2nd Physics exam - SCAN FIRST
November 19, 2021 (1 h 30 min)

No document allowed. No mobile phone. Any type of calculator allowed. The proposed grading scale is only indicative.
The marks will account not only for the results, but also for the justifications, and the way you analyze the results. Moreover, any result must be given in its literal form involving only the data given in the text. It is also reminded that the general clarity and cleanness of your paper may also be taken into account.

Exercise 1 : Optics - Lens doublet [≈ 3 pts.]

Consider a doublet of thin lenses under paraxial conditions. The doublet is composed of a first lens $\mathscr{L}_1$, of focal length $f_1' = 40\,\text{cm}$ and of a second lens $\mathscr{L}_2$, of focal length $f_2' = -20\,\text{cm}$. The distance between both lens optical centers is 1.00 m. A sharp image can be observed on a screen placed 40 cm after $\mathscr{L}_2$.

1. Complete the ray-diagram in figure 3 and find the position of the object. (no other explanation is required except the « auxiliary » rays in dashed lines).
2. Place the intermediate image on the ray-diagram.

Exercise 2 : Optics - Archeology of teaching accessories [≈ 6 pts.]

A few decades ago, there were overhead projectors in classrooms that allowed a document to be projected onto a screen (see Fig.1). The document had to be written or printed on a transparent sheet placed on the illuminated horizontal surface. A thin horizontal converging lens (here with a focal length of 317 mm according to the manufacturer and of diameter 10 cm) and a mirror placed at 45 ° made it possible to send the image of the document on the screen placed on the wall. The distance between the lens-mirror assembly and the illuminated object was adjustable in height over a range of between 35 and 45 cm (therefore the object-lens distance was adjustable). The overhead projector was placed on a table which could move around the room.

FIGURE 1 – Overhead projector

A teacher wants to project an image that is three times the size of his document on the screen, so that it is clearly visible to all the students.

1. Justify that the mirror is used only to rotate the optical axis by 90°.
2. Give a clear schematic representation of an optical system that is equivalent to the overhead projector but **but that does not contain any mirror**. Define on the scheme all the quantities you need to solve the problem (symbol, value, etc.).
3. Is the image is upright or reversed ? Explain your answer.

4. Find the value of the object-lens distance by calculation. Is it compatible with the overhead specifications?

5. Where should the overhead projector be placed in the room to get a sharp image on the screen.

Exercise 3 : Measures - friction due to viscous liquids. [≈ 5 pts.]

The force of viscosity on a small sphere of radius a, moving at speed v through a fluid of viscosity η, is given by Stokes law : $f = 6\pi\eta a v$.

1. Give the dimension of η as a product of powers of base dimensions.

2. In the cgs system of units,the centimeter, the gram and the second are used as base units. In this system of units, the viscosity η of olive oil at 20°C is 0.8400. What is the unit of η in the cgs system of units?

3. Compute the value of η in the international system of units.

The limit speed v_{lim} of a sphere of radius a and density ρ_s, falling down in a viscous medium of viscosity η and density ρ_m, is given by : $v_{lim} = \frac{2}{9}\frac{(\rho_s-\rho_m)ga^2}{\eta}$ where g is the gravity.

4. Using dimensional analysis, check the homogeneity of this formula.

5. Compute the limit speed in $\mathrm{km\cdot h^{-1}}$ of a sphere made of glass, of radius $a = 5,00\,\mathrm{mm}$ and density $\rho_s = 2,53\,\mathrm{g\cdot cm^{-3}}$, falling down in olive oil (at 20°C), with $\rho_m = 0,91\,\mathrm{g\cdot cm^{-3}}$.
   Reminder : $g = 9,81\,\mathrm{m\cdot s^{-2}}$.

Exercise 4 : Estimation of a battery discharging time [≈ 6 pts.]

Students are provided with an unknown battery. They are willing to extract its electrical characteristics in order to estimate its discharging time once the battery is connected to a load resistor.

In this regards, they assume that the battery can be described as a real voltage source (electromotive force $e > 0$) in series with an internal resistance (r).

In order to obtain the current-voltage characteristics of the battery, they use the experimental setup depicted in Fig.2. Note that the provided scheme is incomplete.

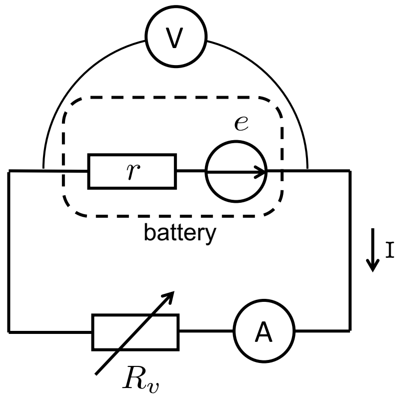

FIGURE 2 – Experimental setup

The experiment consists in connecting the battery to a variable resistance R_v in order to modulate the current intensity I flowing out of the battery. Students then use a voltmeter in order to measure the voltage difference across the battery (U_b) using active sign conventions while the current intensity is measured through an ammeter.

1. (a) Complete experimental scheme of Fig. 2 using +/− signs to distinguish the 2 terminals of the voltmeter & ammeter and making clear the orientation of U_b (keep I in the same orientation as in Fig.2).
   (b) Express U_b in terms of e, r and I.

Upon varying R_v, they obtain many couples of (U_b, I) values and build the Current-Voltage characteristics of Fig.4, which also accounts for the measurement uncertainties.

2. Using a graphical method, the principle of which you will briefly explain, extract e and r together with their uncertainties from the experimental data of Fig.4. Express the final results with appropriate units in the form $X = (X_0 \pm \Delta X)$

The battery is now connected to a load resistor $R_0 = 5\,\Omega$.

3. (a) Using a graphical method exploiting Fig.4, determine the 2 extreme possible operating points.
   (b) Deduce the electrical power dissipated in the load resistor (R_0) together with it uncertainty.

The battery has a capacity C_b of $3000\,\mathrm{mA \cdot h}$. We will assume that the Current-Voltage characteristics of the battery remains unaffected throughout the discharge process through the load resistor R_0.

4. Estimate the discharging time of the battery (t_d) and the total energy dissipated through R_0 (E_d) together with their uncertainties (you may exploit dimensional analysis).

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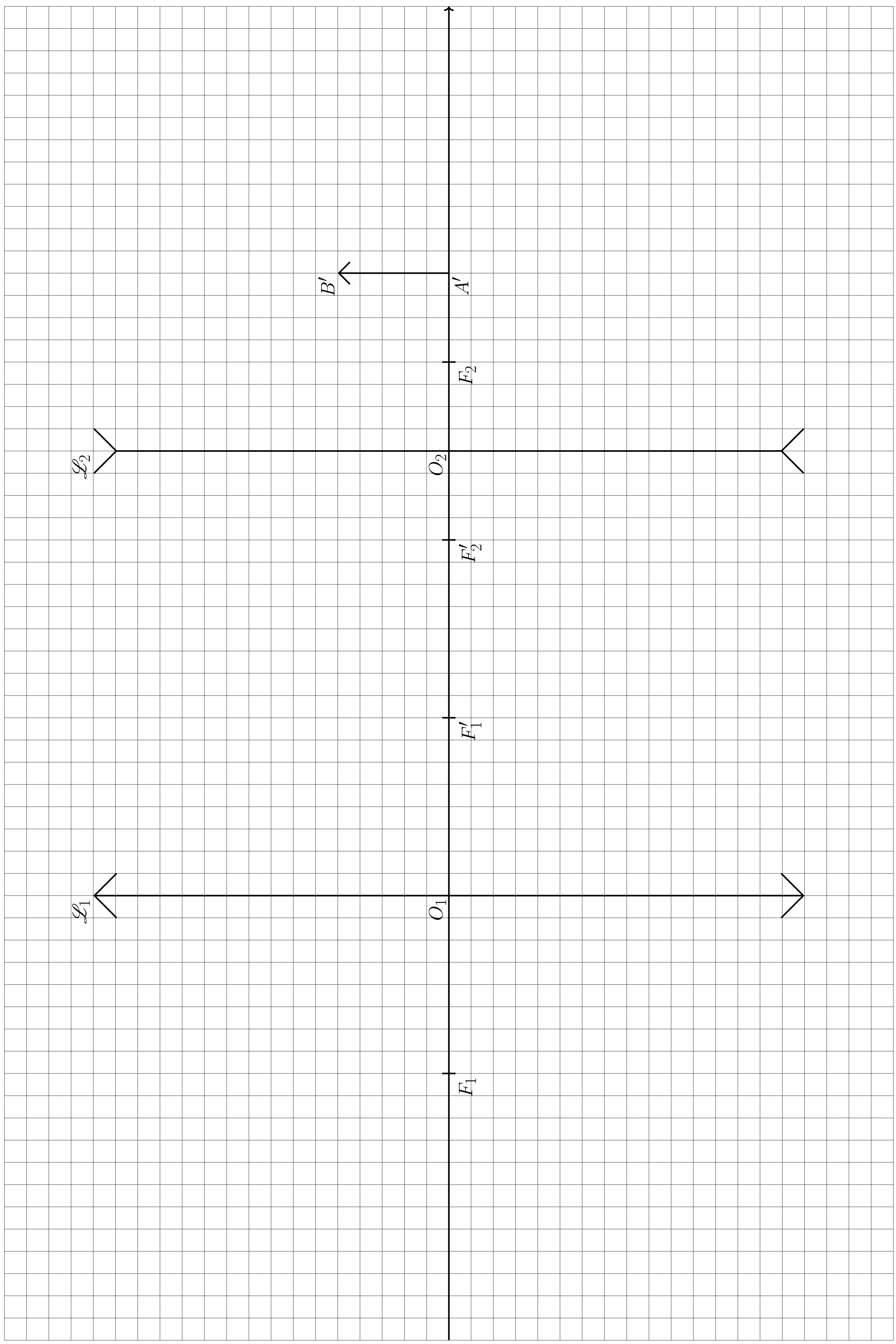

FIGURE 3 – Ray-diagram to be completed. Horizontal scale : 2 squares = 10 cm

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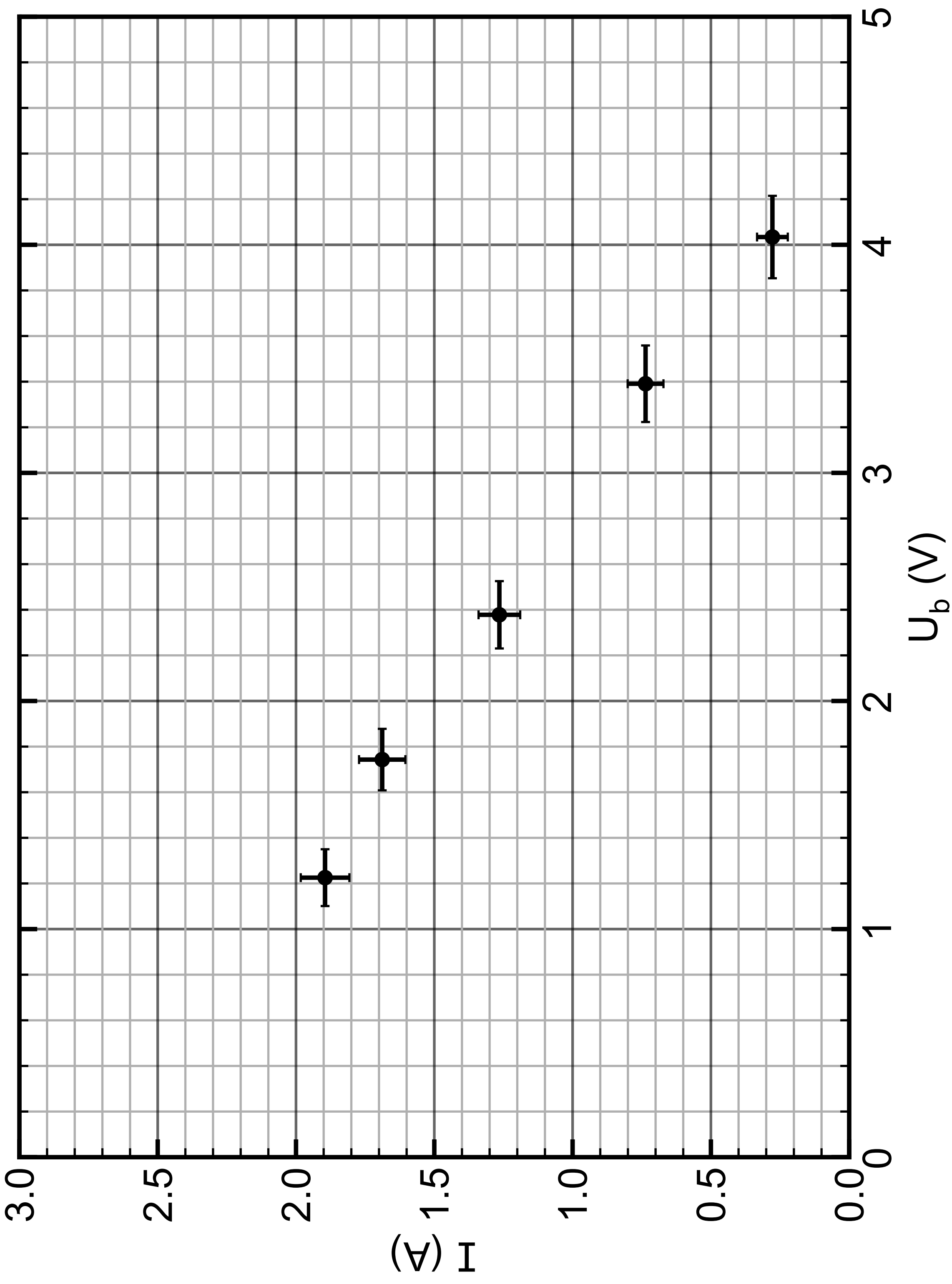

FIGURE 4 – Current-Voltage characteristics of the unknown battery