The direct illumination from one candle placed at a distance of one foot from a surface is defined as….

Foot-candle is also known as a unit of light or light level.

The energy of light from a candle falling on a one foot square area is One Lumen (abbreviation = lm)

The total amount of light coming out of the candle is approximately 13 lumens
The total amount of light coming out of 100-watt A-lamp is approximately 1650 lumens

NOT DEFINED BY DISTANCE
Lighting Math

Lumens versus Candelas

- **Lumen** is an amount of ENERGY
- **Candela** is an amount of INTENSITY
- Lamp output can be measured in **Lumens** and **Candelas**.
- Fixtures alter **Lumen** and **Candela** output (Their values can only be found in Photometry Reports)

Light Measurement

Measures the candlepower distribution of a particular lamp or luminaire.
Information is generated in a -- **Photometric report**

Methods to Calculate Light

**Point-by-Point**
- Direct Illumination from a Fixture or Lamp
  - You need....
    - Photometry
    - Distances from Fixture or Lamp

**Lumen Method**
- Average Light Level in a Room from a Fixture
  - You need....
    - Photometry
    - Room Dimensions and Surface Reflectance's

Direction of Light

- Goal of a luminaire is to put light where the user needs it
- Convenient way to classify luminaires is by the *direction* of light emitted from the luminaire
- Commission Internationale de l'Éclairage (CIE) sets up these classifications
Lighting Math

CIE Luminaire Types / Distributions

Direct  Semi-Direct  General Diffuse
(IES) Direct-Indirect  Semi-Indirect  Indirect

Candlepower Distribution Curve

- **Candlepower distribution curves** provide intuitive information on how a **luminaire** will perform.
- **Candela** values are used in calculations to predict light levels.

Asymmetrical Distribution Curve

Rectangular Tubular Fluorescent fixture

| 90 deg | Perpendicular |
| 0 deg | Parallel |

Photometry Reports

- Plot of candlepower values
- Summary of candlepower values in different planes
- Fixture Efficiency
- Lumen Summary
- Luminance summary
- Spacing criteria (SC) or Spacing/Mounting Height (S/MH) for uniformity
- Coefficient of Utilization Table
- Guides
**Lighting Math**

**Photometry Reports**

- Lensed Downlight

**Foot-candle** = \( \frac{\text{Candle Power}}{\text{Distance}^2} \)

**Ceiling Fixture Example**

**Ceiling height = 9ft**

FC = 2651 candelas / 9ft²
FC = 2651 / 81
FC = 32.7 foot-candles

**Point-by-Point**

**Indirect Pendant**

**Foot-candle** = \( \frac{\text{Candle Power}}{\text{Distance}^2} \)

**Elevation Section**
Lighting Math

**Point-by-Point**

*Foot-candle = \( \frac{\text{Candle Power}}{\text{Distance}^2} \)*

1. **Ceiling height** = 9 ft
2. **Room Width** = 12 ft
3. **Top Head** = 6 ft
4. **Light Level at the Wall**

To solve for **D**, you can:
1. Scale the Drawing, or
2. Use Trigonometry

\[
X^2 + Y^2 = Z^2
\]
\[
9^2 + 6^2 = D^2
\]
\[
D = \sqrt{9 + 36}
\]
\[
D = 6.7
\]

**Point-by-Point**

To solve for **Angle**, you can:
1. Scale the Drawing, or
2. Use Trigonometry

**Angle** = \( \tan^{-1} \left( \frac{X}{Y} \right) \)

**Angle** = \( \tan^{-1} \left( \frac{3}{6} \right) \)

**Angle** = 26 degrees

**Foot-candle = \( \frac{\text{Candle Power}}{\text{Distance}^2} \)**

**FC** = 169 candelas / 6.7 ft²

**FC** = 169 / 44.89

**FC** = 3.76 foot-candles
Lighting Math

Point-by-Point Factors

- Calculated Levels are Facing the Light Fixture
  - With the exception of directly below

Point-by-Point Factors

- You need to factor an adjustment if you want levels at other angles (IE Horizontal, Vertical Angles)
  - COSINE Adjusted!!

COSINE Adjustments

Foot-candle = \( \frac{\text{Candle Power}}{\text{Distance}^2} \times \cos(\text{Angle of Incidence}) \)

Light Source

\[ \theta \]

Incidence

Reflectance

COSINE Adjustments

Foot-candle = \( \frac{\text{Candle Power}}{\text{Distance}^2} \times \cos(\text{Angle of Incidence}) \)

Light Source

\[ \theta \]

Incidence

Reflectance

Point-by-Point... with COSINE Adjustment

\[ \text{FC} = \frac{\text{CP}}{\text{D}^2} \times \cos(\angle) \]

\[ \text{Ceiling height} = 9\text{ft} \]

\[ \text{Room Width} = 12\text{ft} \]

\[ \text{Light Level at the Vertical to the Wall} \]

\[ 64\text{deg} \]

\[ 6.7\text{ft} \]

\[ 25\text{deg} \]

\[ \text{FC} = 169 / 44.89 \times 0.43 \]

\[ \text{FC} = 1.6 \text{ foot-candles} \]
Lighting Math

Point-by-Point Factors

- Calculated Levels are Initial.
- You need to factor an adjustment for Light Loss
  - Light Loss Factors to Consider
    - Dirt
    - Lamp Depreciation
    - Environment

Foot-candle = \(\frac{\text{Candle Power}}{\text{Distance}^2} \times \cos(\text{Angle}) \times \text{MF}\)

Non-Recoverable Light Loss Factors

- Ballast Factor (*Fluorescent approx 90%*)
- Ambient Fixture Temperature
- Supply Voltage Variation (*Low Voltage approx 4%*)

MF = Maintenance Factors

Non-Recoverable

Recoverable

Recoverable Light Loss Factors

- Lamp Burnouts (*approx 80%*)
- Lamp Lumen Depreciation (*Fluorescent approx 70%*)
- Fixture (Luminaire) Dirt Depreciation
  - *Indirect Lighting (approx 65%*)
  - Industrial Environments (ranges from approx 50% to 80%)
  - Open Fixtures – Lamp exposed (approx 85%)
**Lighting Math**

Multiply one factor against another and you get the………..

\[ MF = \text{LIGHT LOSS FACTOR!} \]

Foot-candle = \( \frac{\text{Candle Power}}{\text{Distance}^2} \) x \( \cos(\text{Angle}) \) x \( MF \)

**Review of Formulas**

- To find Dimensions or Angles of a Triangle

To solve for any item, you can:
  1. Scale the Drawing, or Use Trigonometry

\[ X^2 + Y^2 = \text{Distance}^2 \]
\[ \tan(\text{Angle}) = \frac{X}{Y} \]
\[ \text{Angle} = \tan^{-1}(\frac{X}{Y}) \]

**Methods to Calculate Light**

- **Point-by-Point**
  - Direct Illumination from a Fixture or Lamp
    - You need….
      - Photometry
      - Distances from Fixture or Lamp

- **Lumen Method**
  - Average Light Level in a Room from a Fixture
    - You need….
      - Photometry
      - Room Dimensions and Surface Reflectance's
Lighting Math

Calculations using Lumens

- **Lumen** is an amount of ENERGY
- **Candela** is an amount of INTENSITY
- **Lumen Method Calculation**
  - Calculates the Average Illumination for a room.
  - Takes into account the room surface reflectance’s – but assumes the surfaces are diffuse (not shiny!).
  - Assumes an empty room (without furniture).
  - Can also be used to determine the required Quantity of Fixtures needed for a target light level.
  - Does not determine light fixture layout or location – you must follow mnfrs spacing criteria.

Photometry Reports

- Plot of candlepower values
- Summary of candlepower values in different planes
- Fixture Efficiency
- Lumen Summary
- Luminance summary
- Spacing Criteria (SC) or Spacing/Mounting Height (S/MH) for uniformity
- Coefficient of Utilization Table
- Guides

Coefficient of Utilization

- Also known as CU
- Defines the percentage of light output that is expected from a fixture
- The value is determined by a CU table
- For commercial Reflectance of 80/50/20, the actual CU value is this.

Lumen Method Steps

1. You need Room Dimensions and the Fixture Mounting Height.
2. You need to select a Light fixture
3. Determine the rooms Room Cavity Ratio (RCR).
4. Look-up the fixtures Coefficient of Utilization for the RCR.
5. Calculate!
**Lighting Math**

**Room Reflectance**

- Room comprised of Walls, Ceiling, and Floor.
- Walls typically have Doors and Windows
- All surfaces have a reflectance value to bounce light.
- Light from Light Fixture bounces off of all surfaces.

**Room Reflectance**

- Surfaces with less reflectance will bounce less light
- Typical Reflectance Values:
  - 75%-90%: White, Off White, Grey, Light tints of Blue or Brown
  - 50%-60%: Medium Green, Yellow, Brown, or Grey
  - 15%-25%: Dark Grey, Medium Blue
  - 5%-10%: Dark Blue, Brown, Dark Green, and many wood finishes

**Room Cavity Ratio**

- Room Cavity Ratio (aka RCR) is the volume between the Fixture and Height of Calculation
- Workplane height is typically 30-inches above the floor
- A rooms RCR will always be between 1 and 10

\[ RCR = \frac{5 \times MH \times (L + W)}{\text{Room Area}} \]
**Lighting Math**

**Room Cavity Ratio**

\[
\text{RCR} = \frac{5xMHx(L+W)}{\text{Room Area}}
\]

- The RCR can vary depending on the height you want to calculate...as shown here with the calculation height at the floor.

- The RCR can vary depending on the height of the fixture...as shown here with Wall Brackets or Sconces.

- The RCR can vary depending on the height of the fixture...as shown here with Pendants.

**Example:**

- Room Width: 12 ft
- Room Length: 15 ft
- Ceiling Height: 10 ft

\[
\text{RCR} = \frac{5(5.5)(12+15)}{(12\times15)}
\]

\[
\text{RCR} = 742.5
\]

\[
\text{RCR} = 180
\]

\[
\text{RCR} = 4.1
\]
Lighting Math

Lumen Method Formula

To Calculate Foot-candle level:

\[ FC = \text{Qty of Fixtures} \times \text{Number of Lamps per Fixture} \times \text{Lumens per Lamp} \times \text{CU} \]

\[ FC = \frac{\text{Area of the Room}}{\text{Total Lumens in the Room} \times \text{CU}} \]

To Calculate number of Fixtures:

\[ \text{Qty of Fixtures} = \frac{\text{FC} \times \text{Area of the Room}}{\text{Number of Lamps per Fixture} \times \text{Lumens per Lamp} \times \text{CU}} \]

\[ \text{Qty of Fixtures} = \frac{\text{FC} \times \text{Area of the Room}}{\text{Total Lumens in the Room} \times \text{CU}} \]

Coefficient of Utilization

- Also known as CU
- Defines the percentage of light output that is expected from a fixture
- The value is determined by a CU table
- For our example:
  - RCR ___
  - the CU is ___
- For commercial Reflectance of 80/50/20, the actual CU value is this.

Lumen Method Example 1

What is the resulting Foot-candle Level at table height from four downlights?

Lumen Method Example 2

How many fixtures do I need to achieve 30-foot-candles at table height?
Lighting Math

Review of Formulas

- Lumen Method

To calculate direct light levels:

1. You need the rooms RCR, and you need a fixtures CU Table

Formulas:

$$RCR = \frac{5(Fixture \, Mtg \, Hgt)(L+W)}{Room \, Area}$$

for light level

$$FC = \frac{(Qty \, of \, Fixtures)(Lamp \, Lumens)(Number \, of \, Lamps)(CU)}{Room \, Area}$$

for number of fixtures

$$Qty = \frac{(FC)(Room \, Area)}{(Lamp \, Lumens)(Number \, of \, Lamps)(CU)}$$

Summary of Calculations

- Overlooks aesthetics, psychological, and physiological variables of the human visual process.
- Since we cannot see foot-candles, it is more useful to calculate perceived surface brightness.
- It is the balance of these relative brightness, not the quantity of light levels, that determines successful Lighting Design.
- Calculation are to be used for lamp and fixture selection, or to evaluate a Lighting Design.

Target Illuminance / Light Levels

Who Defines Light Levels?

- IES of North America
  - Recommended Practices
  - Defines light levels and quality of illumination by task and application
- Codes and Regulations
- The Owner

Definitions:  
- Task = the work performed
- Applications = the project type (i.e. School, Commercial etc.)

Light Levels

- Published Light Level recommendations are for Foot-candles at the work plane (2'6" AFF)
- Recommended values refer to horizontal light levels on a work plane.
- They have limited significance to us when we interpret the actual environment.
- Such factors as lighting walls, brightness accents, shadows, sparkle, and color have a greater influence on emotional reaction.
- IESNA’s recommend light levels are for an age range of 40 – 55 years old
### Lighting Math

#### Ages

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Can Reduce Light Levels</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 40 years old</td>
<td>Can reduce the light levels up to 1/3!</td>
<td>Babies require 3 times more light than a 20 year old!</td>
</tr>
<tr>
<td>Over 55 years old</td>
<td>Can increase the light levels up to 2/3!</td>
<td></td>
</tr>
</tbody>
</table>

**Standard Age Range is 40-55 years old**