Exam 2 — Physics

November, 22, 2019, 4 pm — Duration: 1 hour 30

No document allowed. No mobile phone. Calculator allowed.

The marks will account not only for the results, but also for the justifications, and the way you analyze the results. It is also reminded that the general clarity and cleanness of your paper may also be taken into account (bonus/malus 1 point).

Any result expressed without unit will be considered as wrong. The proposed grading scale is only indicative.

Exercise 1 : Study of an astronomical lens used to observe the rings of Saturn (≈ 9 pts)

Preliminary section

The following optical setups are made with several thin lenses (L_n), of focal lengths f_n', object focal points F_n, image focal points F_n' and optical centers O_n.
The experiments are carried out in air and using paraxial approximation. All optical elements are centered on the same optical axis. The angles defined in the text are oriented.

We consider an afocal telescope, aiming at providing an image at infinity from an object placed at infinity. In the direction of light propagation, the telescope is composed of a first lens (L_1) of focal length $f_1' = 1$ m, and of a second lens (L_2) of focal length $f_2' = -20$ cm.

1) Which lens is the ocular lens? Which one is the objective lens? Give the nature of each lens (converging/diverging).
2) The algebraic distance between both lenses is called $e = \overline{O_1O_2}$. Give the expression of e as a function of both focal lengths and give its value in cm.
3) With this telescope, an observer placed at the Earth's surface observes Saturn and its brightest ring. The center of Saturn is approximated as a point object A placed at infinity on the optical axis. A portion of the ring is considered as a point object B placed at infinity outside the optical axis. The ray coming from B makes an angle α with respect to the optical axis.
   a. On the paper given in **Appendix 1**, one square is equal to 5 mm. Using a horizontal scale of 1/10, place the lens (L_2).
   b. Two rays coming from point B are already on Appendix 1. Trace the intermediate image $\overline{A_1B_1}$ of $\overline{AB}$. Is $\overline{A_1B_1}$ a virtual or real object for the second lens?
   c. Complete the paths of both rays through the afocal telescope. Clearly indicate all the construction lines.
   d. The radius of the ring of Saturn is $R = 10^5$ km. The distance from the Earth to Saturn is $D = 2.10^{12}$ m. Find the expression of the lateral magnification $\gamma_1 = \frac{\overline{A_1B_1}}{\overline{AB}}$ as a function of f_1' and/or f_2', D and/or R. Give its value.

e. α and α' are the angles, with respect to the optical axis, of the incident ray (for α) or the ray emerging from the telescope (for α'). We suppose α and α' are small. Find the expression of the angular magnification G of the telescope, as a function of the focal lengths f_1' and f_2'. Give its value.

f. The resolving power of the human eye is the minimum angle between two rays that can be distinguished. It is equal to 10^{-4} rad. From the values of *R*, *D* and *G*, compute α and α'. Is it possible to see the ring with the naked eye? With the telescope?

Exercise 2 : Measurements and uncertainties (partially guided exercise) (≈ 8 points)

During the first lab, you studied the path of a laser beam through a piece of glass with parallel sides, according to the set-up given in Figure 1.

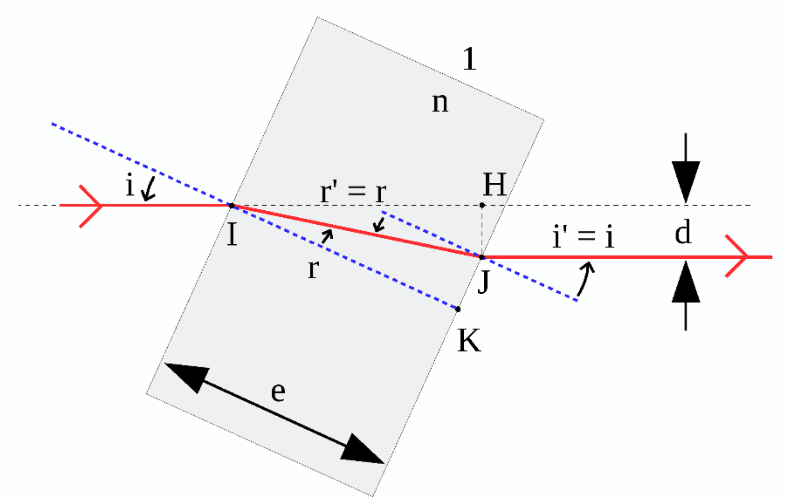


Figure 1 – Path of a ray through a block with parallel sides.

Notations:

We call *i* the incidence angle of the laser beam on the block with parallel sides, *e* the thickness of the block, *d* the shift between the emerging and incident rays, *r'* the incidence angle on the exit diopter at point J, and *i'* the refraction angle after the exit diopter.

With geometric considerations, the equation (1) can be obtained:

$$d = e\frac{\sin(i-r)}{\cos(r)} \qquad (1)$$

Small angle approximation:

Using small angle approximation, it is possible to eliminate *r* in the equation and find a more simple equation between the incidence angle *i* and the shift *d*:

$$d = e \cdot i \cdot \left(1 - \frac{1}{n}\right) \qquad (2)$$

The small angle approximation is a working hypothesis. Experiments are needed to define the angular range for which it is valid.

Important note (reminder): the approximations $\sin(x) \approx x$ and $\cos(x) \approx 1$ are valid only if x is expressed in radians !!

Experiment:

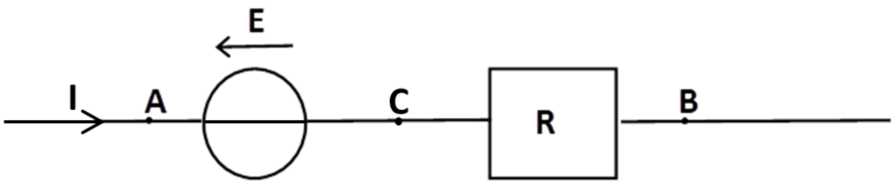
A student wants to determine the maximum incidence angle *i* below which the small angle approximation is valid. He measures the shift *d* for several values of *i* with a block of thickness *e* = (40.0 ± 1.0) mm. The experimental values are given in **Appendix 2**.

We consider that the absolute uncertainty on the incidence angle *i* is estimated to be equal to $\Delta i = 0.8°$. As explained above, the thickness *e* of the block is known with an absolute uncertainty of ± 1 mm. The values of the shift *d* are measured with a relative uncertainty of 7 %. The absolute uncertainties Δd will be given with <u>one significant digit</u>.

1) From **Appendix 2** and with the help of a graph you will draw, give the range of incidence angles *i* for which the small angle approximation is valid. Explain carefully your method.
2) Show that the optical index *n* of the block can be obtained from the (*i*,*d*) experimental values, and give its literal expression. Do not forget to define any quantity introduced.
3) Give the value of the optical index *n* obtained from the experimental data. Present the result as *n* = (… ± …). Explain carefully your method.

Exercise 3: Portion of an electric circuit (≈ 3 points)

We consider below a portion of an electric circuit consisting in an ideal voltage source in series with a resistor, and lying between nodes A and B:



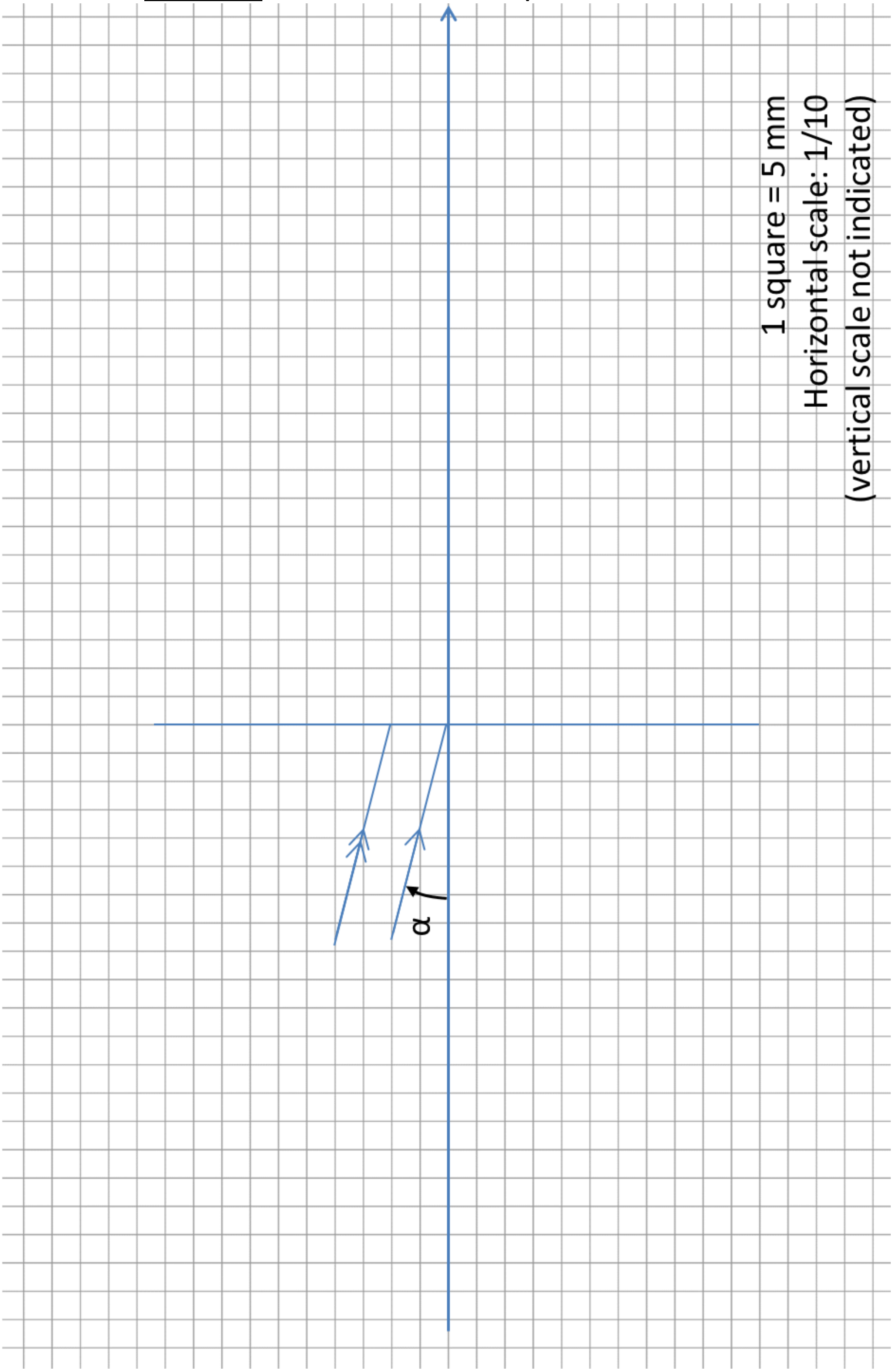
1) Given the physical quantities defined in the figure above, give the expression of the voltage difference *U* across this portion of circuit using active sign convention.
2) We perform electrical measurements using **only** a voltmeter.
   a. Explain how to measure the electric current *I* (make a scheme indicating where and how you would connect the + and COM leads of the voltmeter).
   b. Give the expression of *I* as function of the measured voltage difference V_s.
3) <u>Independent question</u>: The electric power *P* absorbed (or delivered) by a dipole is $P = U \cdot I$, *U* being the voltage difference across the dipole and *I* the current intensity flowing into it. Give the dimension of *U* using base dimensions and justify your answer.

<u>Appendix 1:</u> Exercise 1 – Afocal telescope

LAST NAME:

First name:

Group:



Appendix 2: Exercise 2 – Measurements and uncertainties

LAST NAME: **First name:** **Group:**

Incidence angle *i* (in degrees)		Shift *d* (in mm)	
4.0		0.9	
8.0		1.9	
12.0		2.9	
16.0		3.9	
22.0		5.4	
30.0		7.8	
40.0		11.2	