For this first exam, no penalty or bonus on presentation (cleanness, spelling, grammar, readability...). However those who would deserve a bonus (excellent writing and cleanness) and those who would deserve a penalty should be notified. Note that these +1 pt bonus / -1 pt penalty will be applied on the next exams.

Exercise 1 : Head-up Display [8 pts.]

Elements of correction	**Points**	
Study of the converging lens	**5.5**	
1. Drawing of ray (BO) without deviation Drawing of incident ray (BF), parallel to optical axis after the lens + prolongation in **dotted line** Drawing of incident ray $(B\infty)$ going through F' after the lens + prolongation in **dotted line** Drawing of image A_1B_1 in **dotted line** (no mark if full line) (see figure 1) *This drawing being quite simple, do not put the marks if rays are not rigorously drawn and only 0.25 if prolongations are not in dotted lines.*	**0.25** **0.75** **0.75** **0.25**	
2. Image A_1B_1 is virtual and upright.	**0.5**	
3. Descartes's conjugate equation yields $\overline{OA_1} = \frac{\overline{OA}\cdot f'}{\overline{OA}+f'}$. Numerical application : $\overline{OA_1} = \frac{-15\times 20}{20-15}$ cm $= -60$ cm. Since $\overline{OA_1} < 0$, the image is before the lens, it is therefore virtual. Points for the justification. The magnification relations give $\overline{A_1B_1} = \overline{AB}\frac{\overline{OA_1}}{\overline{OA}}$. Numerical application : $\overline{A_1B_1} = \frac{-60\times 1}{-15}$ cm $= 4$ cm. Since the magnification is positive and greater than 1, the image is upright and bigger. Points for the justification. It can be noted that these values are consistent with the drawing (1 square for 2.5 cm). *Bonus : 0.25* If the drawing and calculations are not consistent without any comment, penalty of 0.25. If the units are missing, mark only half the points.	**0.75** **0.5** **0.5** **0.25** **0.5** **0.5**	
Study of the reflection on the windshield	**2.5**	
4. The image $A'B'$ can be obtained by continuing the previous rays with a reflection on the mirror (the same angles should be noted). The intersection of their prolongation gives the position of B'. Otherwise, one can use the fact that the image of an object by a mirror is its symmetric with respect to the mirror plane (to be mentioned if used).	**1.5**	
5. This image is located before the mirror in the direction of propagation of the emerging rays, it is therefore virtual.	**1**	

Exercise 2 : Where is the object ? [3.5 pts.]

Elements of correction	Points	
Let us consider the rays emerging after the lens, whose prolongation go through B'. The object B should be on these rays.		
Drawing of ray $(B'O)$, no deviation.	**0.5**	
One can then draw the ray parallel to the optical axis after the lens, passing by B'. The part before the lens is in dotted line. This ray goes to infinity on the optical axis, so it results from an incident ray going through F, by definition of the object focal point. The part after the lens is in dotted line.	**1.5**	
Or one can then draw the ray going through F' and B'. The part before the lens is in dotted line. By definition of the image focal point, this ray comes from an incident ray coming from a point at infinity on the optical axis (therefore parallel to the optical axis). The part after the lens is in dotted line. *Of course only two rays were necessary !*		
The point object B is at the intersection of these incident rays. The object AB is a real object, draw in full line.	**1**	
Drawing cleanness and accuracy	**0.5**	

Exercise 3 : About diamond cutting [8.5 pts.]

The schemes, points and angles are indicated on figure 3.

- Problem formulation :

  We are interested in the shining property of a diamond. This can be related to the intensity of light coming from the upper face after reflection and refraction. For that purpose, the ray path is examined in both cases.

- First diopter : for both diamonds, the ray is perpendicular to the upper face, it is therefore not deviated and reaches the lower left face with an incident angle noted i_1 (respectively i_{1g} and i_{1p} for the good and poor quality diamonds).

- Second diopter : Since light propagates towards a less refractive medium, a phenomenon of total reflection can occur. Let's calculate the critical incident angle, noted i_c. This angle is such that the refracted ray exits with an angle of 90° with respect to the normal to the diopter. Applying Snell-Descartes's law for refraction :

  $$n_d \sin(i_c) = n_{air} \sin(90).$$

  We get therefore :

  $$\sin(i_c) = \frac{n_{air}}{n_d}.$$

  Numerical application gives : $i_c = 24,4°$.

- Determination of the incident angles : one needs now to do some geometrical analysis to find the incident angles on the left face. We draw the normal to the diopter on I (and K) in order to visualize the angle i_1. Then we use the fact that the sum of a triangle's angles is 180°. In both cases (good and poor quality diamonds), we find $i_1 > i_c$ (values indicated in figure 3). There is therefore **total reflection on I and K.**

- Third diopter : the ray reaches the lower right face with an incident angle noted i_2 (respectively i_{2g} and i_{2p} for the good and poor quality diamonds). The values of these angles can be determined using the same type of geometrical arguments (using the triangle at the bottom).

  – For the diamond on the right : $i_{2p} = 21°$, which is lower than the critical angle, there is thus **refraction in L.** A small fraction of the light intensity will be reflected towards the upper face and will exit through this face after refraction. This diamond does not look very shining.

– For the diamond on the left : $i_{2g} = 57.5°$, which is again greater than the critical angle, there is again total reflection on J. The ray reaches then the upper right face on M with an incident angle of 17.5°. There will finally be refraction towards the air and most light intensity will exit through the upper face. The diamond will look very shining.

- Conclude : As a conclusion, for the good quality diamond, a ray reaching the upper face perpendicularly will exit through that same face after two total reflections and one refraction, making it look very shining. For the poor quality diamond, the ray will exit from the side after one total reflection and one refraction, making it look less shining.

Skill evaluated	**Points**	
Problem self-appropriation and rephrasing :		
Translate the text into physical terms : "the diamond is shining" can be translated in "high light intensity going out of the upper face". Set the problem.	**0.5**	
Make a clear and well-set scheme : correct drawings : "approximative" equality between angles of reflection and consistent evolution of the ray angles for refraction.	**1**	
Identify on the scheme the relevant physical variables and define them with a **unique** symbol : name the incident angles and the points of incidence for better clarity. No ambiguity on what is named.	**1**	
Build a methodology to solve the problem (analyze) :		
Determine and state the physical laws that will be used : possibility of total reflection or refraction	**0.5**	
Use the methodology :		
Be able to perform analytical calculations and/or use optical schemes efficiently :		
Determine the critical incident angle	**1**	
Determine the different angle values with quick geometrical justifications	**1**	
Carry on a process until the end and answer explicitly to the question asked :		
be able to determine the occurrence of total reflection or refraction by comparing the incident angles to the critical angle.	**1.5**	
Have a critical look on the results (validate) :		
Make sure the question was correctly answered : conclude on the quality of the two diamonds being related to the face from which most light goes out of the diamond.	**1**	
Communicate :		
Be able to write the solution stating clearly the different reasoning that yielded the results obtained : identify clearly the different steps, present them in a logical order.	**0.5**	
Use correctly the logical connectors		
Use of a well adapted scientific vocabulary : do not mistake reflection, refraction		
Write in correct and understandable English	**0.5**	

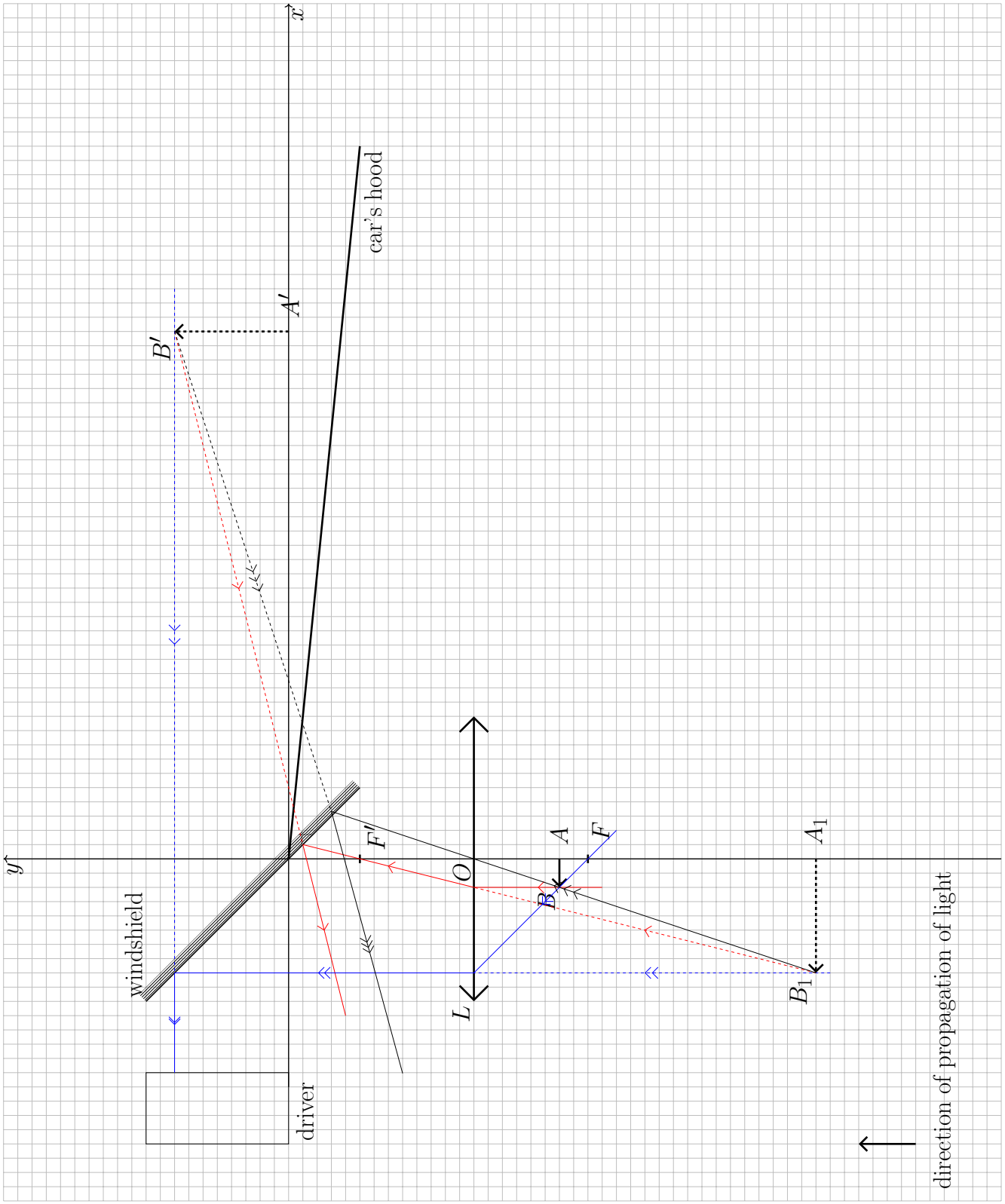

FIGURE 1 – Head-up display device

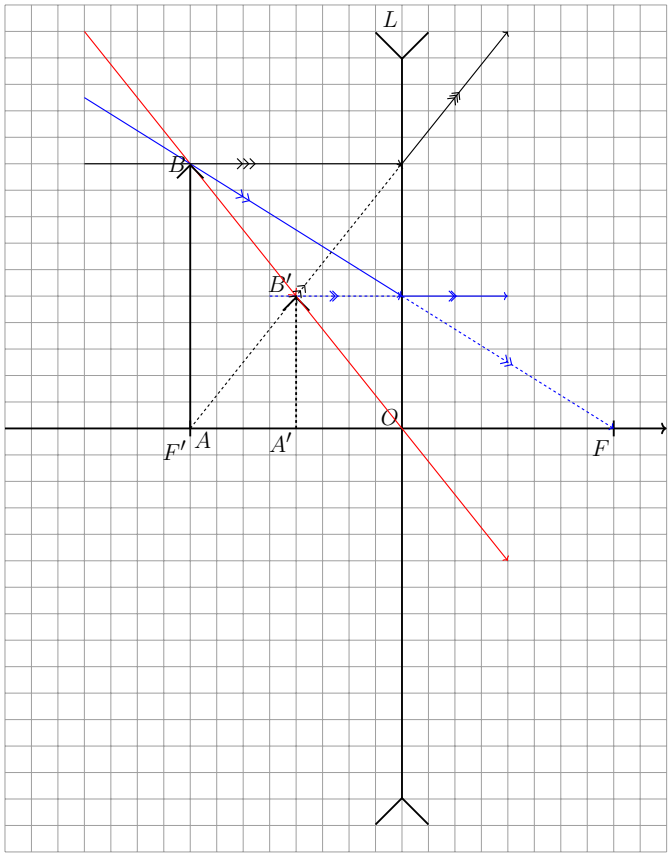

FIGURE 2 – Find the object position

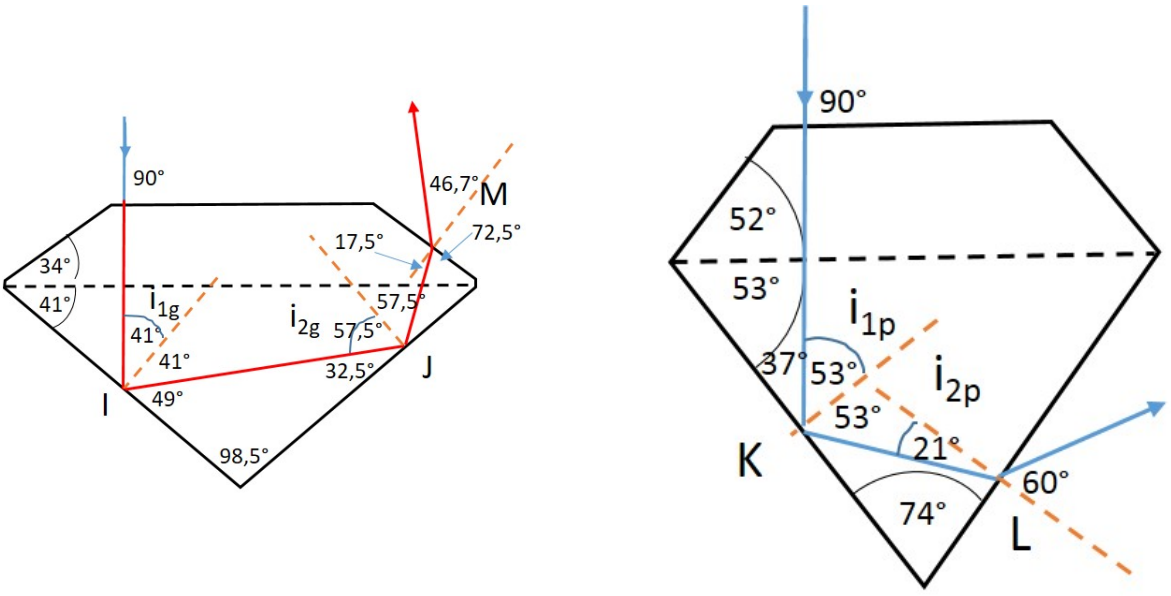

FIGURE 3 – Diamonds of good quality (left) and poor quality (right).