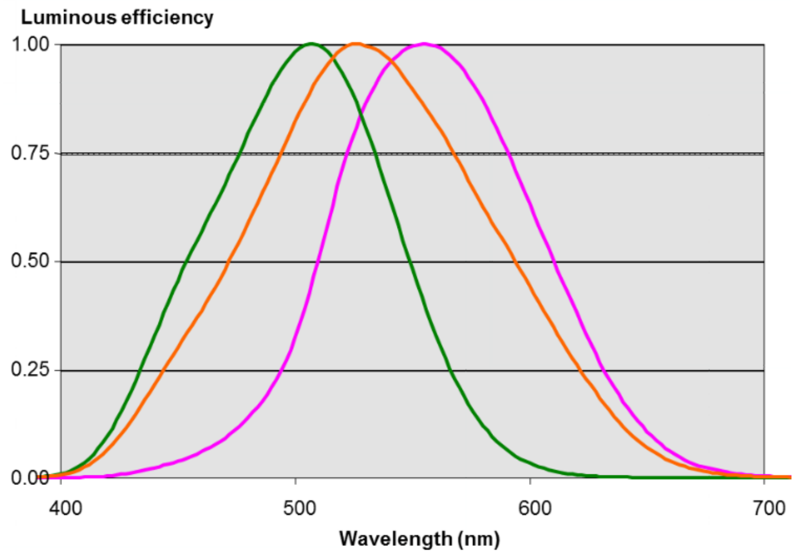
***Mesopic Vision***
***Module 4, Slide 48***


*An illustration of the different regions of human vision.*

The word ***mesopic*** is derived from the Greek word ***meso*** which means middle; and the English word ***optic*** which pertains to vision. So the word literally means "**middle vision**."

Mesopic vision describes the changes in the way people see under low light levels, like those experienced on most roadways at night. This is the area of vision between near total darkness (referred to a scotopic vision) and typical interior light levels (referred to as photopic vision). Under scotopic light levels the human eye exclusively uses its rod photoreceptors. Under photopic light levels, the cone photoreceptors are dominant.

## *Mesopic Vision (continued)*
## *Module 4, Slide 49*

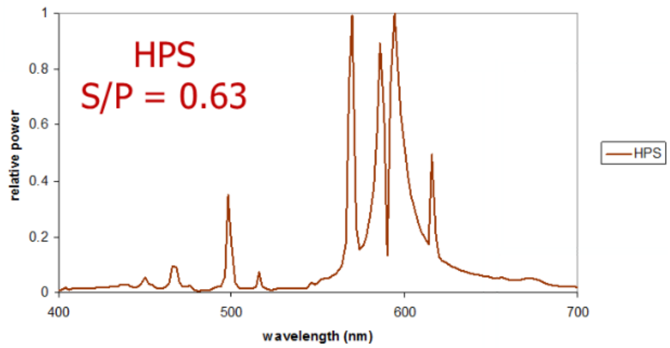


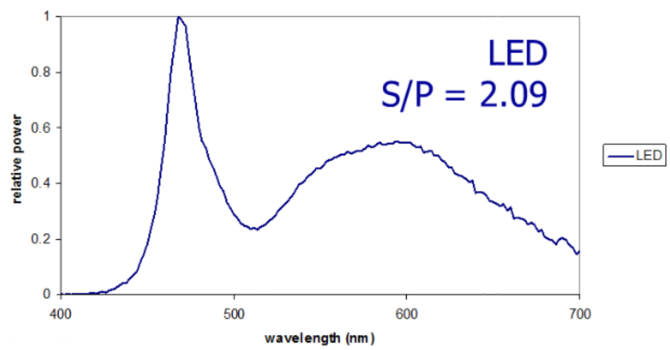

*On the graph above, the peak wavelength sensitivity of rods (scotopic vision) is shown in green. The peak sensitivity of cones (photopic vision) is shown in pink. The mesopic region is shown in orange.*

In the middle or mesopic region of vision, the eye relies on both the rod and cone photoreceptors to varying degrees. This visual region is dynamic, and changes with light level. The lower the light level in the mesopic region the more the rod photoreceptors play a role; the higher the light levels in the mesopic region the more the cone photoreceptors play a role.

This is important because the spectral sensitivity of rod and cone photoreceptors are different. Rod photoreceptors are more sensitive to shorter wavelengths of light than cone photoreceptors. Therefore, as light levels decrease, the visual effectiveness of light sources changes. Light sources with more short wavelength content, such as most LEDs, become more visually effective than light sources, like high pressure sodium (HPS), which have more long wavelength content.

## *Mesopic Vision and S/P Ratios*
## *Module 4, Slide 50*




*Spectral power distributions and S/P ratios of 2 light sources. The light source with more short wavelength energy (LED) has a higher S/P ratio. The SPD curves show the relative amount of energy produced by the light source at each wavelength, from short visible wavelengths (violet/blue) to long wavelengths (yellow//red).*

The first step in determining the mesopic visual efficacy of a particular light source, is to find the scotopic/photopic (S/P) ratio for the source. The S/P ratio provides the relative stimulation of the rod photoreceptors in the eye (scotopic vision) for equal photopic light levels. In other words, if the light source were to be used to provide very low (scotopic) light levels, this ratio would allow you to calculate the visual efficacy of the light source at that level.

As an example, you want to compare two light sources each providing 10,000 lumens. These lumens are rated at photopic light levels.

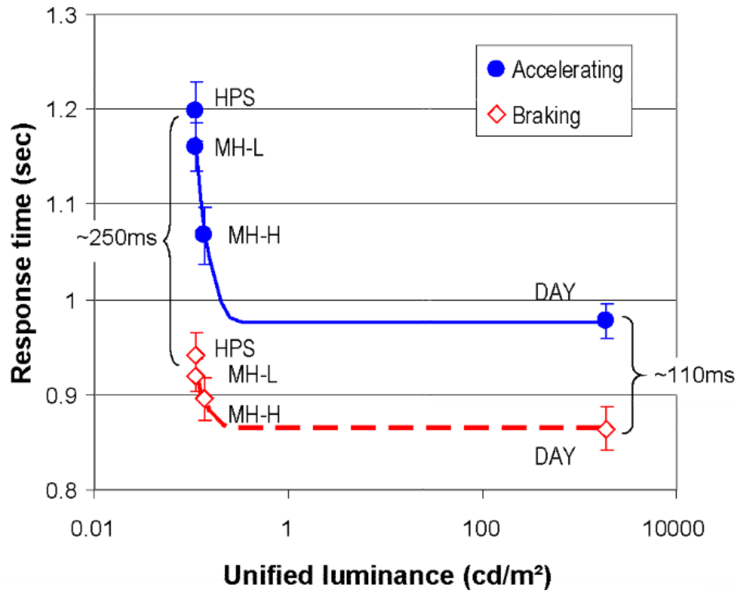
- The 1st light source has an S/P ratio of 0.5.
- The 2nd light source has an S/P ratio of 1.5.

Therefore at scotopic (near dark) light levels:

- The 1st light source will provide 5,000 scotopic lumens.
- The 2nd light source will provide 15,000 scotopic lumens.

S/P ratios for all light sources used for outdoor lighting are available from the manufacturer.

***Mesopic Visual Efficacy***
***Module 4, Slide 51***




*This graph shows response times of drivers as a function of unified luminance of the targets, including headlamp contributions.*

The S/P ratio allows you to calculate the visual efficacy of a light source at scotopic levels. But roadways are not lighted to levels that low. Therefore, you must adjust the S/P ratio depending upon the luminance level of the roadway you are designing. This is done based on a photometric system called the Unified System of Photometry. This system was developed by researchers doing field studies which measured reaction times of drivers under light sources of different S/P ratios at night.

In these studies researchers compared drivers' responses to a target located at the side of the road. This was done both under high pressure sodium (HPS) and metal halide (MH) light sources. HPS has a much lower S/P ratio than MH.  For both acceleration and braking, drivers' performance under MH at 5 lux was equivalent to their performance under HPS at 9 lux. This showed that MH, with the higher S/P ratio, was 40% more visually effective than the HPS.

Most LED sources will also have higher S/P ratios compared to HPS.

## *Unified System of Photometry*
## *Module 4, Slide 52*

**Base light level (photopic luminance (cd/m$^2$)**

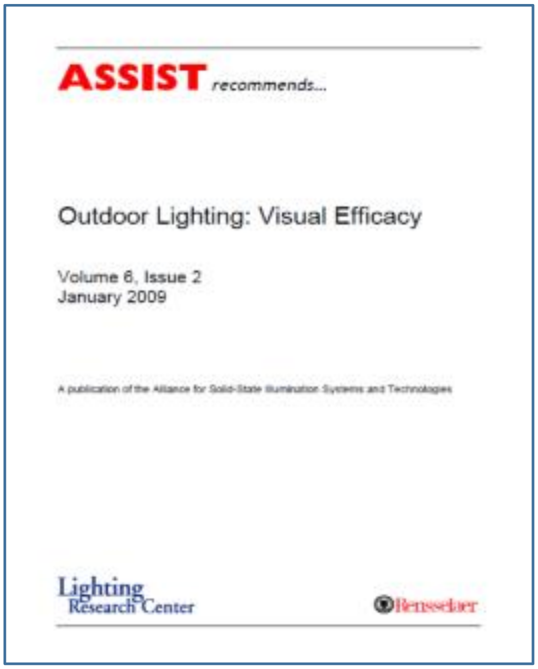
| **S/P** | **0.14** | **0.16** | **0.18** | **0.20** | **0.22** | **0.24** | **0.26** | **0.28** | **0.30** | **0.32** | **0.34** | **0.36** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.25** | 0.0573 | 0.0704 | 0.0849 | 0.1009 | 0.1184 | 0.1373 | 0.1574 | 0.1788 | 0.2012 | 0.2246 | 0.2487 | 0.2736 |
| **0.45** | 0.0864 | 0.1026 | 0.1197 | 0.1377 | 0.1565 | 0.1760 | 0.1963 | 0.2172 | 0.2387 | 0.2607 | 0.2831 | 0.3060 |
| **0.65** | 0.1092 | 0.1273 | 0.1459 | 0.1649 | 0.1844 | 0.2043 | 0.2245 | 0.2451 | 0.2659 | 0.2871 | 0.3085 | 0.3301 |
| **0.85** | 0.1283 | 0.1477 | 0.1672 | 0.1869 | 0.2068 | 0.2268 | 0.2470 | 0.2672 | 0.2876 | 0.3081 | 0.3286 | 0.3492 |
| **1.05** | 0.1448 | 0.1651 | 0.1853 | 0.2054 | 0.2255 | 0.2456 | 0.2656 | 0.2856 | 0.3055 | 0.3254 | 0.3452 | 0.3651 |
| **1.25** | 0.1593 | 0.1803 | 0.2010 | 0.2215 | 0.2417 | 0.2617 | 0.2816 | 0.3013 | 0.3208 | 0.3402 | 0.3594 | 0.3786 |
| **1.45** | 0.1724 | 0.1940 | 0.2150 | 0.2357 | 0.2560 | 0.2759 | 0.2956 | 0.3150 | 0.3341 | 0.3531 | 0.3718 | 0.3903 |
| **1.65** | 0.1843 | 0.2063 | 0.2276 | 0.2484 | 0.2687 | 0.2886 | 0.3081 | 0.3272 | 0.3460 | 0.3645 | 0.3827 | 0.4007 |
| **1.85** | 0.1952 | 0.2175 | 0.2391 | 0.2599 | 0.2802 | 0.3000 | 0.3193 | 0.3381 | 0.3566 | 0.3747 | 0.3924 | 0.4099 |
| **2.05** | 0.2053 | 0.2279 | 0.2496 | 0.2705 | 0.2907 | 0.3103 | 0.3294 | 0.3480 | 0.3661 | 0.3838 | 0.4012 | 0.4182 |
| **2.25** | 0.2146 | 0.2374 | 0.2592 | 0.2801 | 0.3003 | 0.3198 | 0.3387 | 0.3570 | 0.3748 | 0.3922 | 0.4091 | 0.4257 |

*The chart above, taken from the Outdoor Lighting: Visual Efficacy publication shown on the next page, compares the relative mesopic visual efficacy of HPS (the row denoted by S/P=0.65) with LED (the row denoted by S/P=2.05) for local residential roads (average luminance=0.3 cd/m²).*

The Unified System of Photometry is generally used to determine the visual effectiveness of a new or replacement light source, to an existing light source, for example, to compare an LED to an HPS you are replacing.

If you know you want to provide the same visual effectiveness of an HPS light source (S/P 0.65) at a luminance of 0.3 cd/m², with an LED light source (S/P 2.05), you first find the mesopic level for HPS under the 0.3 cd/m² column for its S/P ratio. You then go to the S/P ratio of LED (S/P 2.05), and find approximately the same mesopic level. The column in which you find this level determines the luminance level to which you should design to provide the same visual effectiveness of the HPS light source at 0.3 cd/m². In the case shown on the chart at right, you know you can design to a luminance of 0.2 cd/m² using the LED and your installation will provide the visual effectiveness of the HPS at  a luminance of 0.3 cd/m².

***Unified System of Photometry (continued)***
***Module 4, Slide 53***


ASSIST recommends...

Outdoor Lighting: Visual Efficacy

Volume 6, Issue 2
January 2009

A publication of the Alliance for Solid-State Illumination Systems and Technologies

Lighting Research Center
Rensselaer

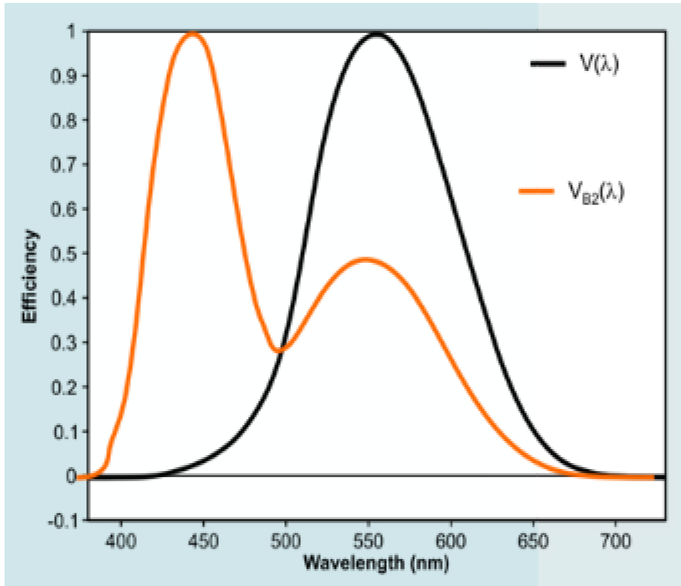
*A guide to using the Unified System of Photometry.*

A guide to using the Unified System of Photometry including the charts used to find luminance equivalents of light sources with a wide variety of S/P ratios is available online at the following link:

http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-VisualEfficacy-Jan2009.pdf

The Unified System of Photometry more accurately characterizes different light sources at any light level, facilitating the specification of effective lighting systems for different applications, including those used outdoors at night.

***Brightness Perception***
***Module 4, Slide 54***



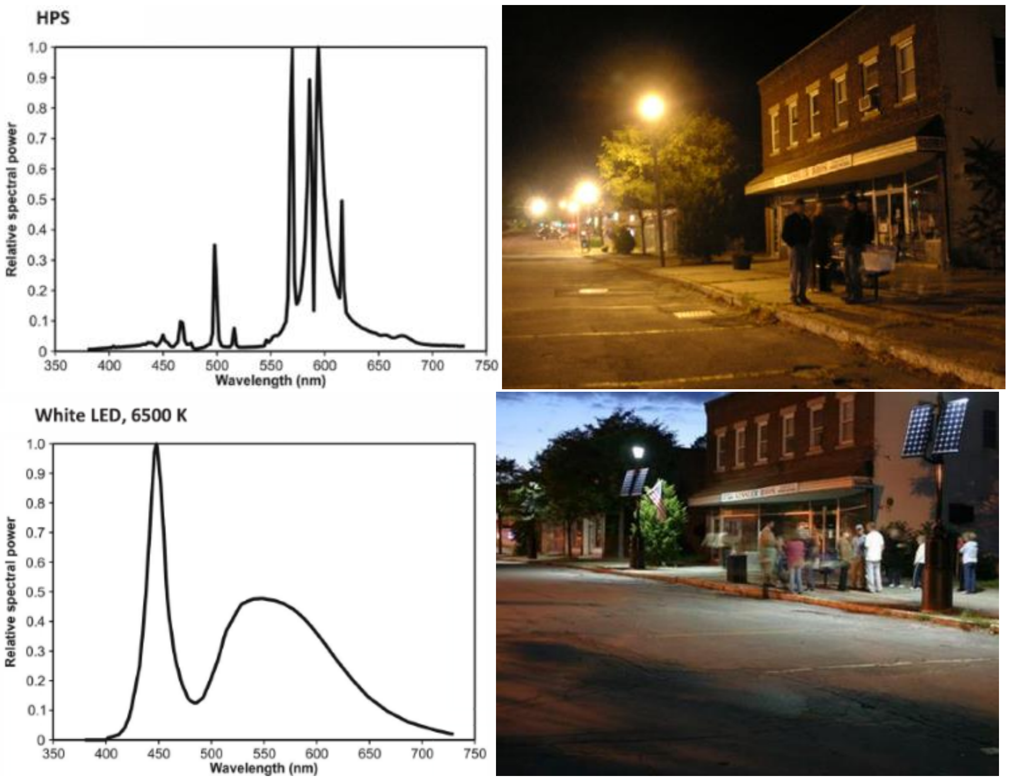

*A graph showing the spectral sensitivity of the human eye for brightness at night [$V_{B2}(\lambda)$] in orange, as compared to the photopic spectral sensitivity curve [$V(\lambda)$], shown in black.*

Similarly to the way that the sensitivity of the human visual system to the spectral wavelengths of light changes as light levels vary at night, our eyes also perceive brightness differently from the photopic spectral sensitivity curve used to determine the lumen output of a light source.

As shown on the graph at right, the response of our eye to brightness (shown by the curve in orange on the graph) is significantly different than the photopic visual sensitivity curve (shown in black).

This mean that light sources that provide more spectral power under the orange curve, such as many LEDs, will appear brighter than their lumen output would predict.

***Brightness Perception and Sense of Security***
***Module 4, Slide 55***




*Graphs showing the spectral power distributions of HPS (top) and LED (bottom) light sources with installation pictures.*

Research has shown that when people perceive an outdoor area, such as a parking lot or street, to be brighter at night, their sense of personal safety and security improves. Therefore, if one of the objectives of a lighting installation is to make people feel safe in an area at night, using the spectral sensitivity curve for brightness will help you to achieve this objective.

Based on the spectral sensitivity of the eye for brightness perception, the illuminance from an LED light source would only need to produce 54 percent of the illuminance from an HPS source to appear equally bright.

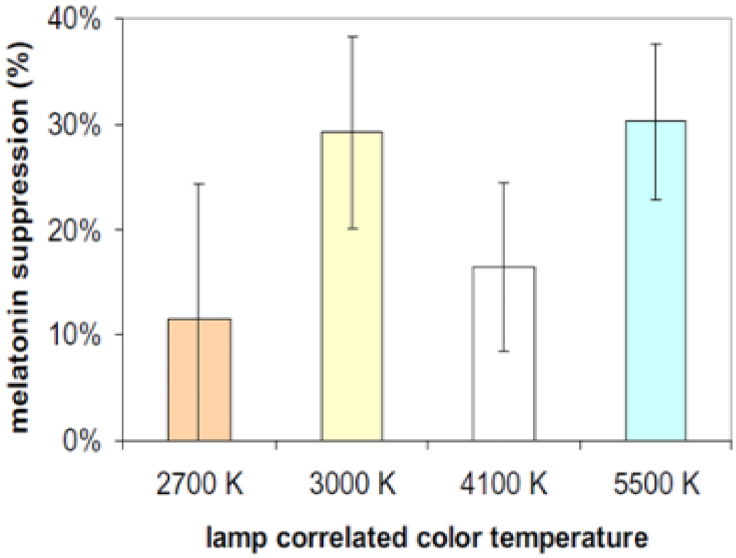
***Summary***
***Module 4, Slide 56***

An HPS installation (left); a white light source installation (right).

When nighttime visibility and brightness (safety/security perception) is important, existing “white” light sources provide equivalent (or better) performance with ~30%-40% less energy than sources such as HPS.

The spectra of LED sources can be selected to provide the visual response you wish to achieve.

***Circadian Impacts of Roadway Lighting***
***Module 4, Slide 57***

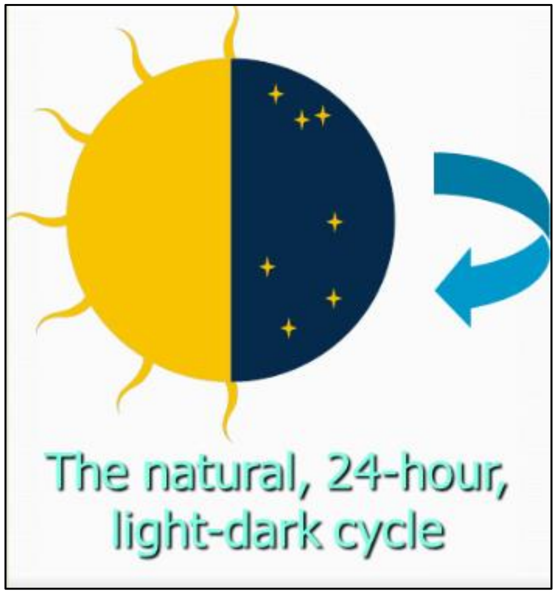



*Graph showing the suppression of the hormone melatonin by light sources of various CCTs. Melatonin suppression is a measure of the degree to which each light source can disrupt the normal functioning of the human circadian system.*

There have recently been some concerns expressed about the negative impacts that outdoor lighting, especially from LEDs, might have on people's health. The concern is that outdoor lighting may disrupt the body's biological clock, referred to as the body's circadian system. Disruption of this system has been shown to have several negative impacts on a person's health.

Some organizations have recommended that roadway lighting designers select light sources with lower correlated color temperatures (CCTs) to help prevent this disruption. However CCT is not a good measure of the spectral output of a light source or its impact on the human circadian system. As shown on the graph at the right, a light source with a lower CCT (e.g., 3000 K) may actually have more of a disruptive impact on the circadian system than a light source with a higher CCT (e.g., 4100 K). Therefore CCT is not a good measure to use for this purpose.

*Circadian Impacts of Roadway Lighting (continued)*
*Module 4, Slide 58*




In order for light to impact our circadian system, the light needs to be at a relatively high level, and we need to be exposed to it for a significant period of time. In general, magnitudes of street lighting are too low to have substantial impacts on circadian rhythms in the general population.

This is still an area where research is ongoing; however, at this time negative impacts on the human circadian system should probably not be a concern in the design and specification of roadway lighting.

This however does not mean that lights should not be shielded or controlled in order to avoid light trespass or glare.

***Self-Assessment Quiz***
***Module 4, Slides 59 to 69***

Please answer each question.

1. Lighting poles placed on the roadside of interstate highways should be breakaway and located at least ____ from the lane edge.
□ A) 15 feet
□ B) 10 meters
□ C) The same distance as the mounting height of the luminaire
□ D) 3 feet

2. When a roadway or pedestrian lighting project includes new or existing trees in close proximity to the lighting, an additional light loss factor of _____ should be included in the design to accommodate light loss due to shading.
□ A) an amount equal to the target illuminance on the pavement
□ B) 50 percent
□ C) 10 to 20 percent
□ D) An amount equal to the mounting height of the luminaire

3. Full intersection lighting should be installed whenever the intersecting roads are not illuminated.
□ A) True
□ B) False

4. When specifying partial lighting for a freeway interchange ____________ should be lighted.
□ A) all of the ramps
□ B) the key decision-making locations along the interchange
□ C) only the connecting roads
□ D) only the entrance and exit points

5. For mid-block crosswalks, it is recommended that lighting be placed on each side of the roadway approximately 15 feet in front of the crosswalk.
□ A) True
□ B) False

6. Lighting located ________ of a roundabout provides better visibility of pedestrian and other vehicles.
□ A) in the center
□ B) at entry and exit points
□ C) at the approach
□ D) around the perimeter

7. In the transition zone of tunnel lighting, light levels are reduced at a rate of no more than ______ until the interior zone light level is reached.

□ A) 3 to 1
□ B) 5 to 1
□ C) 10 to 1

8. Scotopic vision describes the way people see under typical daytime light levels.

□ A) True
□ B) False

9. Correlated Color Temperature (CCT) is a good measure of the impact a light source will have on peoples’ circadian systems.

□ A) True
□ B) False

***See the following page for the answer key to this self-assessment.***

***Self-Assessment Quiz Answer Key***
***Module 4, Slides 59 to 69***

*The correct answers for the self-assessment are provided below.*

1. Lighting poles placed on the roadside of interstate highways should be breakaway and located at least ____ from the lane edge.
☑ A) 15 feet *(see Module 4, Slide 9)*
□ B) 10 meters
□ C) The same distance as the mounting height of the luminaire
□ D) 3 feet

2. When a roadway or pedestrian lighting project includes new or existing trees in close proximity to the lighting, an additional light loss factor of _____ should be included in the design to accommodate light loss due to shading.
□ A) an amount equal to the target illuminance on the pavement
□ B) 50 percent
☑ C) 10 to 20 percent *(Module 4, Slide 13)*
□ D) An amount equal to the mounting height of the luminaire

3. Full intersection lighting should be installed whenever the intersecting roads are not illuminated.
□ A) True
☑ B) False *(Module 4, Slide 21)*

4. When specifying partial lighting for a freeway interchange ____________ should be lighted.
□ A) all of the ramps
☑ B) the key decision-making locations along the interchange *(Module 4, Slide 28)*
□ C) only the connecting roads
□ D) only the entrance and exit points

5. For mid-block crosswalks, it is recommended that lighting be placed on each side of the roadway approximately 15 feet in front of the crosswalk.
☑ A) True *(Module 4, Slide 32)*
□ B) False

6. Lighting located ________ of a roundabout provides better visibility of pedestrian and other vehicles.
□ A) in the center
□ B) at entry and exit points
□ C) at the approach
☑ D) around the perimeter *(Module 4, Slide 39)*

7. In the transition zone of tunnel lighting, light levels are reduced at a rate of no more than ______ until the interior zone light level is reached.

☑ A) 3 to 1 *(Module 4, Slide 44)*
□ B) 5 to 1
□ C) 10 to 1

8. Scotopic vision describes the way people see under typical daytime light levels.

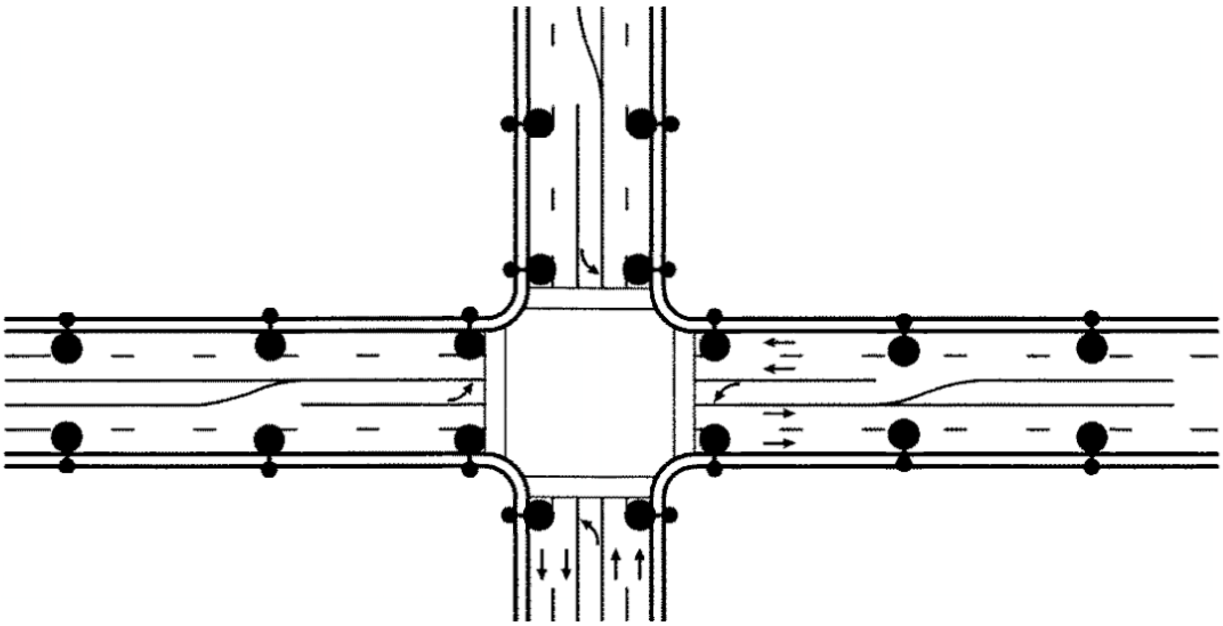
□ A) True
☑ B) False *(Module 4, Slide 48)*

9. Correlated Color Temperature (CCT) is a good measure of the impact a light source will have on peoples' circadian systems.

□ A) True
☑ B) False *(Module 4, Slide 57)*

*Extended Example Problem*

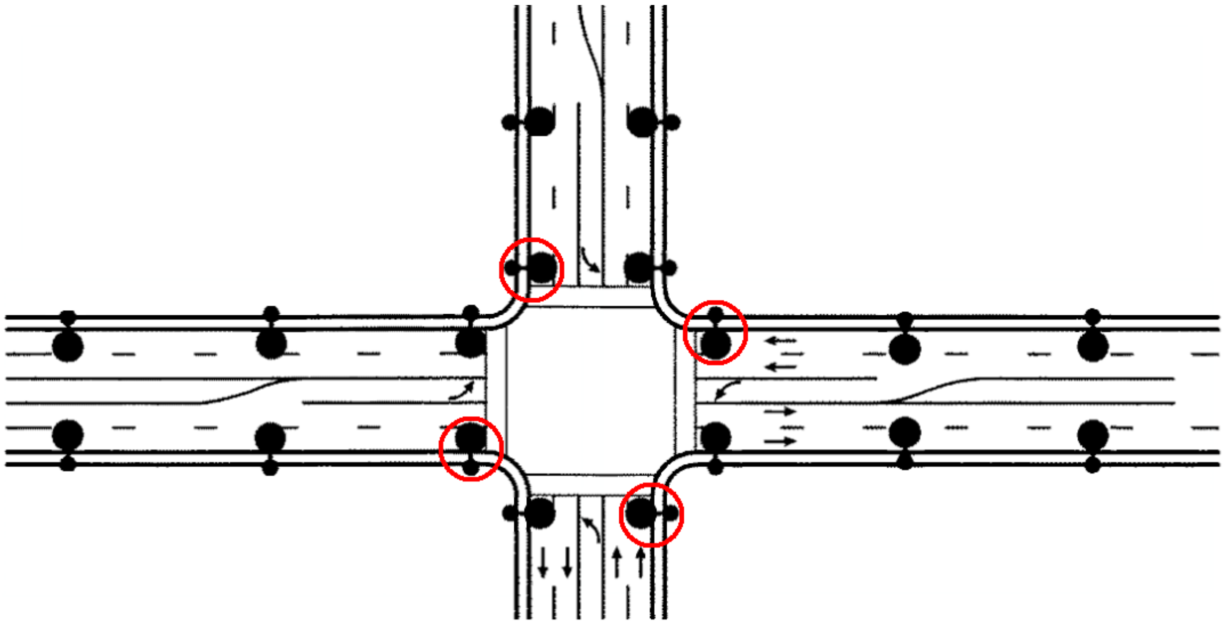
For the intersection shown below, circle the luminaires (shown in black) that should be used to ensure that pedestrians in the crosswalks will be visible.



***See the following page for the answer to this extended example problem.***

***Extended Example Problem (Answer Key)***

For the intersection shown below, the circled luminaires would likely be used to ensure that pedestrians are visible to oncoming drivers.



*References and Other Resources*
*Module 4, Slide 70*


**Roundabouts: An Informational Guide, 2nd Edition**
http://www.trb.org/publications/blurbs/164407.aspx

**AASHTO Roadside Design Guide**
https://bookstore.transportation.org/collection_detail.aspx?ID=105

**Informational Report on Lighting Design for Midblock Crosswalks**
https://www.fhwa.dot.gov/publications/research/safety/08053

**IES Design Guide for Roundabouts, DG-19-08**
https://www.ies.org/store/design-guides/roundabout-lighting/

**IES Standard Practice for Tunnel Lighting, RP-22-11**
https://www.ies.org/store/recommended-practices-and-ansi-standards/tunnel-lighting/

**ASSIST Recommends: Outdoor Lighting – Visual Efficacy**
http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-VisualEfficacy-Jan2009.pdf

**Mesopic Street Lighting Demonstration and Final Report**
http://www.lrc.rpi.edu/researchAreas/pdf/GrotonFinalReport.pdf

**FHWA 2012 Lighting Handbook**
https://safety.fhwa.dot.gov/roadway_dept/night_visib/lighting_handbook

**Trees, Lighting and Safety in Context-Sensitive Solutions**
http://dx.doi.org/10.3141/2120-11

**Demonstrating Urban Outdoor Lighting for Pedestrian Safety and Security**
http://www.utrc2.org/sites/default/files/Final-Report-Demonstrating-Urban-Outdoor-Lighting-Pedestrian-Safety.pdf

## *Credits*
## *Module 4, Slide 72*

Slide 6: Photograph courtesy of Virginia Tech Transportation Institute, WSP Global Inc., and DMD & Associates Ltd.

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