Assignment#1, Fundamentals in BioPhotonics 2023

1) (5%)

Biophotonics is an interdisciplinary field that combines principles from optics, biology, and medicine to study biological systems at the molecular and cellular levels. Provide an example of a biophotonic technique that has been used to study a specific biological process or system, and explain how the technique works and what insights it has provided.

2) (10%)

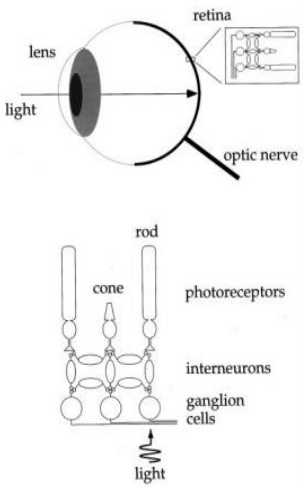
Let's start with a simple calculation of the photon energies (you probably know the needed formulas from high school 😉)

a) Find the number of photons emitted per second for a FM radio station (at 90 kW) that transmits signals 45.3 Mhz. and for a 1.4 mW LED source that generates a beam at 440 nm.

b) A head MRI (magnetic resonance imaging) is operating at 3.5 GHz. If energy of 40 μJ is used in this operation, find the average wavelength and the average number of photons, to which the patient is exposed.

3) (25%)

Now, let's add a little bit of bio and think of how our eyes perceive all those photons!



Rods (peak response at $\lambda = 507$ nm) and cones (peak response at 555 nm) are the photosensitive cells in human eye. Although rods are more sensitive, they cannot register colors (unlike cones).

a) Find the energy of the photons detected by these cells with the highest sensitivity.

b) Studies show that there should be at least 90 photons per second to efficiently stimulate rod cells. Assuming the exposed area is ~0.01 mm^2 calculate the threshold value for the total energy, the photometric flux, the optical power and the intensity.

c) If we have 100 rod cells in the exposed area how many photons each cell detects (detection period is about 0.1 second).

d) Given that the sensitivity of cone cells is 1/220 of the rod cells, find the threshold values for cone cells.

e) What might be the reason for the higher sensitivity of rods?

3) (20%)

Switching from eyes, to some simpler optical elements, prisms are often used to spectrally separate various wavelengths of light.

a) How does a prism-based spectrometer work? (sketch the optical paths for different wavelengths).
b) What does the resolution of such spectrometer depend on? Is there a limit?

4) (20%)

Shifting the focus to another typical element of optical setups – lenses! Think about their optical characteristics within the geometrical/wave optics framework!

a) What is the difference between reflection and reflectance, transmission and transmittance? How are they defined?
b) What is the typical reflectance of the air-glass interface? Why is this important?
c) How do anti-reflective coatings work? Where are they used? Are there any other ways to minimize reflection?

5) (20%)

Now, a slight touch of Maxwell's Equations (no hard maths though!). Assume that a harmonic electromagnetic plane wave in free space has the following E-field:

$$E_z(y,t) = E_{\{0z\}} \sin(\omega \left(t - \frac{y}{c}\right) + \epsilon)$$

Determine the corresponding B-field and sketch the wave.