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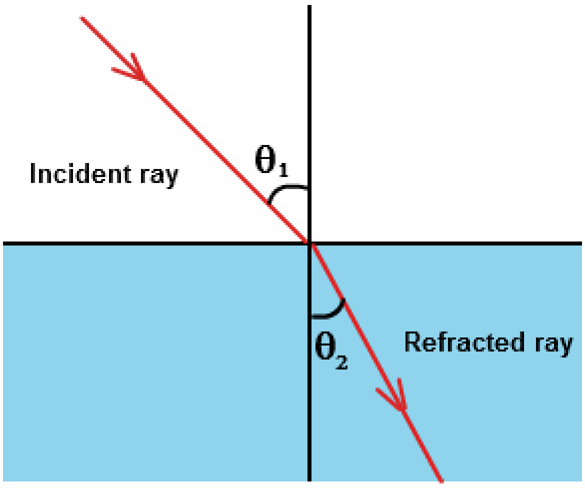
Programmable Optical Devices – Assingment

Option 1

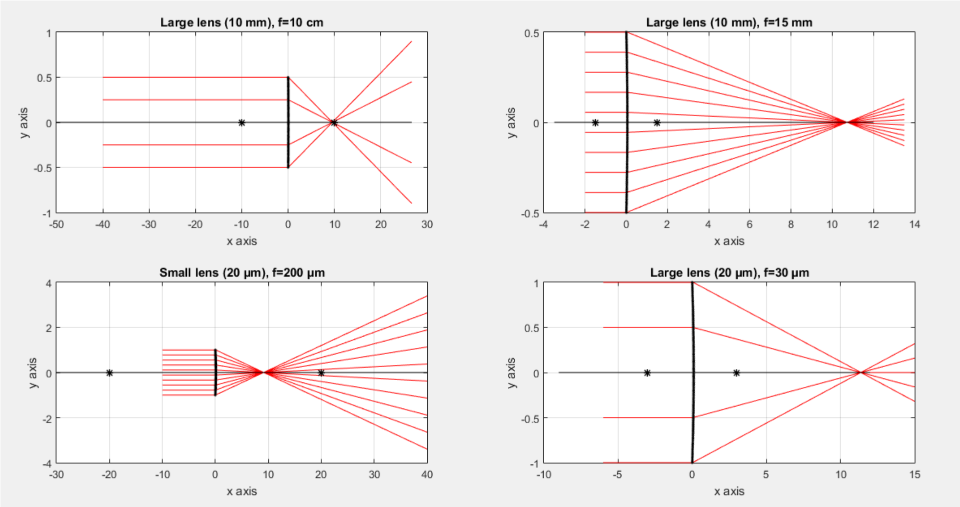
Task 1

Desription of the task: Design lenses using geometrical optics (Snells' law).
Used theoretical background: Snell-Descartes's law is a formula that describes the relationship between the angles of incidence and refraction. In optic we use it when light passing through a boundary between two different isotropic medium. With the following formula we can describe this law: $\frac{sin\theta_2}{sin\theta_1} = \frac{n_1}{n_2}$, where θ are the angle between the ray and the normal of the boundary, n are the refractive index of the known mediums.



Lenses have refracter index too, so we can use Snell-Descartes's law to make hem calculatable. With the following equation we can calculate their focal length: $\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right]$, where n is the refractive index of the material of lens, d is the thickness of the lens and R_1, R_2 are the radius of curvature at the both side of the lens. In this task we have considered thin lenses in 2 cases, beacuse the thickness of these lenses were much smaller than their diameters.

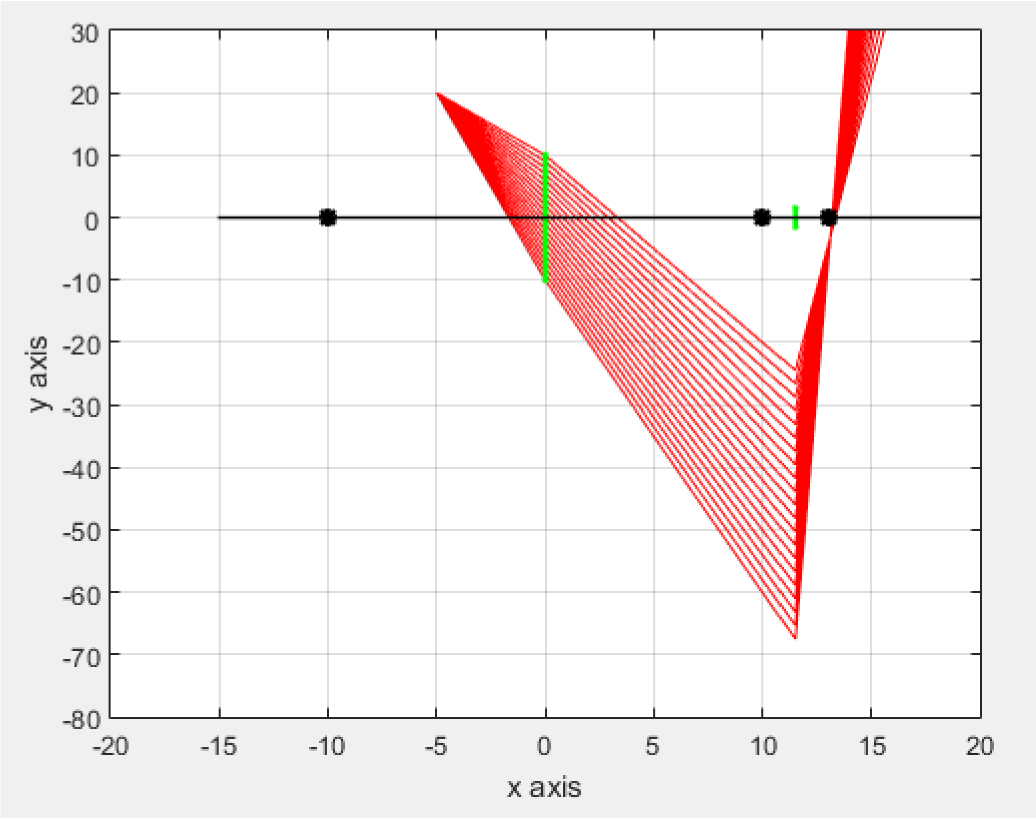
Results: In my Matlab codes I have tried to make some comments at the declaration of the variables to make the code easily interpretable. Therefore here I just try to introduce and explain the results.



This the interpretation of the four lenses in Matlab. We can clearly see that the lenses refract the parallel rays and concentrate them to a single point at their other side. In the first case this point is the focal point of the lens.

Task 2

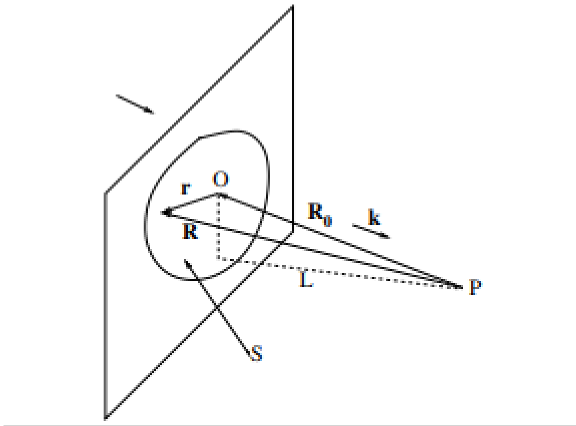
Description of the task: Write a simple Matlab code to calculate the imaging of one of the designed lenses using geometrical optics and Fermat's principle.
Used theoretical background: At the first tack I have mentoined the main points of the geometrical optics, so in this section I try to concentrate to the theoretical part of Fermat's principle. The principle is about the path taken between two points by a ray of light is an extremum path that generally is the minimal path. So we can call this principle the Hamilton's principle of optics and summerized by the following equation: $S = \int_A^B n(\boldsymbol{r})\, ds = min$, where n is refractive index of the medium. In the task I have used two lenses to demonstrate the imaging properties of the lenses.
Results: I have used my first two lenses from Task 1. After ran my code in Matlab, I got the following figure.



In this picture, we can see that rays from the point source of the object plane are going in one single point at the image plane after refrected through the two lenses. So there is a point at the image plane which is the image of the original point source which demonstrate the imaging properties of the lenses.

Task 3

Description of the task: Simulate the imaging of the lens using the simplest form of the Fresnel diffraction formula. Assume a coherent light source with a standard red laser pointer wavelength (λ = 632 nm).
Used theoretical background: In optics the Fresnel diffraction equation for near-field diffraction is a method that can be applied to the propagation of waves in the near field. This is the most general form of the diffraction because there is no restrictions on output layout. The formula is the following: $U(P) = \frac{U_0}{i\lambda}\iint_{\Sigma} \frac{e^{ikr}}{r} cos(\theta)dA$, where P_0 is the observing point, E is the amplitude of the evolving wave, R is the length vector and cosθ is the obliquity factor.



Results: I couldn't make this task in Matlab, so I have just tried to made a review of the theoretical background of the task.

Task 4

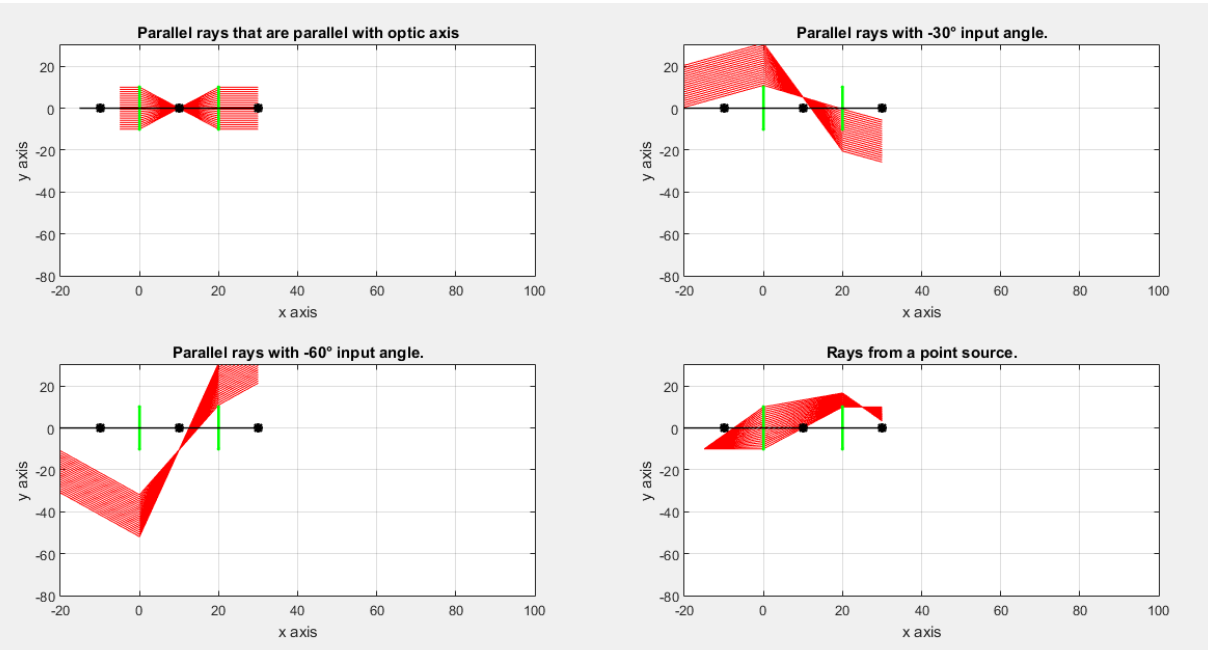
Description of the task: One way to describe light propagation through a spatially inhomogenous medium (i.e. where the index of refraction varies point by point) is to use the Paraxial Helmholtz Equation (PHE). Solving these equation gives you basically everything that is included in scalar diffraction theories – in a sense, this is all you need to understand diffraction, imaging, etc. The method is not horribly accurate though for very much off-axis wave propagation (like short focal distance lenses).
Used theoretical background: The Helmholtz equation is a partical differential equation that often arises in the study of physical problems involving partial differential equations (PDEs) in both space and time. This is a time-independent form of wave equation, and can be solved by the technque of separation of variables. The formula is the following: $\nabla^2 A + k^2 A = 0$, where k is a wavenumber and A is the amplitude.
Results: I couldn't make this task in Matlab, so I have just tried to made a review of the theoretical background of the task.

Option 2

Task 1

Description of the task: Use ray transfer matrices in MATLAB to model the rays through the system. Demonstrate multiple rays (e.g. rays parallel to optical axis, oblique incidence, point source on optical axis, point source off-axis, or

any other interesting case). You should also model rays that are focused to a single point in the Fourier plane (both on-axis and off-axis case).
Used theoretical background: The theoretical was the same that I have used above at Option 1. I would like to mention one more thing that is the ray transfer matrices which I have used in my previous codes too. Ray transfer matrices are used in the design of optical systems. The ray tracing technique is based on two reference planes, called the input and output planes. We can define the following equation: $\begin{pmatrix} x_2 \\ \theta_2 \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} * \begin{pmatrix} x_1 \\ \theta_1 \end{pmatrix}$, where $A \xrightarrow{\theta_1=0} \frac{x_2}{x_1}, B \xrightarrow{x_1=0} \frac{x_2}{\theta_1}, C \xrightarrow{\theta_1=0} \frac{\theta_2}{x_1}, D \xrightarrow{x_1=0} \frac{\theta_2}{\theta_1}$.
Results: I have used the same lenses as the two, and this lens was my predisigned from the Task 1 in Option 1. With this lens I have get the following figure:

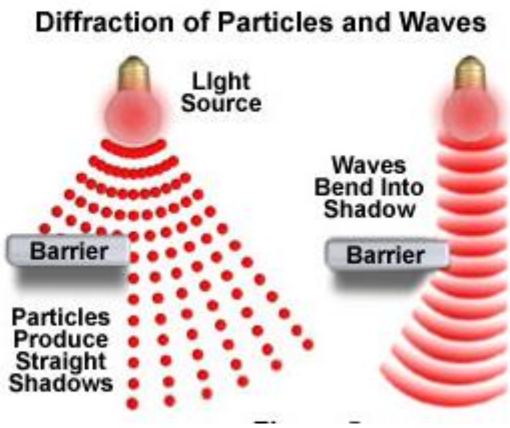


I have made different case by varying the input angle or assuming point source. In the case of parallel rays (independent from their input angle) are concentrating in single points at the Foruier plane (plane between the two lenses). However the rays of the point source ahead in another point at the side of image plane.

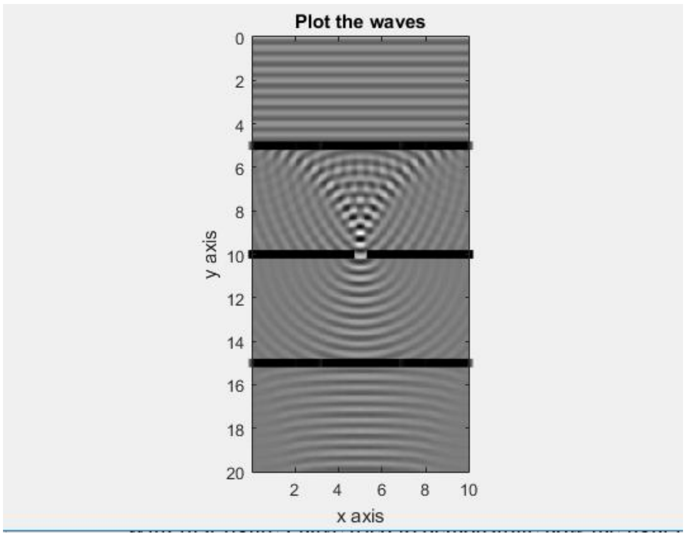
<u>Task 2</u>

Description of the task: First, create a MATLAB script, that simulates waves through the system. This is similar to the simulations we did in class, but now we have multiple elements, so you have to use successive image propagations through multiple planes. (Input image -> L1 -> filter -> L2 -> Output screen) Explain the exact methods/approximations you use.

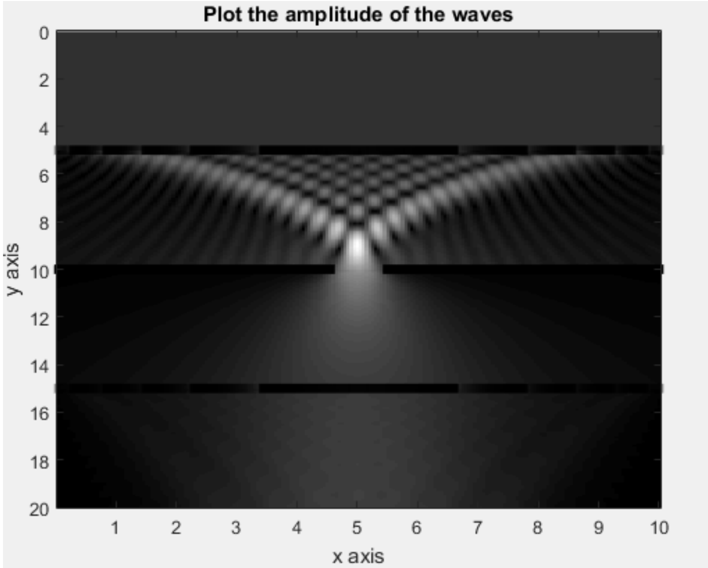
Used theoretical background: The light is a dual nature material, because we can see it as a particle, but other times we can take it as wave. The mathematical wave theory of light was worked out by Christian Hyuugens in 1678. Light waves are also called electromagnetic waves because they are made up of both electric (E) and magnetic (H) fields. As many other waves, light have two important characteristics as wave: the wavelength and the frequency. From these two we can calculate its speed too.



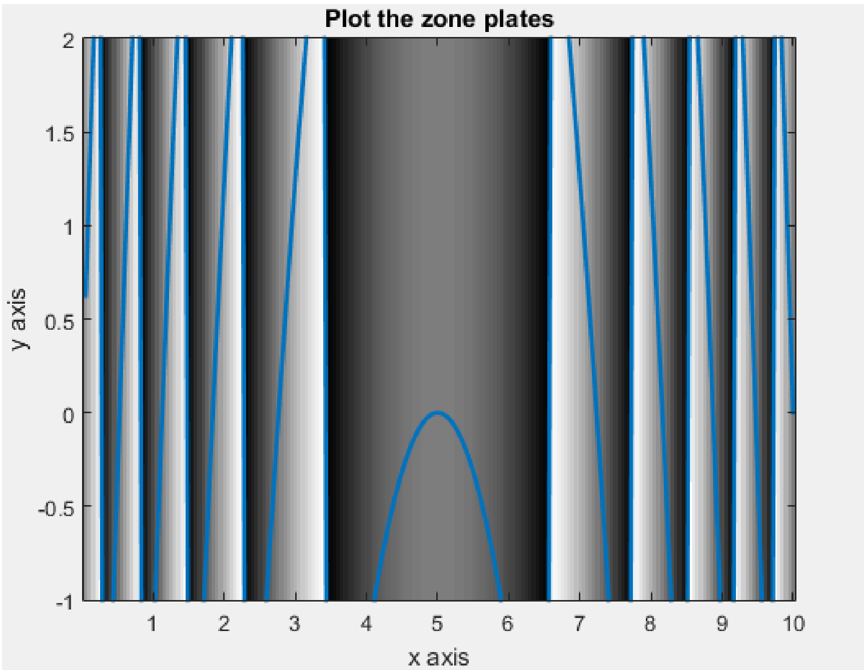
Results: I have written some comments in my Matlab code too, so I just try to focus to the got results.



With first figure I have tried to demonstrate how the light propagate as wave in a dark room by assuming a point like source.



This figure shows how the amplitude of the waves change in the parts of the room. We can clearly see that the amplitude become less with growing of the length from the source.



The final picture is the zone plate which is used for focusing light in optics like lenses. However, light through a lens undergoes refraction but light through a zone plate undergoes diffraction.