Lab 1: Photometry

Purpose

The purpose of this lab is to explore the properties of illumination on a surface as a function of the distance of the surface from the light source.

Safety

1. Locate fire extinguishers.
2. Turn off gas valves.
3. Remove combustable materials.
4. Tie back long hair and loose clothes.
5. Place candles on secure, fire proof bases.
6. Deposit used matches in fireproof containers.

Materials

1. 5 candles
2. Matches
3. Scissor for adjusting candle wicks
4. 1 large sheet of stiff white paper
5. 1 meter stick
6. Dark room

Procedures

1. **Paper setup:**
    1. Orient paper in landscape position (long side toward you) and create a vertical fold down the middle such that you can stand the paper on the table at a 90 degree angle.
2. **Reference candle setup:**
    1. Place one candle at an exactly measured distance from one side of the paper (**reference side**) such that the other side of the paper (**test side**) is in the candle's shadow. (Note: This reference candle will not be moved for the rest of the lab.)
3. **Test candle(s) setup:**
    1. Place the first **test candle** in front of the **test side** of the paper (opposite the 90 degree angle and on the same side of the paper) such that when you light it, the reference side will be in the shadow of the test candle. Position the test candle the same distance from the paper as the reference candle.
    2. Light both candles and look at the paper from a head on position (nose pointing toward the bent edge), such that you can see both sides equally. When each side is equally illuminated, the folded paper edge will nearly disappear.
    3. If both sides are not equally illuminated when the candles are positioned at equal distances, trim the wicks to create equal light from each candle.
    4. Record the distances.
    5. Add a second candle to the test side, checking that its flame is of nearly equal size to the other candle's flame. Trim the wick as needed.
    6. Record record its distance from the paper.
    7. The test side will now be more luminous than the reference side. Move the test candles away from the paper until the two sides of paper appear to be of equal luminosity when viewed from the head-on position.
    8. Record the distance of the test candles in the table.
4. Repeat with a third test candle, and record your results.
5. Repeat with a forth test candle, and record your results.

Observations

In the table below, record the distances of the candle placements for equal illumination. When computing the ratio of distance of multiple candles to one candle, reduce this ratio so it is in the form $X : 1$ where X is the quotient of the distance of all test candles from the paper divided by the distance of the single candle from the paper. Two decimal place accuracy is good enough. Example: 1.41 : 1.

$$\frac{\textit{Distance of all test candles}}{\textit{Distance of reference candle}} = X$$

Total Test Candles	**Distance**	**Ratio of Distances**	$\sqrt{\# \textit{ of candles}}$
1			1
2			1.414
3			1.73
4			2

Questions: The Nature of Light 1

1. What is the difference between luminous matter and illuminated matter? Give an example of each.

2. The textbook claims that light travels in a straight line. Do you think this is always true? Why?

3. Roemer discovered an error in his work while studying the moons of Jupiter. What was the cause of his error?

4. Michelson's octagonal mirror rotated 625 revolutions/second. How much time is required for one revolution?

Lab 1: Photometry Conclusions

1. Luminous matter
    1. Luminous matter emits light.
2. Illuminated matter
    1. Illuminated matter reflects light.
3. Candela
    1. Luminous intensity, (I), measure by comparison to the international unit of the candela (text p290 sec 17:4)
4. Luminous Flux
    1. Measured in lumens (lm), Rate at which light is radiated (candelas/sec)
    2. Surface area of a sphere: $4\pi r^2$
    3. A point light source of 1 candela of luminous flux at the center of a sphere of radius 1m radiates 4π lumens on the surface of that sphere.
    4. Lumens are power units and are a measure of light energy per second (candelas/sec)
    5. 1 Candela is the equivalent of 1/683 Joules of energy per steradian, so 1 candela per second has 1/683 watts of power per steradian or $4 \times \pi \times \frac{1}{683}$ watts of power omni-directionally (this is a composite definition from various Wikipedia definitions of SI units of luminance. http://en.wikipedia.org/wiki/Unit_conversion)
5. Illuminance (illumination of illuminated bodies)
    1. Illuminated bodies can absorb or reflect light
    2. Illuminance (E) is directly proportional to the # of candles and inversely proportional to the square of the distance between the candles and the illuminated surface. or
    3. Illuminance (illumination) is the rate E, measured in $\frac{lumens}{m^2}$, or $\frac{lm}{m^2}$, at which light falls on a unit area some distance from a light source.
    4. Unit of illuminance is lux (lx) where $1\frac{lm}{m^2} = 1lx$
    5. Surface area of a sphere is $4\pi r^2$
    6. A point light source of 1 candela of luminous flux at the center of a sphere of radius $1m$ radiates 4π lumens onto the 4π square meter surface of that sphere. Thus the sphere is uniformly illuminated with 1 lux, or 1 $\frac{lm}{m^2}$.
    7. A $2cd$ light source would emit 8π lumens, $3cd$ emits 12π, etc.
    8. 1 lumen is the amount of light that illuminates 1 sq meter of surface of a sphere of 1m radius with a 1 candela point source at its center.
    9. Illumination is measured in lumens per square meter, $\frac{lm}{m^2}$, abbreviated as lux (lx)

Term	**Abbreviation**	**Description**
Candela	cd	
Lumen	lm	
Luminous Intensity	I	
Illumination	E	
Unit of Illuminance	lux or lx	

About Photometry

Photometry is the science of the measurement of light, in terms of its perceived brightness to the human eye (visible light). It is distinct from radiometry, which is the science of measurement of all radiant energy (including visible light) in terms of absolute power.

Photometry and the eye

The human eye is not equally sensitive to all wavelengths of visible light. Photometry attempts to account for this by weighting the measured power at each wavelength with a factor that represents how sensitive the eye is at that wavelength.

The standardized model of the eye's response to light as a function of wavelength is given by the luminosity function. The eye has different responses as a function of wavelength when it is adapted to light conditions (*photopic vision*) and dark conditions (*scotopic vision*).

Photometry is typically based on the eye's *photopic response*, and so photometric measurements may not accurately indicate the perceived brightness of sources in dim lighting conditions where colors are not discernible, such as under moonlight or starlight.

Photopic vision is characteristic of the eye's response at luminance levels over three candela per square metre. Scotopic vision occurs below $2 \times 10^{-5} cd/m^2$. Mesopic vision occurs between these limits and is not well characterized. ("Meso" means between, as in Mesoamerica.)

Photometric quantities

Measurement of the effects of electromagnetic radiation became a field of scientific study around the end of the 18th century. Measurement techniques varied depending on the effects under study and gave rise to different nomenclature (naming systems). The total heating effect of infrared radiation as measured by thermometers led to development of *radiometric units* of total energy and power. Use of the human eye as a detector led to *photometric units*, weighted by the eye's response characteristic.

Many different units of measure are used for photometric measurements. People sometimes ask why we need so many different units, or they may ask for conversions between units that can't be compared in that way, such as *lumens* and *candelas*.

For example, we are familiar with the idea that "heavy" can refer to weight or density, but these are fundamentally different ideas. One is related to the effect of gravity, while the other is an inherent quality of matter.

Similarly, "bright" can refer to a light source that delivers a high luminous flux (measured in lumens), or a light source that concentrates its luminous flux into a narrow beam (meaured in candelas), or to a light source that is seen against a dark background.

Because of the ways in which light propagates through three-dimensional space—spreading out, becoming concentrated, or reflecting off shiny or matte surfaces—and because light consists of many different wavelengths, many different types of measurements and units are needed.

Photometric versus radiometric quantities

There are two parallel systems of quantities known as *photometric* and *radiometric* quantities.

In *photometric quantities*, every wavelength is weighted according to how sensitive the human eye is to it. For example, the eye responds much more strongly to green light than to red, so a green source will have greater luminous flux than a red source with equal radiant flux. *Radiometric quantities* measure the unweighted absolute power of the radiation.

Radiant energy outside the visible spectrum does not contribute to photometric quantities at all. For example a 1000 watt space heater may put out a great deal of *radiant flux* (1000 watts, in fact), but as a light source it puts out very few *lumens*, because most of the radiant energy is infrared, leaving only a dim red glow visible to the human eye.

Every quantity in one system has an analogous quantity in the other system. Some examples of parallel quantities include:

Photometric	**Radiometric**
Luminance	Radiance
Luminous flux	Radiant flux
Luminous intensity	Radiant intensity

Sources

- *Wikipedia, https://en.wikipedia.org/wiki/Photometry_(optics), 2023-04-23