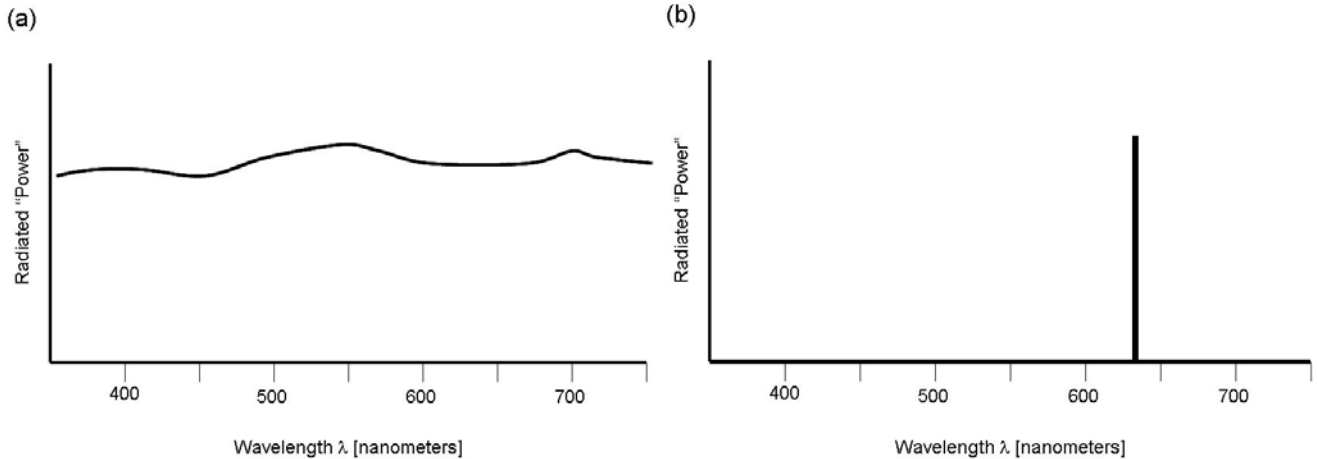


SIMG-215-02 Fundamentals of Imaging Science

Solutions to Midterm: 12 October 2006

1. On the graph labeled (a), sketch a spectrum of light that might be emitted from a source that emits light by a thermal interaction (e.g., the Sun). On graph (b), sketch the spectrum of light that might be emitted from a source that emits light by an atomic interaction (e.g., a laser). Describe the differences between the two in a sentence or two.



The spectrum of a thermal source is continuous and appears to be fairly “flat” in the visible region of the spectrum. The spectrum of a source that emits light by atomic interaction is discrete (i.e., isolated spectral “lines” – possibly more than one).

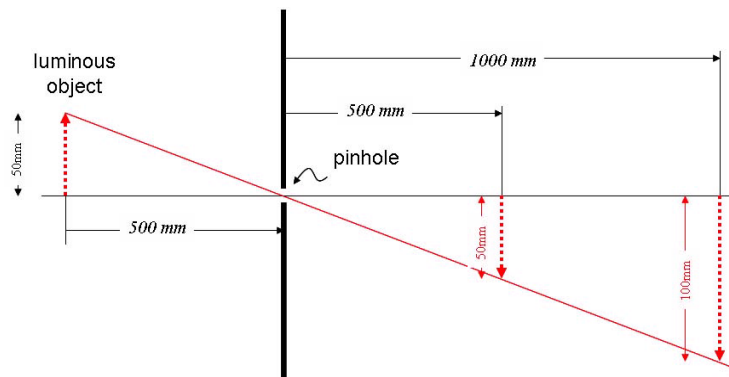
2. The diagram below shows a luminous (“glowing”) object and a sheet of opaque material with a small pinhole. The object is 50 mm tall and located 500 mm from the pinhole.

- (a) What are the sizes and orientations of images on observation screens located at distances of (a) 500 mm and (b) 1000 mm from the pinhole? Hint: You may draw appropriate rays from the object to the image on the diagram.

The image created by the pinhole imager maintains its “sharpness” (or lack of same) at all distances from the pinhole. From the sketch of the ray from the “tip” of the luminous object, we see that the height of the ray on the “image” side is proportional to the distance from the pinhole, i.e., doubling the distance doubles the “height” of the ray from the axis.

- (b) Describe the advantages and disadvantages that would accrue if the pinhole is very small and if it is enlarged.

As you saw in the lab, enlarging the pinhole makes the image “brighter” but “fuzzier” (less sharp). A small pinhole produces a sharp image that is not bright.



3. The same object used in the previous problem is located 500 mm from a lens.

(a) What is the focal length f of a lens that will produce an image located 500 mm from the lens?

$$\frac{1}{z_1} + \frac{1}{z_2} = \frac{1}{f}$$

Note that the object and image distances are identical

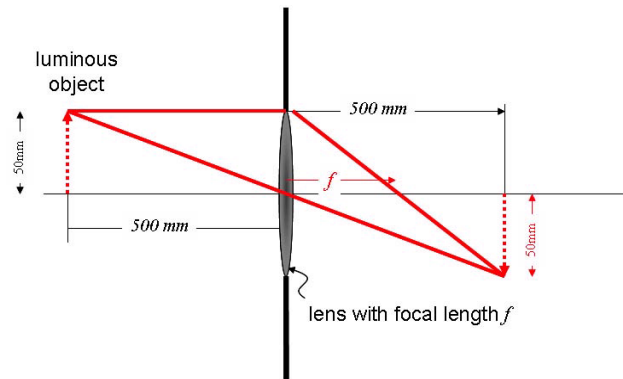
$$\begin{aligned} \frac{1}{500 \text{ mm}} + \frac{1}{500 \text{ mm}} &= \frac{2}{500 \text{ mm}} = \frac{1}{250 \text{ mm}} = \frac{1}{f} \\ \Rightarrow &\boxed{f = +250 \text{ mm}} \end{aligned}$$

(b) What is the magnification M_t of the resulting image?

$$\boxed{M_t = -\frac{z_2}{z_1} = -\frac{500 \text{ mm}}{500 \text{ mm}} = -1}$$

image is the same size as the object but inverted

(c) (OPTIONAL BONUS) What is the focal length of the lens that will produce a virtual image that twice as large as the object?



$$\text{virtual image is upright} \quad \Rightarrow \quad M_t = +2 = -\frac{z_2}{z_1} \quad \Rightarrow \quad z_2 = -2 \cdot z_1 = -1000 \text{ mm}$$

$$\frac{1}{f} = \frac{1}{500 \text{ mm}} + \frac{1}{-1000 \text{ mm}} = \frac{2}{1000 \text{ mm}} - \frac{1}{500 \text{ mm}} = +\frac{1}{1000 \text{ mm}}$$

$$\boxed{f = +1000 \text{ mm}}$$

4. We discussed *local averaging* and *local differencing* as image processing operations. Briefly describe what these terms mean and tell what imaging operations for which they might be useful.

In local averaging, the gray value of the pixel at the center of a neighborhood is replaced by the average of the pixel gray values in the neighborhood (or, more generally, a “weighted average” where the weights may vary). This is analogous to “integration” in calculus. In local differencing, the gray value of a pixel is replaced by the difference of gray values of some neighboring pixels, which is analogous to differentiation in calculus.

The “variation” of gray values is reduced by an averager, which means that it will reduce the visibility of random variations in gray value (what we call “noise”), but it will also reduce the real variations in gray values at edges.

The “variation” in gray values is increased by a differencer, which also sets any nonzero constant gray value to zero.

5. The speed of light propagation in vacuum is $c \cong 3 \times 10^8$ meters per second. The index of refraction of air (at standard temperature and pressure) is $n \cong 1.0003$.

- (a) By what multiplicative factor is the speed of light in air slower than the speed in vacuum? (you need only write down the equation; you need not evaluate to give a number)

The speed of light is slower, which means that the multiplicative factor is less than one

$$v = \frac{c}{n} = \frac{c}{1.0003} \cong \frac{3 \times 10^8 \frac{\text{m}}{\text{s}}}{1.0003} \cong 2.9991 \times 10^8 \frac{\text{m}}{\text{s}}$$

- (b) In the early 1600s, Galileo tried to measure the speed of light with two lanterns. He sent a man to a hilltop some distance away at night with one shielded lantern. Galileo uncovered one lantern and the man was instructed to uncover his lantern at the instant when Galileo’s light became visible. What is the problem with his experiment? (side comment: Römer used a method based on Galileo’s idea to measure the speed of light in the 1670s, except that his method required no second person and the light traveled only one way. This would be a very appropriate topic for a short paper)

The most obvious problem is the reaction time of the assistant on the distant hill – he or she could not possibly have uncovered the lamp quickly enough to get a useful measurement of the elapsed time. A second problem is means to measure the timing – Galileo knew about using pendula to measure time, but he had no tool available to measure such short time intervals. Römer did so by measuring the long time intervals between the predicted and actual times when moons of Jupiter appeared and disappeared in eclipses caused by the shadow of the planet. This allowed him to get a good estimate of the speed of light using an hourglass!

6. List three (3) physical interactions that can occur between light energy and matter. For each of these, give an example of how that interaction makes an object “visible” to an imaging system.

Several choices: scattering of light by molecules (what makes the sky blue and sunsets red), absorption of light by matter (used in a pinhole camera), refraction of light by Snell’s law (used to construct lenses), emission of light by thermal or atomic interactions, reflection of light by objects (forming colors).

7. In your own words, describe how a charge-coupled device (CCD) is able to create and read out an image. Use figures to illustrate your answer.

The image is created by absorption of light in the silicon crystal, which “kicks” electrons up into energy levels that may be transported. The free electrons are “moved” under the action of timed voltages down a column and then across a row to an amplifier, using the “bucket brigade” analogy. The figures are available in the slides.

8. We stated that the charge-coupled device (CCD) has almost completely replaced photographic emulsions in astronomical applications and it is clear that this is becoming true in consumer applications (e.g., family snapshots). Explain why these changes are occurring, including several reasons for the change.

Many reasons exist:

- (a) *images may be viewed immediately on the LCD display on modern cameras (believe it or not, early CCD cameras did not have these!)*
- (b) *unsatisfactory images may be deleted*
- (c) *images may be immediately downloaded, printed, transmitted by e-mail*
- (d) *cost of sensors continues to decrease*
- (e) *camera capabilities are growing, e.g., zoom lenses*

But photographic emulsions are still cheaper to purchase initially and cheaper make large numbers of prints, also if correctly stored, the negatives and prints last longer than printed electronic images. The media for the electronic images must be updated every few years to ensure that they are archival.

Midterm statistics:

Possible Score	60 (+ 5 bonus)
Mean Score	48.6
Standard Deviation	7.5
Maximum	62
Minimum	25