EXPERIMENT 7
BEAM EXPANDER AND BEAM SPLITTER

PURPOSE

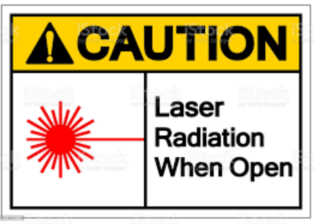
You will perform two experiments. The aim of first is to design and setup 5x/8x beam expanders. The aim of the second one is to obtain power characteristics of a beam splitter.

EQUIPMENT

DC source, optical powermeter, uncoated thin lenses, beam splitter, millimetric paper.

NOTE

Lasers can cause damage in biological tissues, both to the eye and to the skin. Unprotected Human Eye is extremely sensitive to laser radiation and can be permanently damaged from direct or reflected beams. High power lasers can also burn the skin. There are some government regulations that define classes of laser according to the risks associated with them.



THEORY

Beam Expander

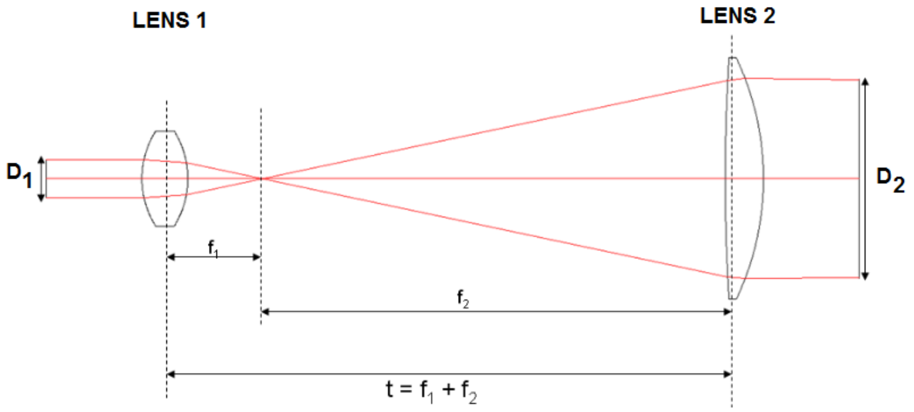
Beam expansion or reduction is a common application requirement in most labs using lasers or light sources and optics. There are many ready made beam expanders available on the market, but they are exapnsive. A commertial beam exapander is shown in Figure 1. We have one in our optics lab which is 10x variable beam expander.

Figure 1: A commertial beam expander.

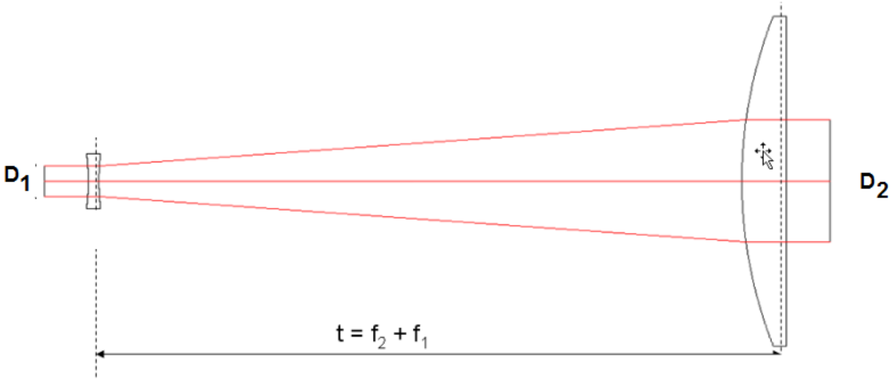
One can build a beam expander from off-the-shelf components (lenses) which can fit into most budgets. The quality of the output is dependant only on the input beam and the component optics used. To create a beam expansion unit, it is important to know a few simple optical relationships, as well as what your input to output beam diameter ratio requirement is.

Simple beam expanders (sometimes referred to as telescopes) in their most basic forms generally consist of two lenses. The first lens should have a diameter larger than the maximum expected input diameter of the incoming light source. For example, if the diameter of the incoming beam is 10mm, a 12mm diameter lens will do a nice job with a little room to spare. The input beam is assumed to be collimated.

There are mainly two types of beam expander (BE); Keplerian BE and Galilean BE, see Figure 2. For both designs, rays propagates from left to right. Also, input and exit rays are parallel to optical system, namely, the afocal system. In a Keplerian BE, two lenses are positive and they have common focus in between. However, in a Galilean BE, first lens is negative and second lens is positive, and the input beam is not focused at any point.



Keplerian BE



Galilean BE

Figure 2: Keplerian BE (top) and Galiean BE (bottom). Rays propagate from left to right.

For both beam expanders, the following two thin lens equations are used in the design:

$$m = -\frac{f_2}{f_1} = \frac{D_2}{D_1} \quad \text{and} \quad t = f_1 + f_2$$

f_1 = focal length of first lens
f_2 = focal length of second lens
D_1 = diameter of input beam
D_2 = diameter of output beam
m = magnification of the system
t = distance between lenses

Example 1:

If $f_1 = +10$ mm, $f_2 = +100$ mm and $t = 10+100 = 110$ mm, then $m = -100/10 = -10$. Therefore, we have beam 10x Keplerian BE.

Example 2:

If $f_1 = -10$ mm, $f_2 = +100$ mm and $t = -10+100 = 90$ mm, then $m = -100/(-10) = +10$. Therefore, we have beam 10x Galilean BE.

Note that, in some laser applications we require a specific zoom beam expander (ZBE). In this case, we need at least a third lens. Two of them has to be moveable. An example ZBE is shown in Figure 3.

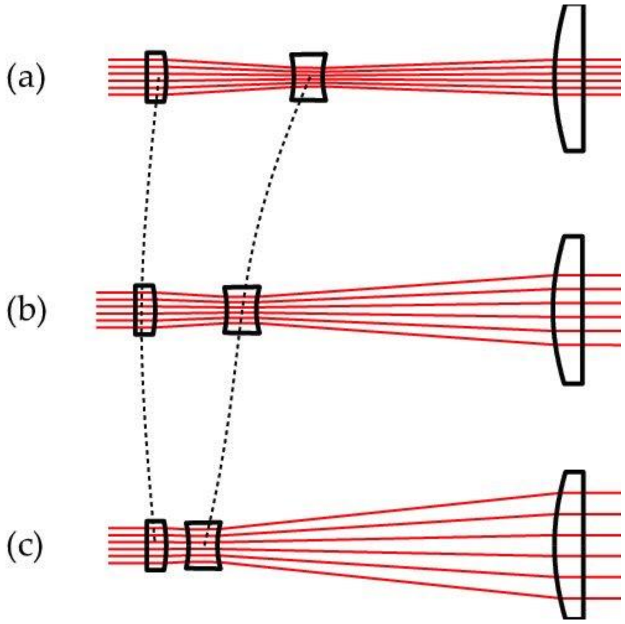


Figure 3: ZBE. Lens 3 is fixed. Position of Lens 1 and 2 adjusted such that the system is afocal.

Beam Splitter

A beam splitter (BS) is an optical component that splits a beam of light in two. BS can also be used in reverse to combine two different beams into a single one. BS are often classified according to their construction: cube or plate, See Figure 4. Cube BS is made from two triangular glass prisms which are glued together at their base. Plate BS design is the use of a half-silvered mirror. BS are used in many applications; interferometers, quantum optics and etc.

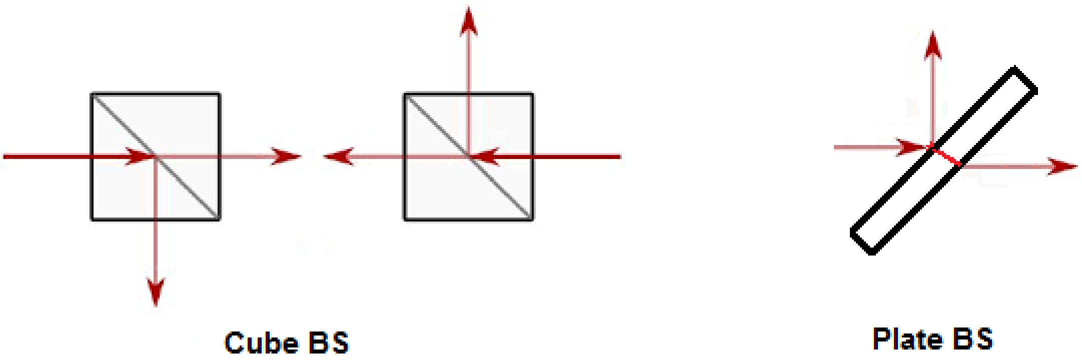


Figure 4: Two types of beam splitters

PROCEDURE

Part 1 *Beam Expander*

Setup is shown in Figure 5. In our lab, we have positive and negative lenses, each with 25.4 mm in diameter. The focal lengths in mm of them as follows:

P = {+1000, +750, +400, +300, +250, +200, +175, +150, +125, +75, +60, +50, +40, +35, +30, +25}
N = {-100, -75, -50, -25}

Using any of two lenses above

a) Build 6x Keplerain BE
b) Build 8x Galilean BE

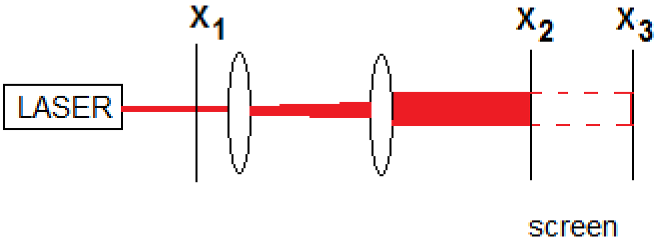


Figure 5: Exp. 1

For each setup, measure beam diameter D_1, D_2, and D_3 at a distance corresponding to different positions, x_1, x_2 and x_3, respectively. Note that, set the displacement $\Delta x = x_3 - x_2 > 1$ m. In order to verify BE equations, fill Table 1 and evaluate percentage difference between two magnifications [PD=100*$|m_1-m_2| / (m_1+m_2) / 2$].

Table 1: Data for Exp 1

Design	Focal length f_1	Focal length f_2	Distance t	Diameter D_1	Diameter D_2	magnification $m_1 = f_2/f_1$	magnification $m_2=D_2/D_1$	% diff PD
Keplerian								
Galilean								

Part 2 *Cube Beam Splitter*

Setup is shown in Figure 6. Measure the optical powers (P_1, P_2 and P_3) at three different locations as shown in the figure and fill Table 2.

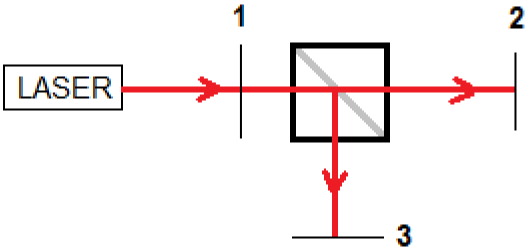


Figure 6: Exp. 2

Table 2: Data for Exp 2

Measurment	**Power(W)**	**Percentage Energy**
P_1		100 %
P_2		
P_3		

QUESTIONS

1. Determine maximum Keplerian BE magnification that can be achieved using only the lenses in our lab. Do not forget to consider the diameter of lenses.
2. Determine maximum Galilean BE magnification that can be achieved using only the lenses in our lab. Do not forget to consider the diameter of lenses.
3. We want to design a 15x magnification Galilean BE. Separation between lenses should be 7 cm. What are the focal lengths and diameters of the lenses required?
4. Explain why the percentage energy sharing beween P_2 and P_3 are not equally divided (50%-50%) in Table 2.