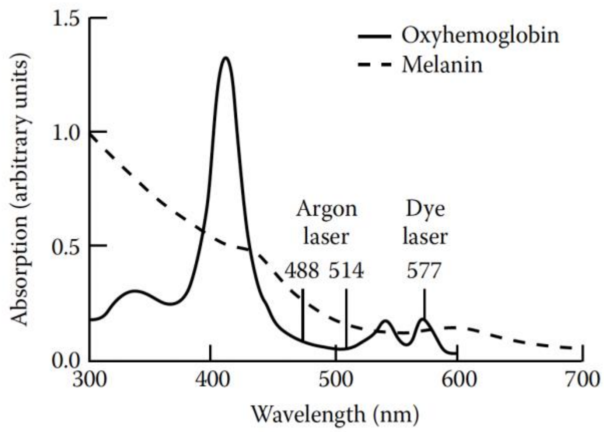
Physics in Modern Medicine **Winter 2023**

Homework #2

Chapter 3 – Lasers in Medicine

Questions

Q3.1 From the figure below, melanin absorbs in a wide range of wavelengths, but the largest absorption occurs between $300nm$ and $400nm$. From this a surgeon might opt to select a UV laser.



Q3.2 The absorption characteristics would be that the tissue would have to be able to preferentially absorb blue-green light while reflecting longer wavelength light (reds, for example.) For blood, the hemoglobin tends to absorb green/blue light (and reflect red) when the hemoglobin is bound to oxygen. This would also be appropriate for the iris of a brown eye, but not for the lens of the eye, which would transmit all of the light.

Q3.3 Since tooth is white in color it will reflect all of the visible light that is incident. Painting the enamel black will cause the incident light to be absorbed and not reflected.

Problems

3P.1 Photon energies

a. The energy of any photon is given as $E = \dfrac{hc}{l}$. For each of the wavelengths given we calculate the photon energy from the formula. The energies are given in the table below in Joules and in eV, where $1eV = 1.6 \times 10^{-19}J$. Based on the table below, the excimer produces the most energetic photon while the CO_2 produces the least.

Laser Type	Wavelength (nm)	Energy (J)	Energy (eV)
CO_2	10,600	$1.8x10^{-20}$	0.113
Nd:YAG	1064	$1.9x10^{-19}$	1.188
Argon	512	$3.9x10^{-19}$	2.438
Excimer	200	$9.9x10^{-19}$	6.188

b. The laser radiation types are given in the table below

Laser Type	Radiation Type	Color if visible
CO_2	Far infrared	
Nd:YAG	Infrared	
Argon	Visible	Green
excimer	ultraviolet	

c. Based on the table in part a, the only laser with enough energy output to break a chemical bond is the excimer.

3P.2 A Nd:YAG laser

a. The instantaneous laser power per pulse is given as $P_{inst} = \frac{E}{t} = \frac{100\times10^{-3}J}{1\times10^{-9}s} = 1 \times 10^{8}W$.

b. The average power is given as $P_{avg} = E \times R = 100 \times 10^{-3}J \times 10s^{-1} = 1W$.

c. The exposure time is given by the energy per pulse divided by the average power. Thus, we have $t_{exp} = \frac{E}{P_{avg}} = \frac{10J}{1\frac{J}{s}} = 10s$, which is probably reasonable for exposure to remove some cells.

3.P.3 Typical power densities for ophthalmological surgery applications can be obtained by dividing the intensity of the laser by the area of the focused spot

a. We have a $500\mu m$ spot diameter and a power $P = 200mW$ for photocoagulation of the retina and other parts of the eye. The area of a circular spot $A = \pi r^2$, where r is the radius. This corresponds to a power density of:

$$I = \frac{P}{A} = \frac{200 \times 10^{-3}W}{\pi\left(\frac{500\mu m}{2} \times \frac{1 \times 10^{-6}m}{1\mu m} \times \frac{100cm}{1m}\right)^2} = 100\frac{W}{cm^2}.$$

b. Photovaporization of cataracts or opacities within the eye might use a $50\mu m$ diameter spot and a power/intensity setting of roughly $2W$, corresponding to a power density of:

$$I = \frac{P}{A} = \frac{2W}{\pi\left(\frac{50\mu m}{2} \times \frac{1 \times 10^{-6} m}{1\mu m} \times \frac{100cm}{1m}\right)^2} = 1 \times 10^5 \frac{W}{cm^2}.$$

c. Comparing the two settings by dividing our answers for the power densities in parts a and b, we see that the photovaporization configuration has a power density of *1000 times higher* than that for photocoagulation. That extra intensity allows surgeons to vaporize the tissue, rather than merely slowly heating it for purposes of photocoagulation.

3P.4 Power Density of a Laser

a. The spot size is evaluated from $d = \frac{2\lambda f}{\pi D} = \frac{2 \times 514 \times 10^{-9} m \times 0.02 m}{\pi \times 0.001 m} = 6.6 \times 10^{-6} m.$ This is an extremely small spot size, too small for photocoagulation in the ophthalmological applications discussed in the text, and it would likely correspond to inappropriately high power densities for such procedures. This can be compensated for by inserting a lens that spreads out the laser beam before it passes through the eye, leading to a larger spot size, and hence a safer value of the power density.

b. The power densities are given as $I_1 = \frac{\pi D^2 P}{\lambda_1^2 f^2}$ and $I_2 = \frac{\pi D^2 P}{\lambda_2^2 f^2}$ so that the ratio of the power densities is $\frac{I_1}{I_2} = \frac{\lambda_1^2}{\lambda_2^2}$. Since the power density depends inversely on d and d depends directly on λ, the shorter focal length leads to a smaller d and thus a higher power density.

c. We can use the above formulas to compute that the ratios between the power densities will be:

$$\frac{I_1}{I_2} = \frac{(532nm)^2}{(355nm)^2} = 2.3$$
$$\frac{I_1}{I_2} = \frac{(1064nm)^2}{(355nm)^2} = 8.9$$
$$\frac{I_1}{I_2} = \frac{(10600nm)^2}{(355nm)^2} = 892$$

The ultraviolet will have a power density 2.3 times that of the ND:YAG green line, 8.9 times that of the ND:YAG infrared line, and 892 times that of the infrared carbon dioxide laser. The variation of spot size with wavelength can be a very large effect—the power densities can be improved by a factor of *almost 1000 times* by using the shorter wavelength.