1. [6] Consider you want to perform corneal refractive surgery using ablative laser processes.
   For this task you have available a Nd:YAG laser with an energy of 2 mJ, pulse time of 12 ns and a beam quality factor of 6, with an output diameter of 2 mm. Knowing that the onset for optical breakdown in cornea tissue is approximately 2.31 x 10^{10} W/cm^2, setup an “optical probe” using the necessary lens system, which will allow you to do the job.

   Lens set: +100 mm; +50 mm; +25 mm; -50 mm; -25 mm.

   a) Calculate the energy density at the focal point at the output of your probe.
   b) Make a simple scheme of the optical probe, indicating components and distances. Justify your choices.
   c) Estimate your working tolerance, i.e, how far can the cornea surface be from the focal point and still be ablated? Consider a diffraction limited beam.

a)

The Power density of a focused laser is given by:

$$I_0 = \frac{\pi E_L D^2}{4\tau_L f^2 \lambda^2} \times \frac{1}{(M^2)^2} = \frac{I'_0}{(M^2)^2}$$

Considering the data from our laser: E= 2 mJ, t=12 ns, M2=6, D=2 mm and using the most powerful (+25 mm) lens available we obtain a power density of just:

I = 2.06x10^9 W/cm^2

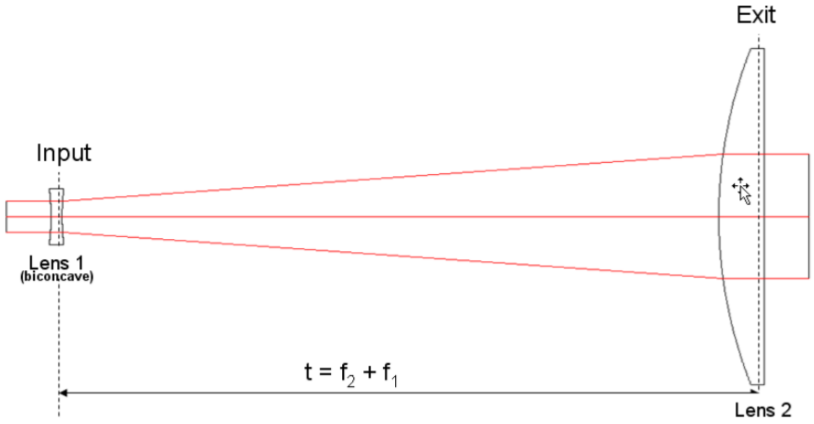
which is smaller than the threshold of 2.31x10^{10} W/cm^2 by a factor of 11.2.

So, in order to go above threshold for plasma formation we have to increase the power density for at least 12 times.

Looking at the above relation we see that if the initial beam diameter is increased by a factor of 2 we can achieve a 4 fold increase in the power density. So to attain an increment of approximately 12 times, we need to expand our beam at least 3.5 times.

Looking at the available lenses we see that we can use them to expand and them focus the beam.

(b) If we take the -25 mm, and +100 mm and build a beam expander as follows:



This gives us a magnification factor of M=-f2/f1= -100/25=-4

Therefore the 2 mm input will transform into an output beam with 8 mm in diameter. If we apply the +25 mm lens at the output of the expander we now get:

(a) I= 3.29×10^{10}W/cm2 which is well above the threshold.

c) We have in the focus a power density of I= 3.29×10^{10}W/cm2 which is 1.4 x I threshold.

This means if the spot area is enlarged by a factor of 1.4 we go bellow the necessary power density.

A factor of 1.4 in the area corresponds to a factor of $1.4^{-1/2}$ in the radius. I.e. if the spot radius increases by $1.4^{-1/2}\approx1.2$ we loose the plasma condition.

On the other hand from $$2w_0 = \frac{4\lambda}{\pi}\frac{f}{D} = 1.27\lambda\ f_{/\#}$$

We can estimate that we have at the focal spot a radius of $w_0=2.11\text{x}10^{-6}$ m.

So we want to find out at which distance from the focus the radius w(z) becomes equal to 1.2 w_0.

Considering

$$w(z)^2 = w_0^2 \left[1 + \left(\frac{z}{z_0}\right)^2\right]$$

$W(z)=1.2W_0$

$$2z_0 = \frac{2\pi n w_0^2}{\lambda}$$

We get $Z=0.63Z_0$

Calculating Zo, assuming n=1, we get

Z_0= 1.323x10-5 m

So z≈8 um.

This way, the laser will only by ablative in a region around the focus of +-8 um.