Lasers e Óptica Biomédica
série 2

Mestrado em Física Médica

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1 Fiber Optics and Lasers

1. laws of reflection and refraction.
   (a) indicate different forms of polarized light.
   (b) two optical fibers are characterized by a core of glass (silica) refractive index of $n = 1.5$ and diameter $\Phi = 500\,\mu m$. One of the fibers, called fiber A, has a cladding (second glass layer) made of an optical material with refractive index $n_{clad} = 1.43$. The other fiber, designated as fiber B, does not have any additional layers or protective sleeve.
      i. Estimate the maximum angle of the cone of light corresponding to the light guided in each of the fibers.
      ii. Describe the spatial distribution of light emerging from the exit of the fiber.
2. A HeNe beam power of 1mW was injected into a fiber optic numerical aperture NA = 0:20.
   (a) what) lens should be used after the output of the fiber, so as to produce a collimated beam of 3 cm in diameter?
   (b) assuming 100% efficiency in injection of the beam into the fiber, determine the irradiance of the collimated beam after the lens chosen in the previous paragraph.
   (c) compare with the original laser beam irradiation, assuming that it has a diameter of about 1 mm.
   (d) what can you comment about the perception of the human eye of these two beams projected on a blank sheet of paper?
3. An optical fiber has its axis oriented at 10° relative to the normal of the surface of a material consisting mainly of water. If the numerical aperture of the fiber is NA = 0.173,
   (a) what is the range of variation of reflectance on this surface, in this configuration?
   (b) repeat for the fiber axis oriented at 60° from the normal.
4. A pulsed laser emits 50 mJ energy pulses at the rate of 10 Hz. Each pulse lasts1μs. The beam is focused on an area of 0.0001 cm^2 . Determine:
   (a) the average power;
   (b) the power per pulse;
   (c) the mean and pulse intensities, at the focal spot;
   (d) fluency at the focal spot.
5. Determine the percentage of optical power contained within the circle of radius equal to the beam waist of a collimated Gaussian beam profile.

6. A circular aperture is placed in the path of a collimated laser beam with Gaussian energy profile. What diameter should have this opening in beam waist units w_0 so that the transmitted optical power is exactly 99% of the maximum value?

2 Doppler measures

1. Doppler Effect: consider a sound source, which emits f_0 frequency waves. The source is in the vicinity of a listener. Derive expressions for the sound frequency perceived by the listener, in the following cases:

   (a) source moves at the speed v_{source} relative to the observer, and the observer is static;

   (b) the observer moves at speed v_{obs} to the source, and the source is static;

   (c) both source and observer are moving at speeds v_{source} and v_{obs} (displacements on the same spatial line);

   (d) instead of sound waves consider a beam of light incident on a moving mirror; what is the frequency deviation introduced in the reflected beam?

2. Doppler effect in astronomical observations, refers frequently a "red shift" of the optical spectrum emitted by stars. Can you explain what this shift refers to , and how to measures the velocity of the stars?

3. One can measure the speed of blood flow by Doppler effect. For the scenario of an artery that passes close to the surface of a member (leg or arm),

   (a) what kind of waves can you use to perform this measurement?

   (b) what is the frequency shift induced by the movement of red blood cells, the speed v_{blood}, when the emission and detection is performed on a line of sight at an angle θ to the direction of blood movement?

3 Light and Matter

3.1 turbid media

1. What is meant by mean free path and depth of penetration, in the context of propagation of light beams in turbid media?

2. In a totally absorbing medium (no diffusion) and absorption coefficient μ_a :

   (a) what percentage light is available after propagating a distance L?

   (b) derive the expected value for the optical path length of a non absorved propagating photons (survivor).

3. Determine the mean free path of radiation from KrF , HeNe, and CO_2 lasers in water, and skin.
   [Http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3321368/, Julia L. Sandell and Timothy C. Zhu, A review of in-vivo optical properties of human tissues and its impact on PDT, J Biophotonics. November 2011; 4 (11-12):. 773-787]

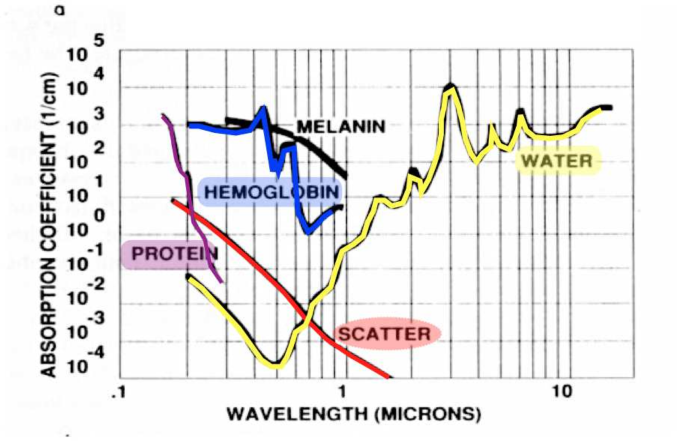
4. A collimated laser beam at 632.8 nm, 3 mm beam waist and 1 mW optical power, addresses the cornea.

   (a) Estimate the power of red radiation incident on the retina;

   (b) Calculate the irradiance on the retina, assuming a focal spot fo $10\mu m$;

(c) Calculate the diffraction limit of the human eye considering the laser beam size, and a fully dilated pupil (aperture of 7 mm), and compare the physiological dimensions of the rods and cones.

5. Consider the absorption curves of the figure



(a) Calculate the length of absorption to skin and water, associated with commonly used lasers: Argon, Krypton and ND: YAG doubled in frequency; Nd: YAG; CO_2 .

(b) identify lasers that can have a good performance in the (photo) coagulation process of the blood, or small blood vessels, is coagulated by thermal heating.

6. Identify which particles / structures / objects can induce a strong Rayleigh scattering, in light ranges:

(a) Ultraviolet and Visible;

(b) Infrared;

(c) Microwave.

7. Show that the Henyey-Greenstein phase function is reduced to $p(\theta) \approx\sim \frac{1}{4\pi}(1+3g\cos\theta)$ after when the light scattering is slightly frontal.

8. Explain the meaning of the different terms of the phase function known as \ delta -Eddington,

$$p(\theta) = \frac{1}{4\pi}\{2f\,\delta(1-\cos\theta) + (1-f)(1+3g\cos\theta)\}$$

where $\delta(x)$ is the function δ Dirac, and f indicates the forward scattering contribution, compared to the total scattering.

3.2 turbid media - biological tissues

1. A laser beam of a Nd: YAG, 2 mm diameter, on an experiment of light interaction with a biological tissue. The laser operates in pulsed regime, 10 Hz rate, and pulse energy 1 mJ and duration of 6 ns.

(a) The beam is expanded to 2 cm in diameter. For this purpose we use a pair of lenses, the first a diverging lens and the second a converging one.

i. generally sketch the expansion scheme of the beam dimension provided by the pair of divergent-convergent lenses;

   ii. the mounting space available for beam expansion is about 10 cm; in a drawer lenses of different focal lengths are available: {-9; -12; -18; -25; -50; 50; +75; +100; +125; 150; 200} [mm]; choose the pair of lenses which gives the desired expansion in the available space.

(b) at the interaction zone, a lens of 25 mm focal length and 1 inch in diameter is used to focus the light into the tissue.

   i. what is the minimum spot diameter on the expected tissue?

   ii. which is the maximum irradiance?

   iii. what possible effects may be induced by interaction of light with the biological tissue?

(c) if the beam had not been expanded, and the same lens was used close to the tissue, what would chang in the answer for the previous paragraph?

(d) discuss the advantages or disadvantages embodiment of beam expansion at the expense of two converging lenses.