ARE 361: Fundamentals for Lighting Design
HW #4: Practicing the Fundamentals
Assigned: Period 2.1
Due: Period 3.2

BACKGROUND
Answers for most questions are provided because I want you to be sure that your calculation process leads to the correct answers. Solving these problems will help your comprehension of basic photometric units and the geometric and mathematical relationships between them. When a question challenges you, (re)read and review the readings to develop your understandings of the relationships. When you can express fundamental photometric concepts and relationships using equations, the numerical results will follow.

Complete your work using good engineering problem solving practices, which (depending on the question) may include: sketching the situation; writing down the symbols, quantities, and units of known values; writing down relevant equations to clarify relationships between known and unknown quantities; solving for the unknown quantities; boxing your answers showing both quantities and units.

Garbage answers are unacceptable. For example, in the answer is $40\pi$, and the solution offered comprises random numbers in a made-up equation that yields $40\pi$, that will not be tolerated and will result in an assignment grade of zero. Poorly documented answers are also not acceptable. Clearly and neatly show your work; it is the steps that matter, and it is the steps that illustrate your understanding and will prepare you for the midterm exam. Also bear in mind that an answer is not correct unless the units are correct.

LEARNING OUTCOME MAPPING

<table>
<thead>
<tr>
<th>Course Learning Outcome</th>
<th>ABET Student Learning Outcome</th>
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<tr>
<td>1. Compute and manipulate photometric quantities such as luminous flux, luminous intensity, illuminance, exitance, and luminance.</td>
<td>7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies. [Maps to course learning outcomes 1, 2, 3, and 4.]</td>
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QUESTIONS
1. Use software (e.g., Excel, Word, PowerPoint) to create a table to remind you of the names, symbols, units, and definitions of the five basic photometric units. The table should have the following column headings: Photometric Quantity, Symbol, Unit, and Definition. And the following row headings: Luminous Flux, Luminous Intensity, Illuminance, Exitance, and Luminance. Fill in each of the cells with the appropriate information. The Definition column should be a phrase or sentence describing the quantity. Label the table at the top with the title “Photometric Units”. Review it often to commit these concepts to memory!
2. What is the total lumen output of a uniform ten candela source? \[40\pi \text{ lm}\]

3. A uniform point source illuminates a surface with fifty lumens of flux (Note: The term “uniform” is used here to mean that the source has the same luminous intensity in all directions). The surface subtends two steradians.
   3.1. What is the luminous intensity of the point source? \[25 \text{ cd}\]
   3.2. What is the total lumen output of the light source? \[100\pi \text{ lm}\]

4. A surface is two-square feet, Lambertian, and has a reflectance of 70%. If it is receiving 100 lumens.
   4.1. What is its illuminance in footcandles? \[50 \text{ fc}\]
   4.2. What is its exitance in SI units? \[377 \text{ lumens/m}^2\]

5. The uniform point source shown below emits 1,000 radiant watts and has a luminous efficacy of 55 lumens per watt.
   5.1. What is the luminous intensity distribution of this source? Sketch an intensity diagram and give an equation. \[I_{\alpha,\beta} = 4,377 \text{ cd}; \alpha = 0^\circ \text{ to } 360^\circ, \beta = 0^\circ \text{ to } 180^\circ\]
   5.2. Describe in a sentence or two the difference between Photometry and Radiometry.
   5.3. **Irradiance** is completely analogous to illuminance; the difference is that irradiance is a radiometric quantity and illuminance is a photometric quantity. Knowing the difference between radiometry and photometry, what are the units of Irradiance?
   5.4. What is the irradiance at point “A” at the center of circular area “D”? \[0.91 \text{ W/ft}^2\]
   5.5. What is the illuminance at point “A”? \[50 \text{ fc}\]
   5.6. If surface “D” has a radius of 3.0’, what is the total number of lumens incident on the surface? \[1,314.5 \text{ lm}\]
   5.7. If surface “D” has a radius of 3.0’, what is the illuminance at point “B” in US Customary units? \[43.2 \text{ fc}\]
   5.8. What would be the diameter of area “D” if it intercepts 127 watts from the source? \[16.7 \text{ ft}\]
6. A point source emits 725 lumens in a spherically uniform way. A hemispherical reflector is placed about the source as shown. The interior of the reflector exhibits a perfectly specular reflectance of 0.65. The reflector is 2.5’ in radius and is placed such that the source is at the center of the opening of the hemisphere.

6.1. What is the illuminance (in US Customary units) at any point on the interior of the reflector? [9.23 fc]

6.2. What is the total number of lumens leaving the reflector? [236 lm]

6.3. If the input power to the source is 50 Watts, what is its efficacy? [14.5 lumens/watt]

6.4. What is the irradiance at point “A”? [0.049 watts/ft²]

6.5. The answer to question 6.4 ignores reflected radiation from the hemispherical reflector. Why is that correct?

7. Suppose Labsphere Part No. SRT-MS-180 is uniformly receiving 1700 lumens. The SRT-MS-180 is a diffuse multi-step reflectance target with overall dimensions of 18” × 18”. It is subdivided into four strips, each 18” × 4.5”, with individual strip reflectances of 99%, 50%, 25%, and 12%.


7.2. What is the exitance of the darkest strip in US Customary Units? [90.7 lm/ft²] Metric Units? [975.9/m²]

7.3. What is the average exitance of the entire target in US Customary units? [351.3 lm/ft²] Metric Units? [3782 lm/m²]

7.4. What is the luminance of the darkest strip in Metric units? [310.6 cd/m²]

7.5. What is the average reflected luminous intensity at 30° from normal? [217.9 cd]

8. An old textbook on astronomy says that experiment shows that when the sun is overhead, sunlight illuminates a white surface about 65,000 times greater than a uniform 1 candela source illuminates the same white surface at a distance of one meter.

8.1. Calculate the flux density (footcandles) of full sunlight at the earth’s surface. [6,041 fc]

8.2. What is the apparent luminous intensity of the sun (the distance from earth is approximately 15 × 10¹⁰ meters)? [1.4625 × 10²⁷ cd]

8.3. What is the approximate lumen output of the sun? [1.838 × 10²⁸ lm]
8.4. Assuming that the moon is a perfectly smooth sphere with a reflectance of 12%, what is the illuminance on the earth’s surface due to a full moon? Ignore atmospheric attenuation and note your sources for any additional values required for this calculation. [0.159 lux, based on these assumptions: 1) the sun is the same distance to both the earth and moon; 2) the moon has a radius of \(1.737 \times 10^6\) m; 3) the distance from the moon to the earth is \(384.4 \times 10^6\) m; 4) the moon is a Lambertian reflector with 12% reflectance; 5) atmospheric attenuation is ignored.]

8.5. According to Wikipedia [LINK], the full moon provides about 0.05 lx to 0.1 lx of illumination. Our calculation ignored atmospheric attenuation, probably not a reasonable assumption. And 12% reflectance was also a bit high [SOURCE]. Still, we’re close!