

# **BUILDING ILLUMINATION AND DAYLIGHTING**

## **BLDG 474 VV, BLDG 6731 VV**

### Lecture 2

## Fundamentals: Basic concepts and lighting metrics

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**Centre for Net-Zero Energy Building Studies (CZEBS)**  
**Department of Building, Civil, and Environmental Engineering**

# FINAL PROJECT

## Project Guidelines

- Design or research study on a topic of interest to the student (naturally, related to the course)
- Project abstract of 300 words. Due September 28<sup>th</sup> (lecture 4)

## Expectations

- Originality, thoroughness, prioritization of important aspects, academic integrity
- Individual projects for graduate students, group projects (2 people) for undergraduate students
- **Project presentation has changed to November 23<sup>rd</sup> (lecture 12)**
- Final project report due December 14<sup>th</sup>

# FINAL PROJECT

## Project ideas

- **Beacon: solar-power bus shelter in Loyola campus**  
(façade and lighting design)
- **Solar Decathlon China: private residence**  
(façade and lighting design)
- **Varennes Library: institutional building**  
(façade and lighting design)
- **Concordia living lab: private and open-space offices**  
(occupancy behaviour and lighting design)

**The project could be a design study or an experiment**

# THE SIX LIGHTING METRICS

# LUMINOUS FLUX ( $\Phi$ )

**Definition:** Luminous flux is the light-power emitted toward all directions

**Symbol:**  $\Phi$

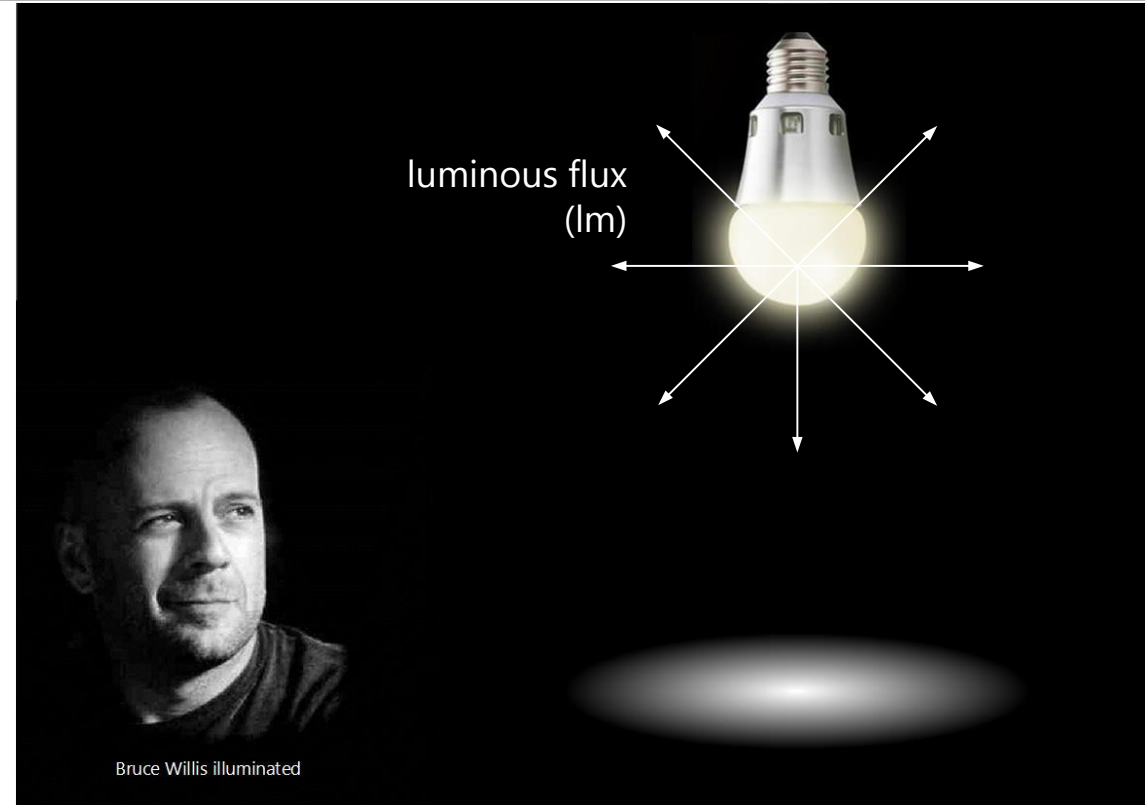
**Unit:** lumen (lm) is the "unit of light" that leaves a lightbulb

**Depends on direction:** No

**Intuitive approach:** Luminous flux is comparable to the flow of water leaving the sprinkler nearly in all directions

**Did you know:** Luminous flux is typically rated when you buy a lightbulb

Type of light bulb	Luminous flux (lm)
60-watt Edison lamp	400
12-watt LED	1,600
100-watt Incandescent	1,700
32-watt Fluorescent compact (CFL)	2,100
25-watt Fluorescent tube	2,250
250-watt High Intensity Discharge	29,000



# LUMINOUS EFFICACY ( $\eta$ )

**Definition:** Luminous efficacy is a measure of how well a light source converts electric-power to light-power

**Symbol:**  $\eta$

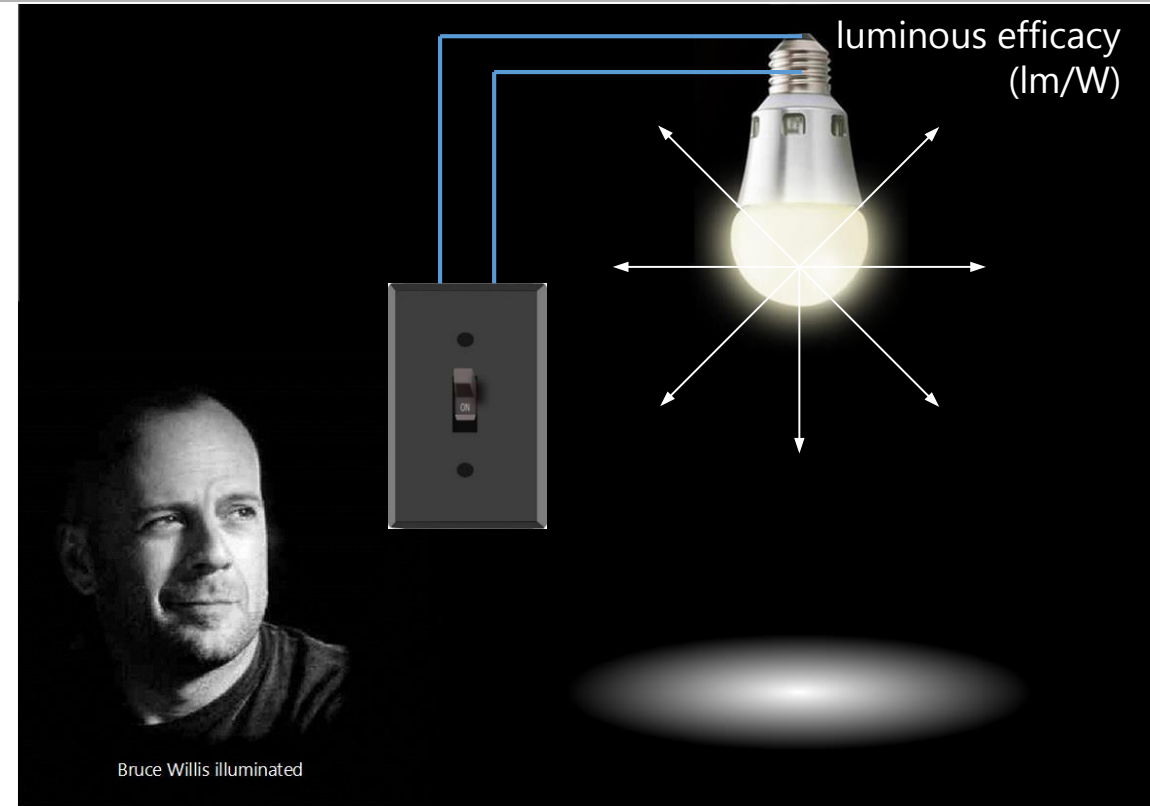
**Unit:** lm/W

**Depends on direction:** No

**Did you know:** Luminous efficacy is also rated when you buy a lightbulb

**Did you also know:** Luminous efficacy of the Sun is  $\sim 94$  lm/W

Type of light bulb	Luminous flux (lm)	Luminous efficacy (lm/W)
60-watt Edison lamp	400	7
12-watt LED	1,600	133
100-watt Incandescent	1,700	17
32-watt Fluorescent compact (CFL)	2,100	66
25-watt Fluorescent tube	2,250	90
250-watt High Intensity Discharge	29,000	116



# ILLUMINANCE (E)

**Definition:** Illuminance is the luminous flux incident on a surface, per unit area

**Symbol:** E

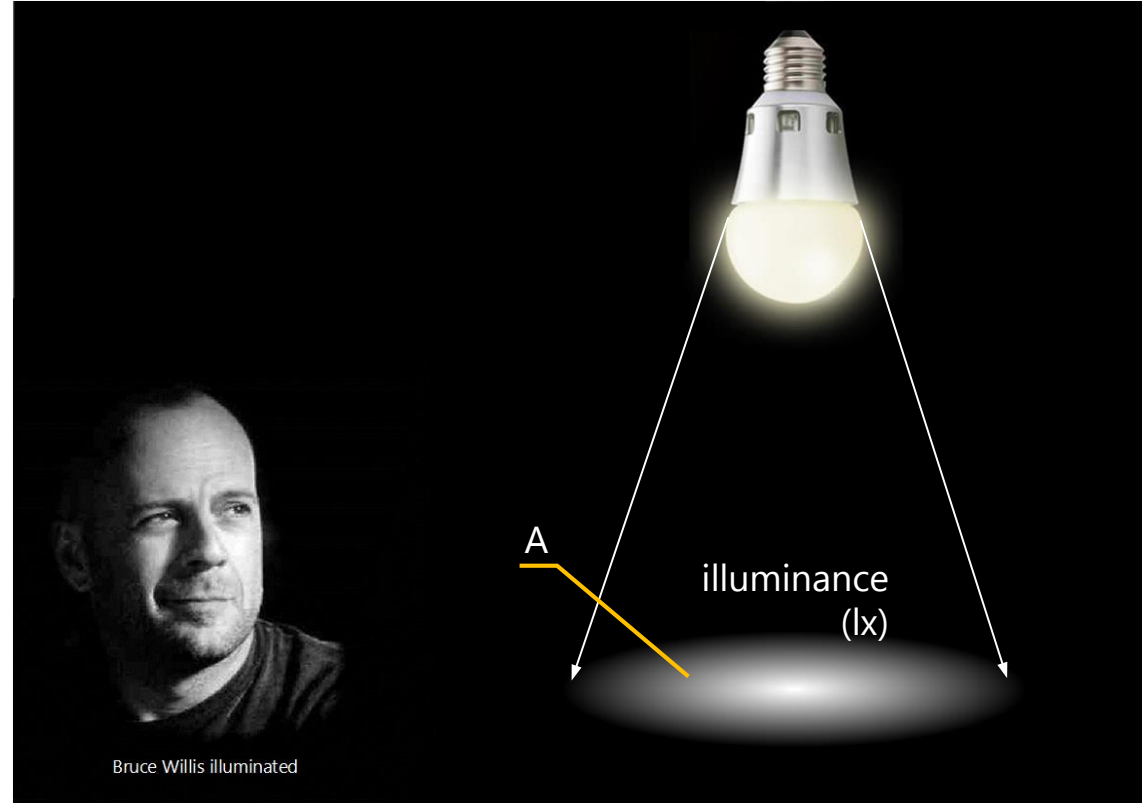
**Unit:** lux, lx (=lm/m<sup>2</sup>)

**Depends on direction:** No

**Intuitive approach:** Illuminance is comparable to the water flow that ends up on the surface area of interest

**Did you know:** Illuminance is the quantity that is most typically used to describe how well lit a place is

$$E(\text{illuminance}) = \frac{\Phi(\text{incident luminous flux})}{A(\text{surface area})}$$



# ILLUMINANCE (E)

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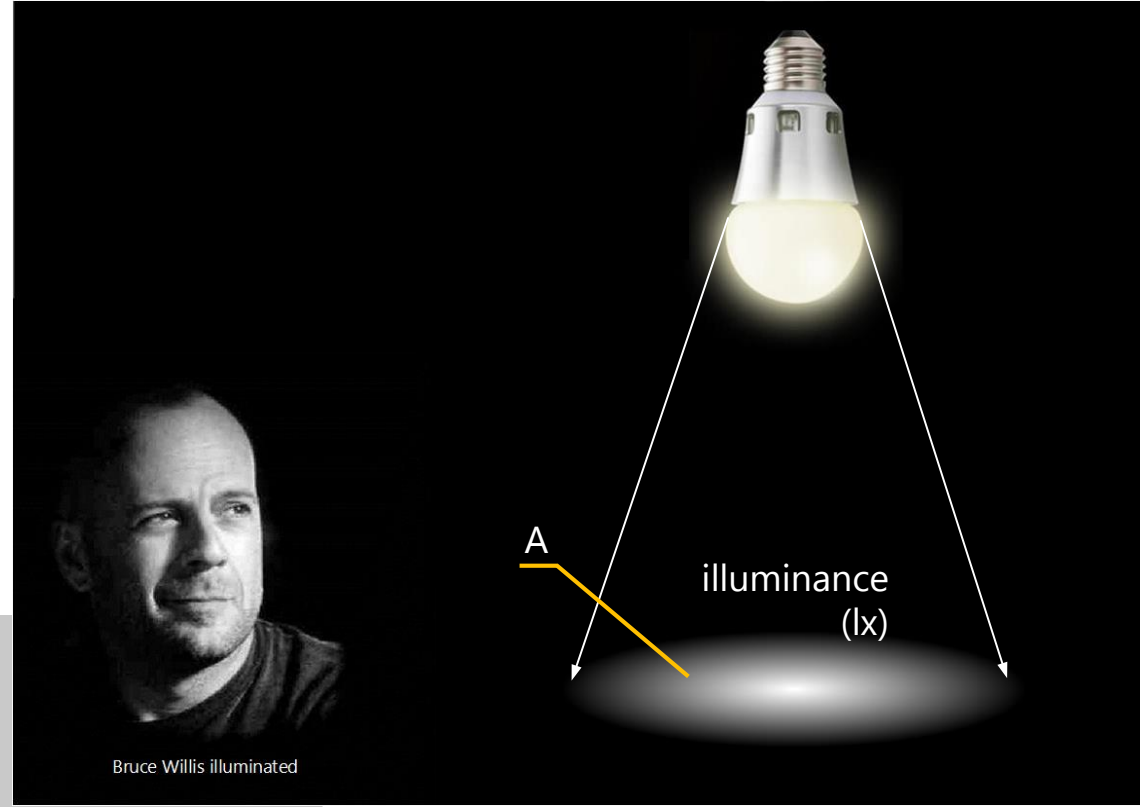
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## Recommended Target Illuminances (lux)

Visual Ages of Observers (years)  
where **at least half** are

	<25	25 to 65	>65	Some Typical Application and Task Characteristics	Visual Performance Description
Q	200	400	800	<ul style="list-style-type: none"> <li>• Some indoor education situations</li> <li>• Some indoor commerce situations</li> <li>• Some indoor sports situations</li> <li>• Some indoor industrial situations</li> </ul>	Visual performance is typically daily life- and work- related, including much reading and writing of hardcopies and electronic media consecutively and/or simultaneously.
R	250	500	1000		
S	375	750	1500		
T	500	1000	2000	<ul style="list-style-type: none"> <li>• Some sports situations</li> <li>• Some indoor commerce situations</li> <li>• Some indoor industrial situations</li> </ul>	<b>Small-scale, cognitive visual tasks</b> Visual performance is work- or sports-related, close and distant fine inspection, very small detail, high-speed assessment and reaction.
U	750	1500	3000		
V	1000	2000	4000		

SOURCE: IESNA Lighting Handbook, 10th Ed., New York, 2011.

# LUMINOUS INTENSITY (I)

**Definition:** Luminous intensity is the light-power emitted in a particular direction per unit solid angle

**Symbol:** I

**Unit:** candela, cd (=lm/sr)

**Depends on direction:** Yes

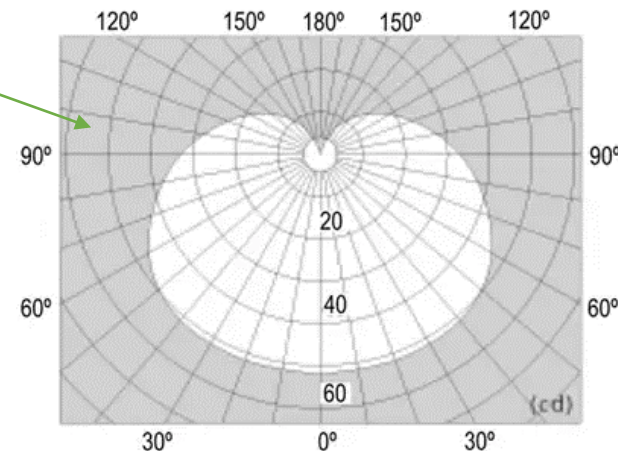
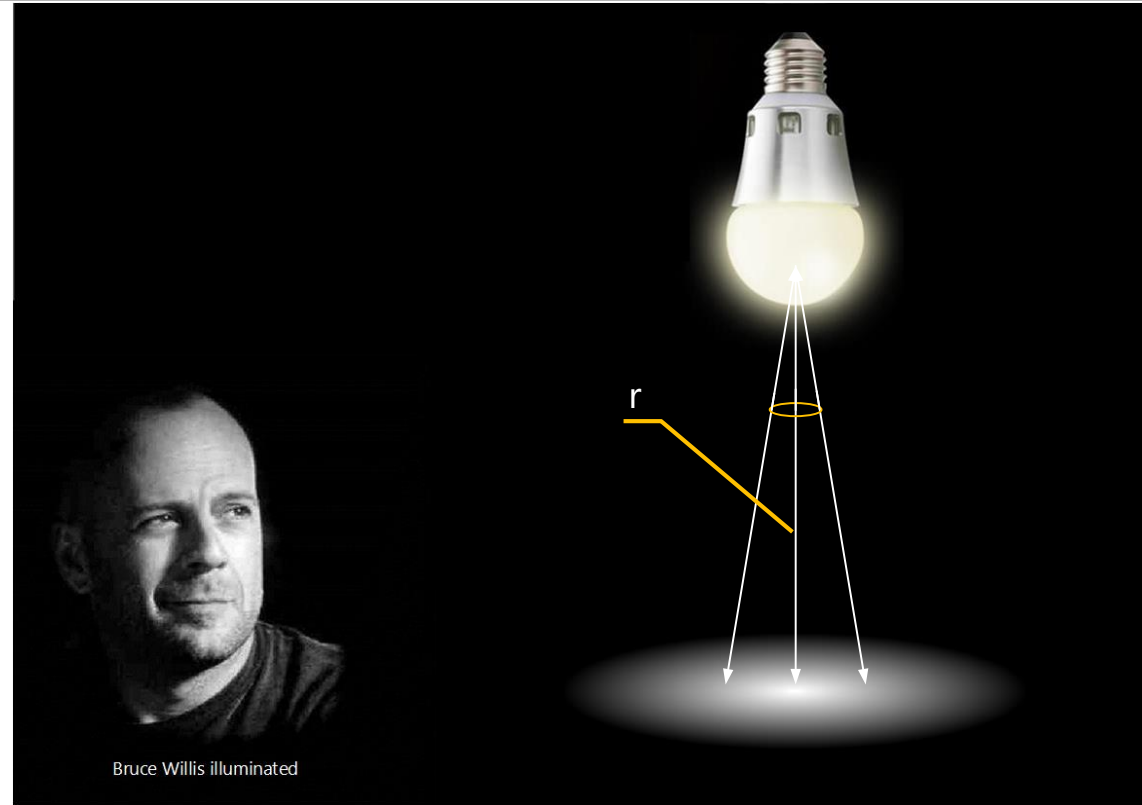
**Intuitive approach:** You can think of luminous intensity as the "pressure" or "force" pushing the light out of the lightbulb

**Did you know:** The original definition of candela, made in 1860, referred to the luminous intensity of a candle. Hence the name

**Did you also know:** Every lightbulb has its characteristic intensity distribution diagram

## Inverse Square Law of Illumination

$$E(\text{illuminance}) = \frac{I(\text{Luminous intensity})}{r^2(\text{distance from the source})}$$



# LUMINANCE (L)

**Definition:** Luminance is the intensity of a source in a given direction divided by the projected area in that direction

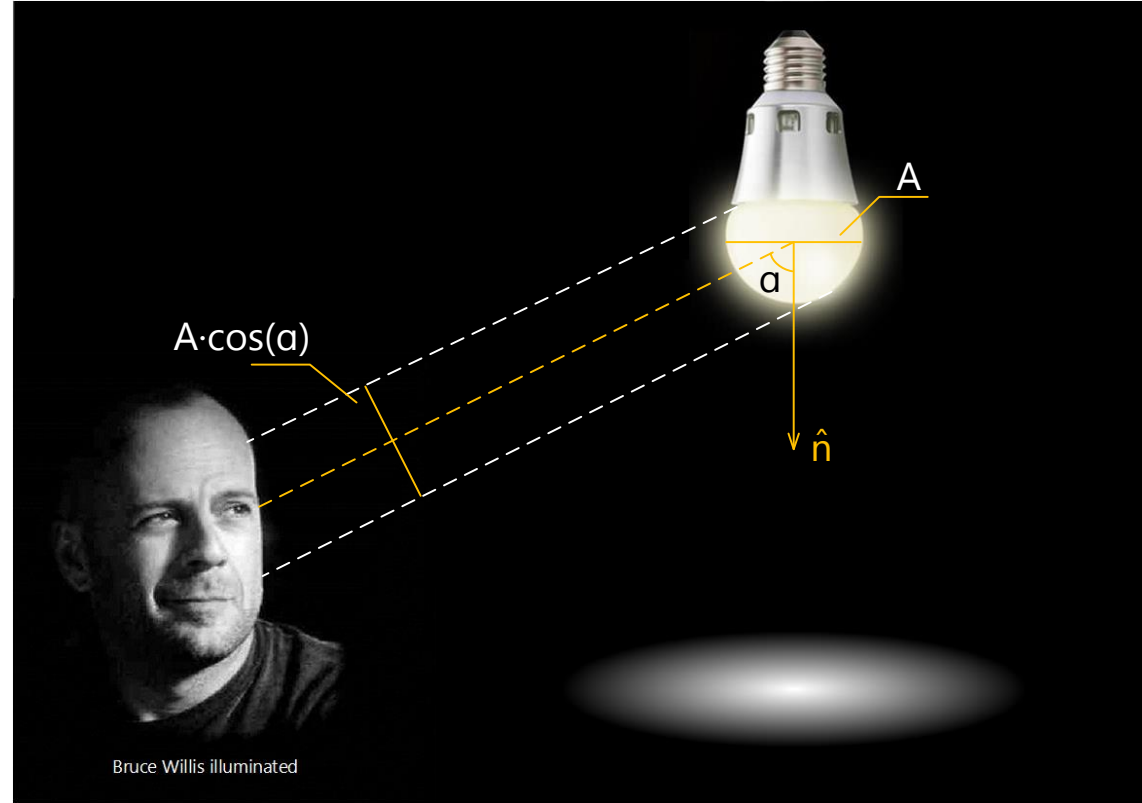
**Symbol:** L

**Unit:** cd/m<sup>2</sup>

**Depends on direction:** Yes

**Intuitive approach:** Luminance can be used to indicate how bright a surface will look. An observer sees the "luminance of a surface, but not the illuminance.

**Did you know:** High luminance or high variation on luminance (contrast) through out the visual field is what creates glare



$$L(\text{luminance}) = \frac{I(\text{Luminous intensity in the direction of the observer})}{A \cos \alpha (\text{projected area of the source seen by the observer})}$$

# LUMINANCE (L)

**Definition:** Luminance is the intensity of a source in a given direction divided by the projected area in that direction

**Symbol:** L

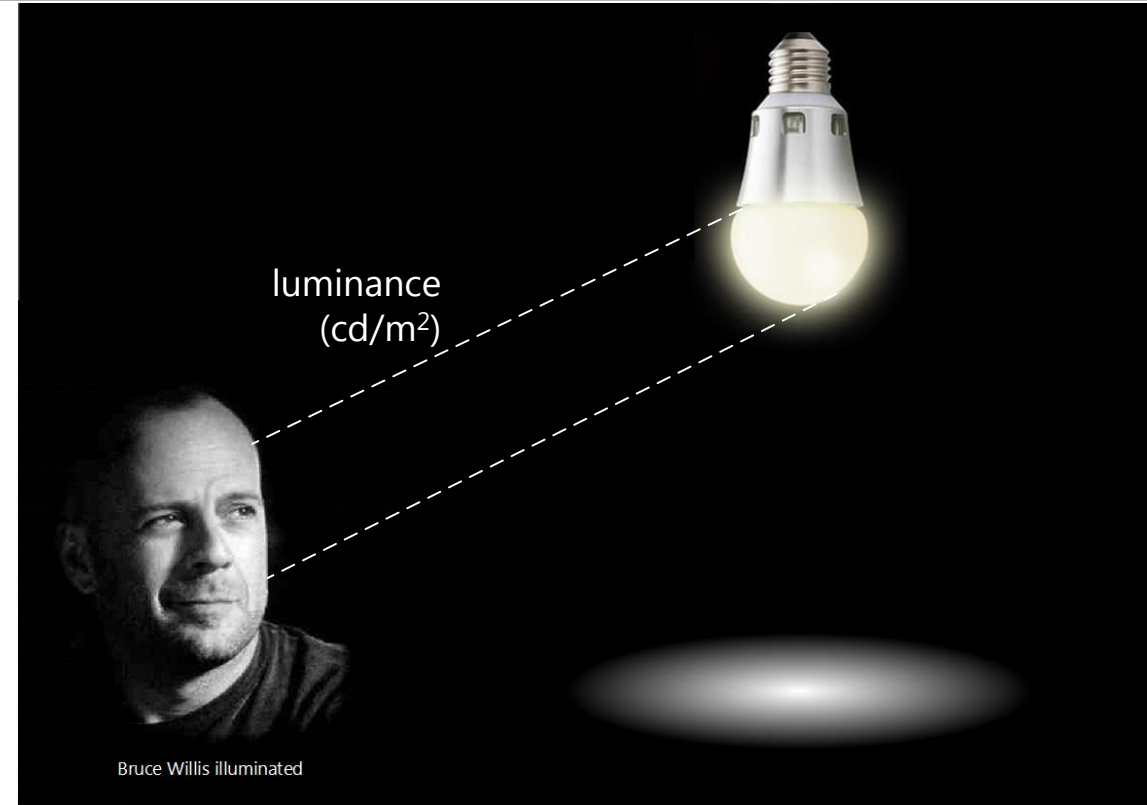
**Unit:**  $\text{cd}/\text{m}^2$

**Depends on direction:** Yes

**Intuitive approach:** Luminance can be used to indicate how bright a surface will look. An observer sees the "luminance of a surface, but not the illuminance.

**Did you know:** High luminance or high variation on luminance (contrast) through out the visual field is what creates glare

Source of Surface	Luminance ( $\text{cd}/\text{m}^2$ )
Sun	1,550,000,000
Moon	2,500
Candle	10,000
32-watt Fluorescent compact (CFL)	6,500
Zenith sky	1,100
Snow under sunlight	11,600,000



# LUMINOUS EXITANCE (M)

**Definition:** Luminous exitance is the luminous flux leaving (reflected or transmitted) a surface, per unit area

**Symbol:** M

**Unit:** lux, lx (=lm/m<sup>2</sup>)

**Depends on direction:** No

**Intuitive approach:** Luminous exitance is comparable to the amount of water that bounce off (reflected) or goes through (transmitted) the surface area of interest

**Did you know:** A Lambertian surface is one that is perfectly diffusing. By definition, a Lambertian surface has the same luminance from any point of view (L=const).

$$M(\text{luminous exitance}) = \frac{\Phi(\text{departing luminous flux})}{A(\text{surface area})} \quad (1)$$

where

$$\Phi(\text{departing}) = \rho\Phi \quad \text{or} \quad \Phi(\text{departing}) = \tau\Phi \quad (2)$$

$$(1), (2) \rightarrow M = \rho E \quad \text{or} \quad M = \tau E$$



# LUMINOUS EXITANCE (M)

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**Symbol:** M

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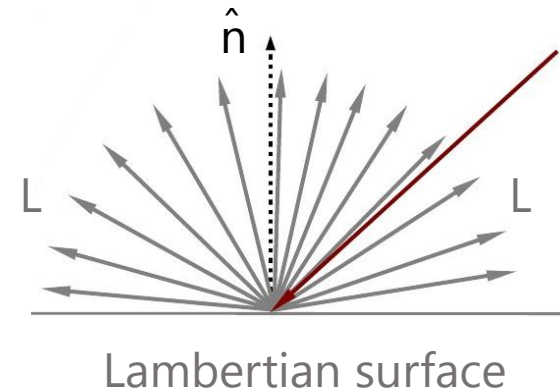
**Depends on direction:** No

**Intuitive approach:** Luminous exitance is comparable to the amount of water that bounce off (reflected) or goes through (transmitted) the surface area of interest

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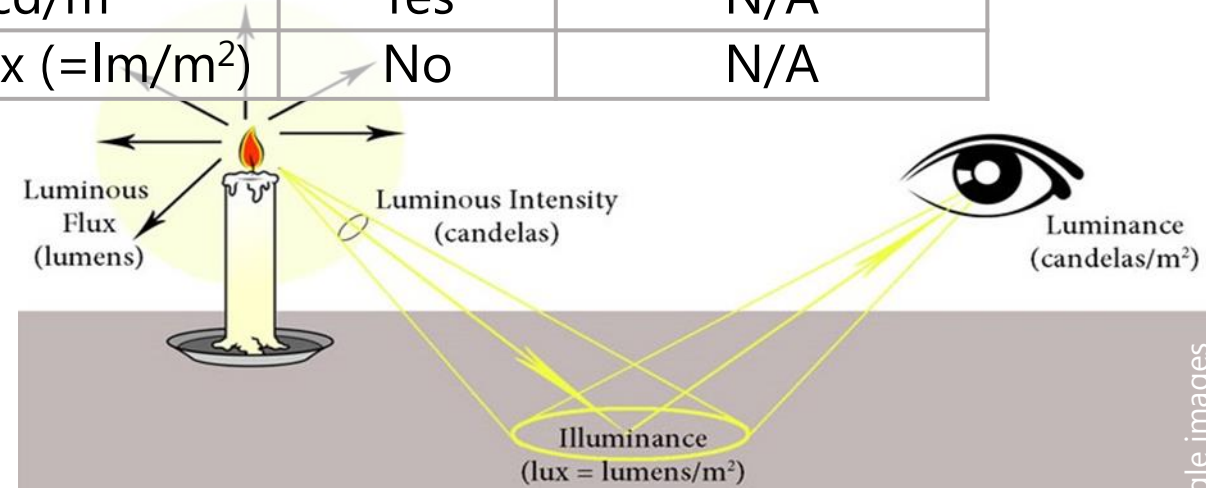
For Lambertian (perfectly diffusing) surface

$$M(\text{exitance}) = \pi L(\text{luminance})$$

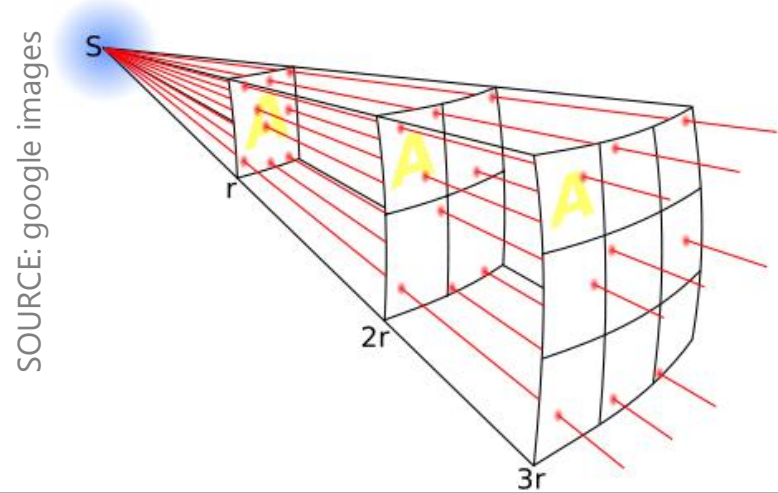


# SUMMARY: THE SIX LIGHTING METRICS

Metric		Unit		Depends on Direction	Characteristic of the light source
Name	Symbol	Name	Symbol		
Luminous Flux	$\Phi$	lumen	lm	No	Yes
Luminous Efficacy	$\eta$	lumen per watt	lm/W	No	Yes
Luminous Intensity	I	candela	cd (=lm/sr)	Yes	Yes
Illuminance	E	lux	lx (=lm/m <sup>2</sup> )	No	N/A
Luminance	L	candela per sq. metre	cd/m <sup>2</sup>	Yes	N/A
Luminous Exitance	M	lux	lx (=lm/m <sup>2</sup> )	No	N/A



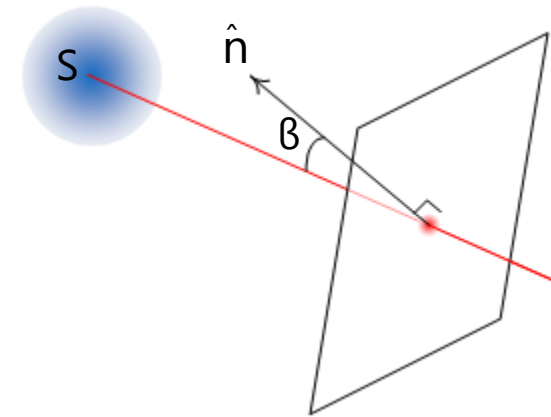
# INVERSE SQUARE LAW OF ILLUMINATION



As you move away from a source, the same intensity ( $I$ ) has less effect.

The illuminance on a surface perpendicular to the ray

$$E(\text{illuminance}) = \frac{I(\text{Luminous intensity})}{r^2(\text{distance from the source})}$$



**For the general case**

The illuminance on a surface with an incidence angle  $\beta$  with respect to the ray

$$E(\text{illuminance}) = \frac{I \cos(\beta)}{r^2}$$

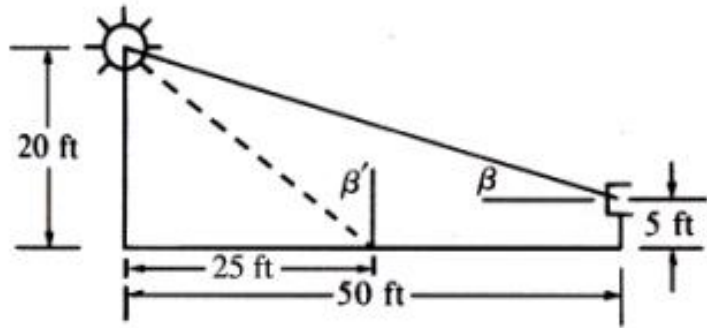
**Let's assume an uniform point-source in the centre of a sphere**

- Point source: source is smaller than any other dimension present
- Uniform source:  $I = \text{const}$

# EXAMPLE 2.1

A globe street light has a uniform intensity of  $I=2000$  cd.

Find the illuminance ( $E$ ) on the vertical stop sign shown in the figure



## Solution

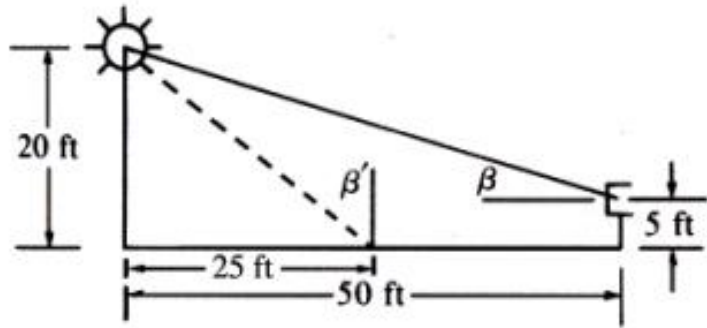
We have a uniform point-source.

- The square of the distance of the stop sign from the source is:  $r^2 = (20-5)^2 + 50^2$
- The incidence angle ( $\beta$ ) with respect to the ray is:  $\beta = \arctan(15/50) \sim 16.7^\circ$
- The illuminance on the vertical stop sign is the given by the general inverse square law of illumination

$$E = \frac{I \cos(\beta)}{r^2} = \frac{2000 \cdot \cos(16.7^\circ)}{(20-5)^2 + 50^2} = 0.70 \frac{\text{lx}}{\text{ft}^2} = 0.70 \text{ fc (footcandles)}$$

## EXAMPLE 2.2

If the pavement has a reflectance of 35%, what is the luminous exitance ( $M$ ) at a point on the pavement halfway between the pole and the sign



### Solution

Let's assume that the pavement is perfectly diffusing surface

- The square of the distance of the stop sign from the source is:  $r'^2 = 20^2 + 25^2$
- The incidence angle ( $\beta'$ ) with respect to the ray is:  $\beta' = \arctan(25/20) \sim 51.3^\circ$
- The illuminance on the pavement ( $E'$ ) is the given by the general inverse square law of illumination

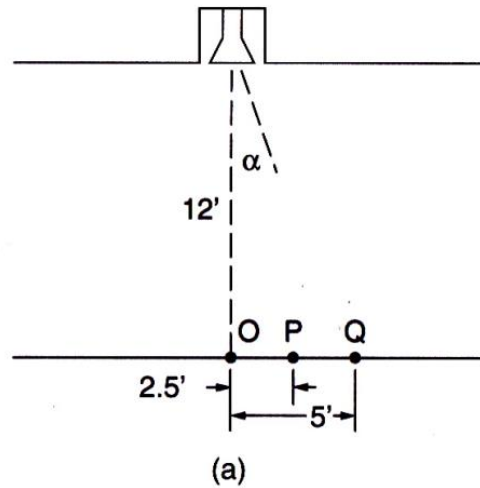
$$E' = \frac{I \cos(\beta')}{r'^2} = \frac{2000 \cdot \cos(51.3^\circ)}{25^2 + 20^2} = 1.22 fc$$

- The luminous exitance is:

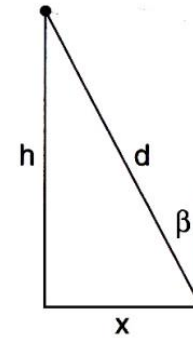
$$M = \rho E' = 0.35 \cdot 1.22 = 0.43 fc$$

# EXAMPLE 2.4

A recessed downlight in a ceiling has the intensity distribution tabulated below. Find the illuminances at points O, P and Q.



$I_{cd}$	$\alpha$ (deg)
5000	0
4500	5
4000	10
3000	15
2000	20
500	25
0	30



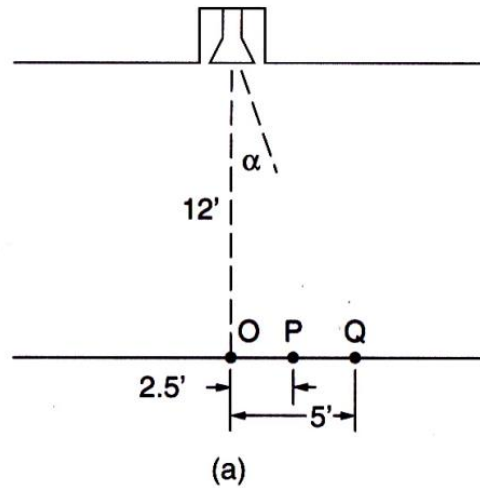
## Solution

- In this problem, the luminous intensity ( $I$ ) is a function of the angle  $\alpha$
- In addition  $\alpha = \beta$
- The illuminance in a given point is:

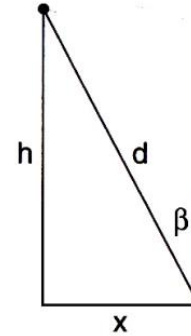
$$E = \frac{I \cos(\beta)}{r^2} = \frac{I \cos(\beta)}{(h/\cos\beta)^2} = \frac{I \cos^3(\beta)}{h^2}$$

# EXAMPLE 2.4

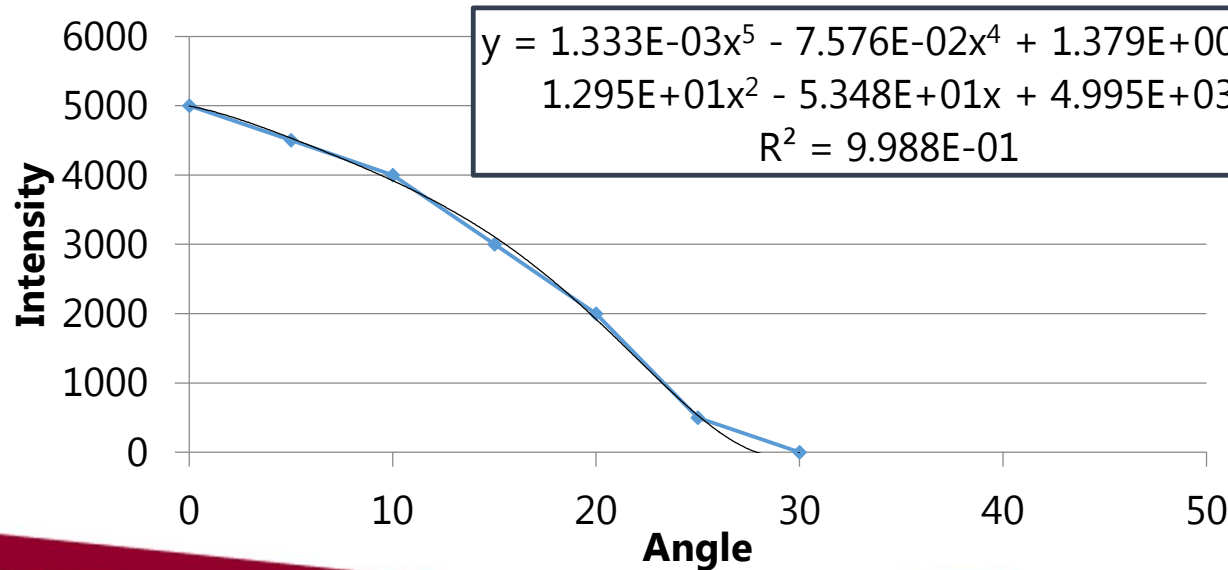
A recessed downlight in a ceiling has the intensity distribution tabulated below. Find the illuminances at points O, P and Q.



$I_{cd}$	$\alpha$ (deg)
5000	0
4500	5
4000	10
3000	15
2000	20
500	25
0	30



## Solution



$$E = \frac{I \cos^3(\beta)}{h^2}$$

Point	$\beta = \alpha$	I (cd)	E (fc)
O	0	5000	34.7
P	11.77	3667	23.9
Q	22.62	1179	6.4

**For the curious ones**

<http://patternguide.advancedbuildings.net>