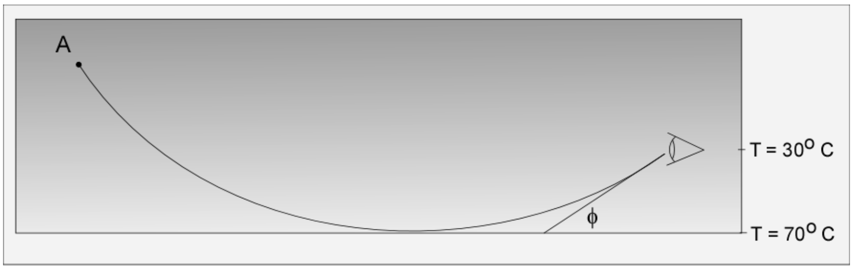
ELEC E-5730 Optics

Exercise II Jan 25 2021

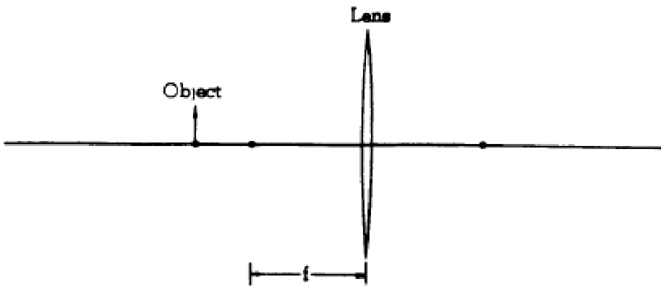
Question Q1. The refractive index as a function of temperature t (in degrees Celsius) is given by: $n(t) = 1.000291 - 10^{-6}\,t$. On a hot summer day the road temperature is 70 C and the temperature at the point of observation is 30 C. A ray of light leaving point A traces the path depicted in the figure below (This phenomenon is known as the 'mirage').



a. Use Fermat's principle to qualitatively explain the path of the ray.
b. Use Huygens principle to qualitatively explain the path of the ray.
c. Use geometric optics to qualitatively explain the path of the ray.
d. At what angle ϕ does the ray reach the observer?

Question Q2. An object is located a distance $3f/2$ from a thin converging lens of focal length f as shown in the diagram below.

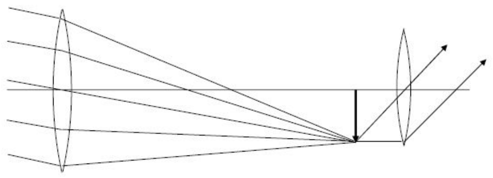
a. Calculate the position of the image.
b. Trace the three principal rays to verify the position of the image.
c. Suppose the object remains fixed and the lens is removed. Another converging ('positive') lens of focal length f_2 is placed in exactly the same position as the first lens. A new real image larger than the first is now formed. Must the focal length of the second lens be greater or less than f ? Justify your answer.



Question Q3. Show that the focal length *f* of a two-lens system does not depend on wavelength if the distance *d* between the two lenses is [hint: Show that $df/d\lambda=0$]:

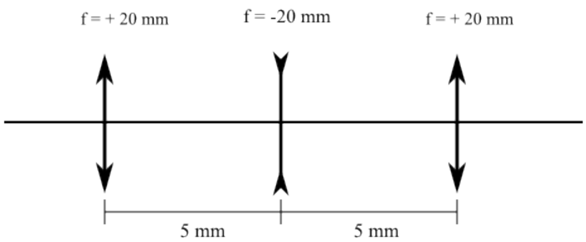
$$d = \frac{f_1 + f_2}{2}$$

Question Q4. Magnification of a simple telescope. A telescope is used to look at the moon (radius 1740 km) from the earth (distance 384 000 km). The objective lens has long focal length of f = 10 m. Let's suppose that the black arrow (see the diagram below) is the real image of the upper half of the moon. What is the linear magnification in this case? A second lens, eyepiece, is next added to increase the viewing angle (just like a magnifying glass). Define the angular magnification. What is the value of angular magnification if the eyepiece has f = 100 mm?



Homework Question HQ 1. (return by January 25 2021) A compound microscope consists of an objective lens of focal length 20 mm and an eyepiece of focal length 62.5 mm separated by a distance of 150 mm. How far away from the objective should an objective be placed to obtain the final image at (a) the least distance of distinct vision (= 25 cm), and (b) at infinity. What is the magnifying power of the microscope in each case?

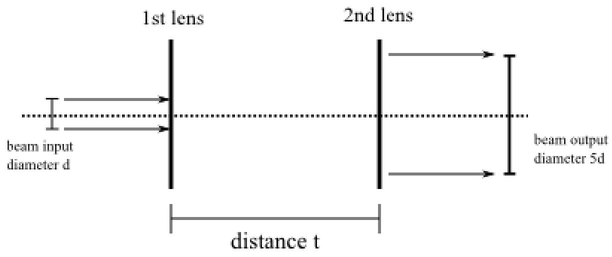
Homework Question HQ 2. (return by January 25 2021) A camera lens is constructed using three thin lenses with focal lengths f_1 = 20 mm, f_2 = -20 mm and f_3 = 20 mm, and separated by 5 mm intervals as shown below. Find the effective focal length, principal planes and principal focal planes of the combination. The lens is used to photograph an object 20 metres high at a distance of 500 m. What is the height of the image on the CCD sensor of a digital camera in this case?



Homework Question HQ 3. (return by January 25 2021) Your task is to design a lens system consisting of two thin lenses with focal lengths f_1 and f_2 and sitting a distance t apart from each other. The lens system must magnify a collimated laser beam having a diameter of 1 mm into a collimated beam having a 5 mm diameter (see the schematic on the next page), that is, the matrix expression for the system is

$$\begin{bmatrix} \pm 5r_1 \\ 0 \end{bmatrix} = M \begin{bmatrix} r_1 \\ 0 \end{bmatrix}$$

a) Solve the general case, that is, express t and f_2 as a function of f_1
b) Take t = 120 mm and calculate M for both positive and negative sign. Verify the design by sketching the lens system for both signs. Where are the principal planes?


1st lens
2nd lens
beam input
diameter d
beam output
diameter 5d
distance t