Z. Magnier

16,5/20

I - Lenses : 8.5 points

Where should the lens be placed?	2.5	2,5
1) We want an image that has the same size but is reversed, which means that $\gamma = -1$ This results in : $\overline{OA'} = -\overline{OA}$, which can be used in Descartes' conjugate equation $\frac{1}{\overline{OA'}} - \frac{1}{\overline{OA}} = \frac{1}{f'}$ $\frac{1}{\overline{OA}} - \frac{1}{\overline{OA}} = \frac{1}{f'}$ resulting in: $\overline{OA} = -2f'$ *Equivalent method with* $\gamma = \overline{FO}/\overline{FA}$	0.5 0.25 1	1,75
2) The object being real, $OA < 0$ so $f' > 0$, it is a converging lens.	0.75	0,75
Ray diagram (see last page)	6	
1) In order to create a virtual object, one needs to use an auxiliary convergent lens. We have to position a light source, a real object and the auxiliary lens so that the image is real. The position of the image is determined using a screen. The first lens L_1 of the diagram should then be placed so that this image would be where the virtual object AB is. Complete scheme with legends of the corresponding experiment with the different elements described	1 0.5	1,75
2) Intermediary image A_1B_1 on the first focal plane of L_2 Final image at infinity Incident ray towards B and F_1, parallel to the optical axis between the two lenses, then passing by F_2' after L_2 (red) Incident ray passing by O_1 and B, parallel to the red ray after L_2 (green) Incident ray parallel to the optical axis towards B, emerging after L_1 from F_1' and then parallel to the red ray after L_2 (blue) If the paths are not complete of only after L_1, only half the points. Cleanness of the drawing, respect of parallelism and dashed/solid lines	0.5 0.5 1 1 1 0.5	4,5

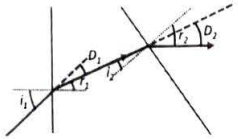


Figure 1: Successive deviations

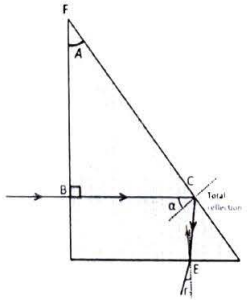
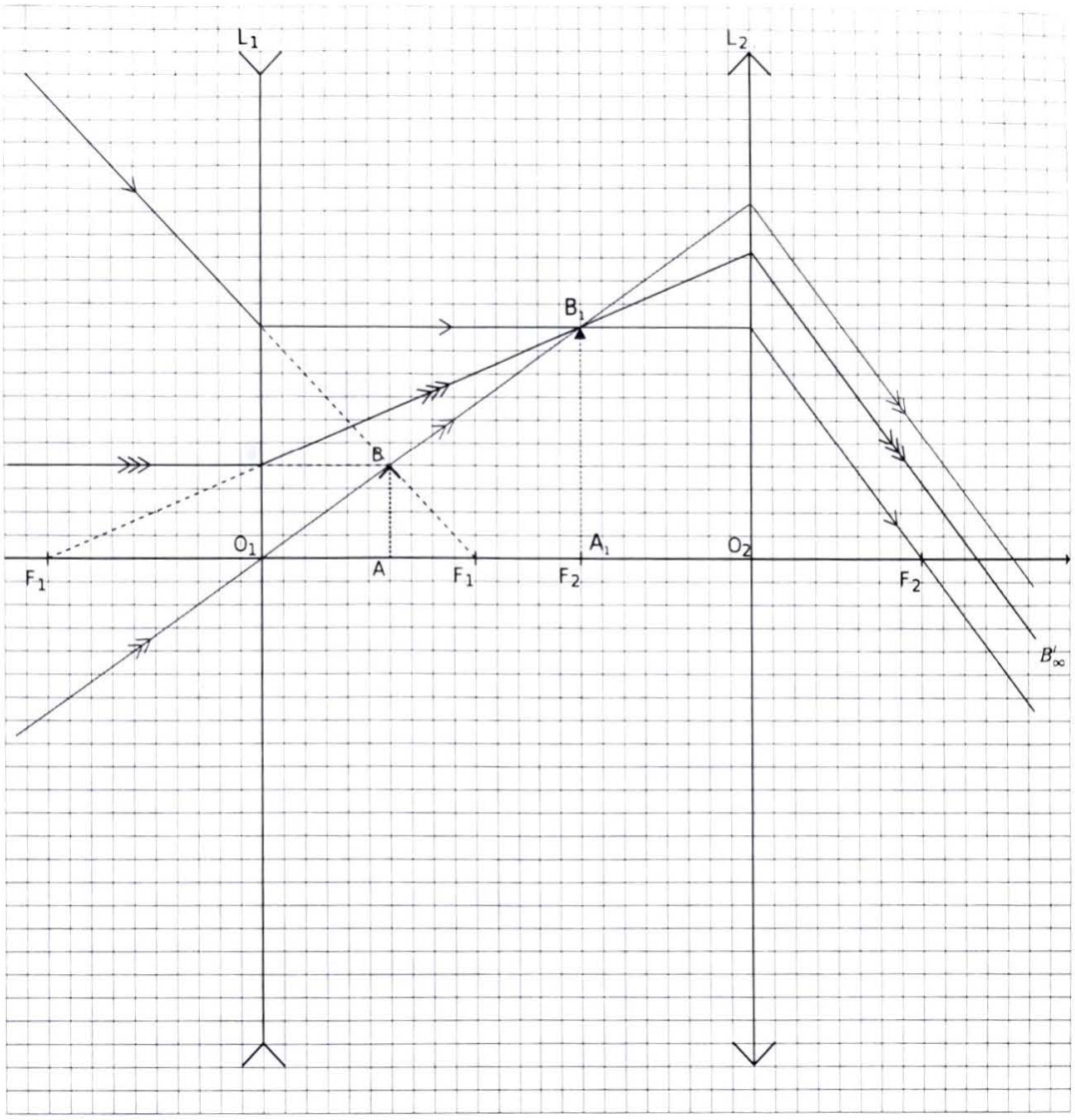


Figure 2: Optical path

II - To make it clear : 11.5 points + 1 point bonus

8,75

1)	In order to light boats located far away, the rays going out of the lens should aim at infinity. The light source must therefore be placed at the first focal point F of the lens.	0.5	0,5
2)	The first focal point of a diverging lens is located after the lens and is therefore virtual. The light source cannot be on this focal point for a diverging lens.	0.5	0,5 bonus +0,25
3)	The paraxial approximation is valid provided the rays remain close to the optical axis and with small angles with respect to the optical axis.	0.5	0,5
	If we use a single lens of large diameter, the rays going from the light source towards the borders of the lens will be at large angles with respect to the optical axis, and large distances. The paraxial approximation will no longer be valid. These peripheral rays will not result in a beam of parallel rays, and will not reach distant boats.	0.5 0.5	1
4)	In order to reduce the light intensity reduction in the initial propagation direction, the scattering power should be as small as possible. According to the expression of the scattering power, one needs to use the largest (visible) wavelength. It is therefore better to use red light.	0.5 0.5 0.5	1,5
5)	we recall that the deviation corresponds to the angle of rotation of the ray after a diopter. Considering the deviations on each diopter: $D = D_1 + D_2$ (see figure 1). First incidence : $D_1 = i_1 - r_1$ Second incidence : $D_2 = r_2 - i_2$ resulting in : $D = D_1 + D_2 = i_1 - r_1 + r_2 - i_2 = i_1 + r_2 - A$	 0.5 0.5 0.5	1,5
6)	a) The prism fulfills its role if the rays exit from the prism horizontally. This implies that D must be equal to i_1.	0.5 0.5	
	b) In that case $r_2 = A$. Since r_2 depends in the incident angle i_1, the apex angle A should be different depending on the prism position relative to the center.	Bonus 0.5	
7)	a) Clean drawing with correct angles (see figure 2)	0.5	0,25
	On the incidence point B on the vertical face of the prism, the ray is perpendicular to the diopter (zero incidence), and is not deviated.	0.5	0,5
	The ray reaches the second face of the prism on C, with an incident angle α. Using triangle BCF we get that $\alpha = A$. On C, the ray is directed towards a less refractive medium, so that total reflection can occur. We define the critical incidence angle i_c such that $\sin(i_c) = \frac{n_{air}}{n} = \frac{1}{1,7}$, hence $i_c = 36°$. As $\alpha = A = 40°$, $\alpha > i_c$, there is total reflection on C with a reflection angle equal to A.	0.5 0.5 0.5 0.25	0,5 0,25 0,5
	The ray finally reaches the bottom face on E with an incident angle $\beta = 180° - 90° - A = 10°$. This time, $\beta < i_c$, the ray will be refracted in the air, with a refracted angle r_3, so that $n \cdot \sin(\beta) = n_{air} \sin(r_3)$, $\Rightarrow 3 = 17°$. There will be partial reflection on E. One can check that the refracted angle is larger than the incident angle β (logical, as the second medium is less refractive).	0.5 0.5 0.5 0.25 bonus 0.25 bonus 0.25	
	b) If the angle i_1 is small, the refracted angle r_1 will be also small. As $i_2 = A - r_1$, the incidence angle i_2 on the second face will be close to A and may be larger than i_c, resulting in a total reflection; the light will therefore not be transmitted towards the boats, making such lighthouse useless...	0.5	0,5


L1
L2
B1
B
O1
A1
O2
F1
A
F1
F2
F2
B'∞

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1)

If the image is reversed with the same size then

$\gamma = -1$

$\Rightarrow \frac{\overline{OA'}}{\overline{OA}} = \frac{\overline{FO}}{FA} = -1.$ $\Rightarrow \overline{FO} = \overline{AF}$ $\Rightarrow f' + \overline{FO} = \overline{A'F} + \overline{FO}$

$\Rightarrow 2f' = \overline{AO}.$

$\Rightarrow -2f' = \overline{OA}.$

2) The object is real so $\overline{OA} < 0$ so $-2f' < 0$

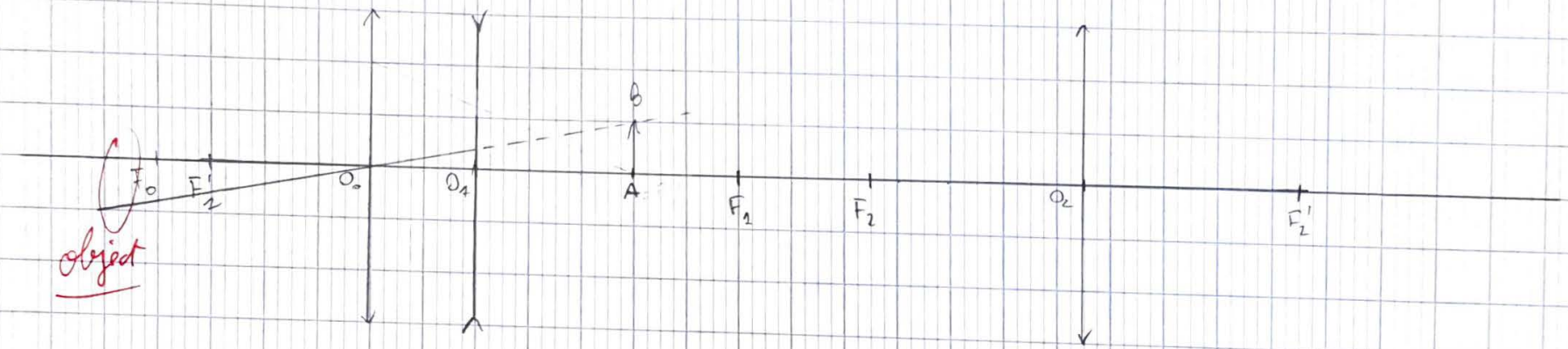
$f' > 0.$

Hence the lens is convergent.

Part II.

1) Scale : 1 square = 1 cm.

To create a virtual object AB, we can place a converging lens before the system and place a real object before that lens so that the image through L_0 is after L_1.



good

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Ex 2

1) Since the boats we want to provide light to are far away and not at a defined place, we want to have an image at infinity. Hence the light source should be placed on the object focal plane, which means that $\overline{SO} = \overline{FO}$.

2) With a diverging lens, in order to have an image at infinity, we would need to place the object on the object focal plane, which is after the lens for a diverging lens. Therefore the object would be virtual so in order to create it, another lens would be needed and the advantage of the Fresnel lens, its reduced weight, would be lost.

Very good

3) The conditions for paraxial approximation are to only take into account the rays that are close to the optical axis and that make small angles with the optical axis.

A single lens of large diameter would not fill these conditions, so there would be no paraxial approximation and the image would not form at infinity.

4) Blue light has a smaller wavelength than red light (400 nm instead of 800 nm). So $P_{scat\,BLUE} > P_{scat\,RED}$.

Therefore a red light is better for large large lighthouses.

5) The first deviation, for the first refraction, is
$D_1 = i_1 - r_1$ (see figure 5)

and $D_2 = r_2 - i_2$ (see figure 5).

Hence the total deviation is $D = D_1 + D_2 = i_1 + r_2 - i_2 - r_1$.
$= i_1 + r_2 - A$ ✓

6) a) The optical system can be used to light boats far away if the angle i_2 is lower than the critical angle for refraction defined by:
$\sin i_c = \frac{n_{air}}{n}$ (Snell-Descartes' law).

Yes, but not only → here question on D

7)a) Since $A = r_2 + i_2$, $i_2 = A - r_2$

$i_2 = 40° - 0°$ (since the ray is not deviated if its incident angle is 0°)

$i_2 = 40°$

Snell-Descartes' law is:

$n \sin i = n' \sin i'$

Hence $\sin r_2 = \frac{n}{n_{air}} \sin i_2 \Rightarrow r_2 = \sin^{-1}\left(\frac{n}{n_{air}} \sin i_2\right)$.

NA: $\sin r_2 > 1$ which means there is no refraction, but reflection. *

b) The critical angle for refraction i_{2c} is defined by:

$$\sin i_{2c} = \frac{n}{n_{air}} \Rightarrow \sin^{-1}\left(\frac{n}{n_{air}}\right) = i_{2c}.$$

NA: $i_{2c} = 36°$

For small angles, $i_2 > i_{2c}$ and there is reflection so the light does not go towards the boats.