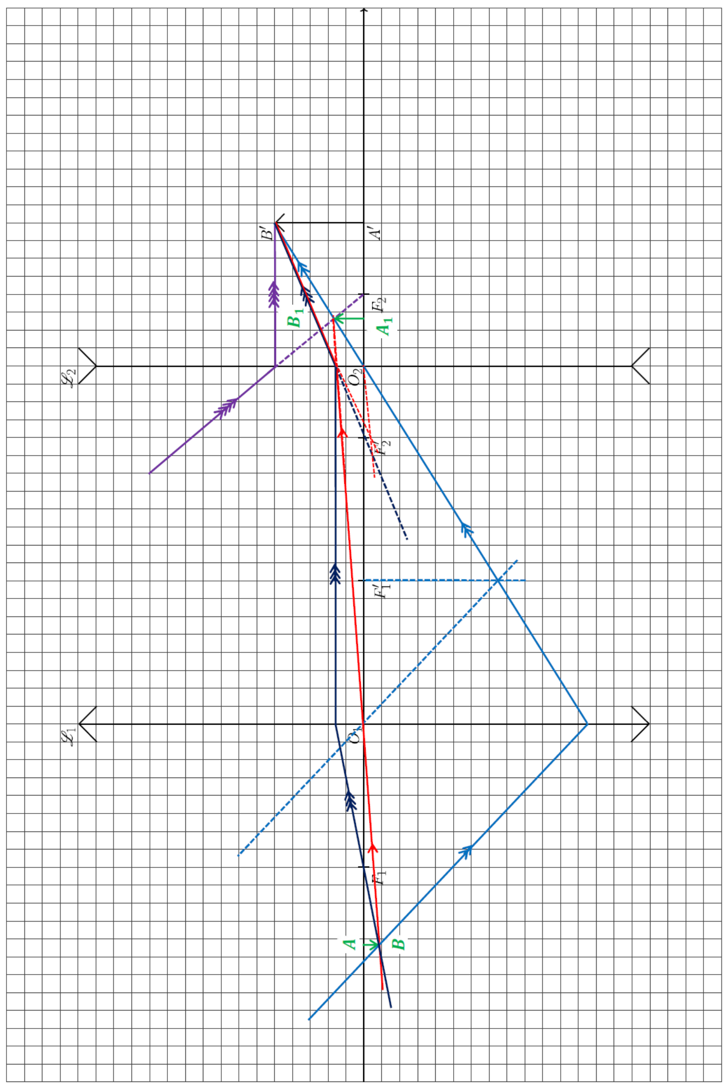
2nd Physics exam - SCAN FIRST
November 19, 2021 (1 h 30 min)
Correction and Grading scale

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

1.  .	Clear scheme with at least two rays coming from ***B***)	/2
2. Position of the intermediate image	Accurate position with at least 2 rays	/1

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

1. For the mirror, the object and the image have the same size. Hence, the mirror does not change the magnification of the whole system.	discussion about the magnification	/0.5
all the rays are refected onto the mirror according to Snell-Descartes' law. In particular, as the mirror makes an angle of 45° with the optical axis, a ray on the optical axis will be reflected at 90° (figure needed to explain what happens on the mirror).	Clear explanation + scheme with at least one ray reflected onto the mirror	/0,5
2. We expect here a ray-diagram with the object, the thin converging lens and the image.	clear ray-diagram	/0,5
All useful quantities should be defined on the ray-diagram : $\overline{AB}$, $\overline{A'B'}$, the center O of the lens and its focal points F and F'.	definition of all quantities	/0,5
We make the assumption that paraxial approximation can be used.	assumption	$+0,5 BONUS$
3. The image is reversed (converging lens with real object and real image).	answer + explanation	/0,5
4. $\gamma = \frac{\overline{OA'}}{\overline{OA}}$ and $\frac{1}{\overline{A'B'}} - \frac{1}{\overline{AB}} = \frac{1}{f'}$	2 formulae	/0,25 each
we get $\overline{OA} = (\frac{1}{\gamma} - 1) f'$	litteral expression	/0,5
numerical application : $\gamma = -3$ and $\overline{OA} \approx 423$ mm.	values with units	/0,5
$\overline{OA}$ is compatible with the overhead projector specifications.	conclusion	/0,5
5. $\overline{OA'} = (1-\gamma) f' = 1268$ mm.	literal expression + value	/0,5+/0,5
The overhead projector has to be placed ≈ 1.3 m away from the screen. It is realistic.	conclusion	/0,5

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

1. f so $[f] = MLT^{-2}$	Dimension of f	/0,25
$[6\pi\eta a v] = [6\pi][\eta][a][v] = 1 \times [\eta] \times L \times LT^{-1}$ $= [\eta] \times L^2 T^{-1}$	Dimension of the other parameters	/0,5
therefore $[\eta] = \frac{MLT^{-2}}{L^2T^{-1}} = ML^{-1}T^{-1}$	Dimension of η	/0,25
2. η is in g.cm^{-1}.s^{-1}		/0,25
3. $\eta = 0,8400\ (10^{-3}\text{kg}).(10^{-2}\text{m})^{-1}.\text{s}^{-1} = 0,08400\ \text{kg.m}^{-1}.\text{s}^{-1}$		/0,5
4. $[v_{lim}] = LT^{-1}$	Dimension of v_{lim}	/0,25

$[\rho_s - \rho_m] = [\rho] = ML^{-3}$	No + in the dimensional equation and correct expression of the dimension of ρ	/0,5
$[g] = LT^{-2}$	Dimension of g	/0,25
$$\left[\frac{2}{9}\frac{(\rho_s-\rho_m)ga^2}{\eta}\right] = \frac{2}{9}\frac{[\rho_s-\rho_m][g][a]^2}{[\eta]} = 1\times\frac{ML^{-3}\times LT^{-2}\times L^2}{ML^{-1}T^{-1}} = LT^{-1}$$	Dimension of the other quantities and correct expression	/0,5
Both terms have the same dimension, so the formula is thus homogeneous.	Clear conclusion showing the relation between dimensional analysis and homogeneity of the formula	/0,25
5. $a = 5,00.10^{-3}$ m, $\rho_s = 2,53.10^3$ kg.m^{-3} et $\rho_m = 0,91.10^3$ kg.m^{-3}	Correct conversion of a (/0,25), ρ_s et ρ_m (/0,5), eventually of other quantities in the international system of units (or another coherent one).	/0,75
$v_{lim} = 1,05$ m.s^{-1}	Numerical application	/0,25
$v_{lim} = 3,78$ km.h^{-1}	Correct conversion in km.h^{-1}	/0,5
Comment : give all the points if the final result is correct, even without explanations. On the contrary, no unit implies no point.		

Exercise 4 : Estimation of a battery discharging time $[\approx 6\,\text{pts.}]$

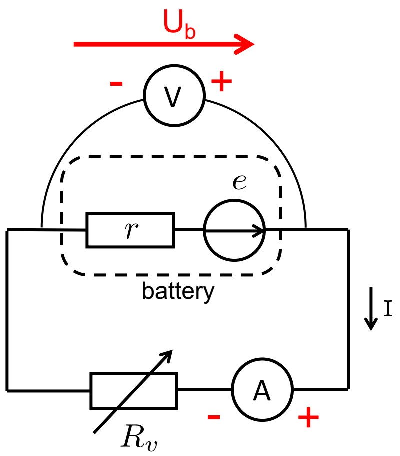


FIGURE 1 – Experimental setup

Q1 : 1.0 Pt
0.5 Pt
U_b orientation and $+/-$ terminals

1. (a) Given measurements are carried out in active sign convention U_b has to be

directed in the same way than I (see Fig. 1).
The orientations of U_b and I then dictate the position of the $+/-$ terminals of the voltmeter and ammeter as shown in Fig.1.

(b) In the convention of Fig. 1 : $U_b = e - r\,I$ *0.5 Pt*

2. Given the expression of U_b, the equation of the $I-V$ curve of the battery is : **Q2 : 3.0 Pts**

$$I = \frac{e-U_b}{r}$$

1 Pt
I vs U_b + extraction method of e and r

e can be deduced from the intercept of the $I-V$ curve while r can be deduced from the inverse of the slope.

Considering the uncertainty boxes of Fig.2, the curves of minimum and maximum slope can be plotted. These curves are used to extract e_{min} (resp. r_{min}) and e_{max} (resp. r_{max}).

1 Pt
plots of $I-V$ curves on Fig.2 using uncertainty boxes

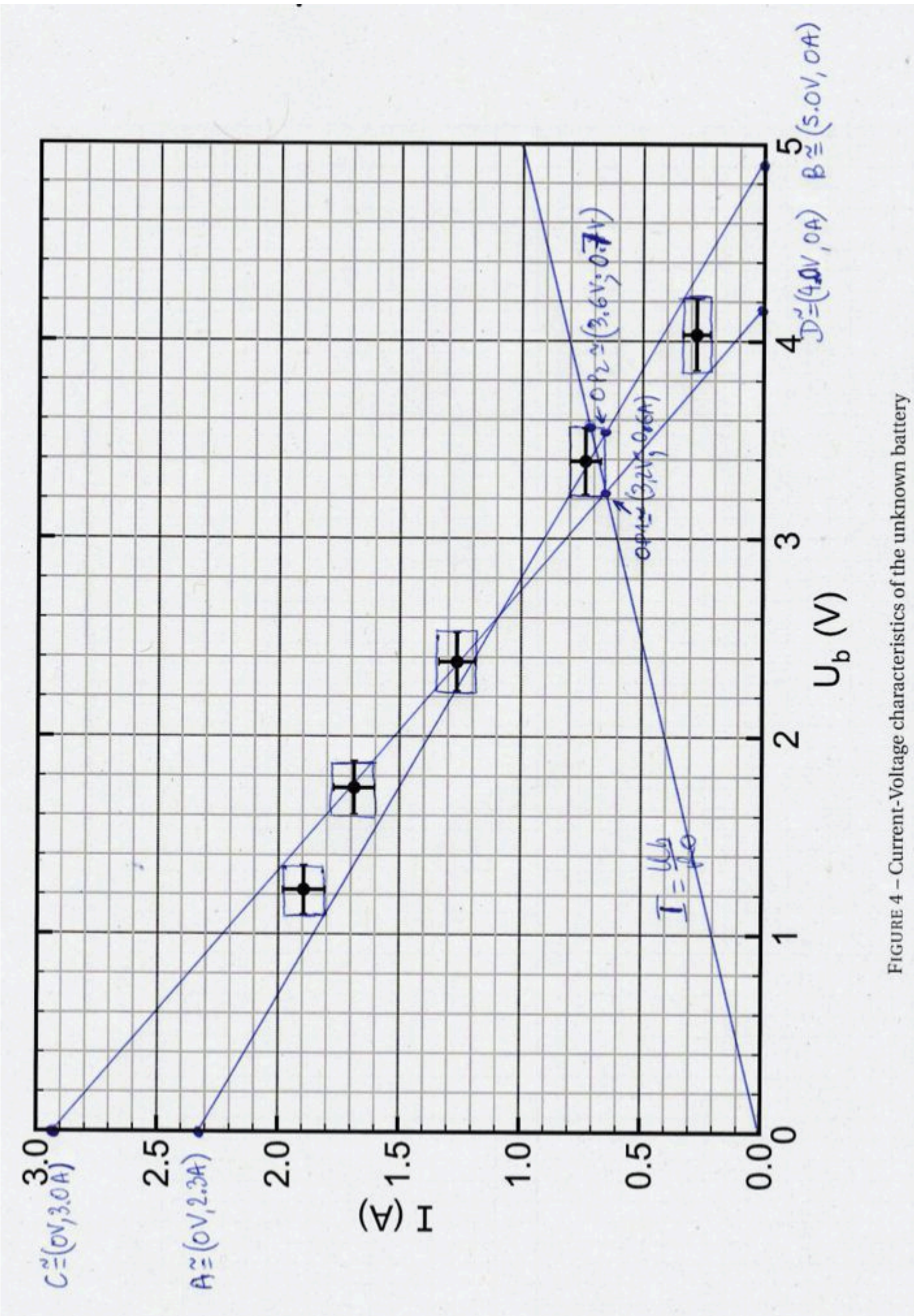


FIGURE 2 – Current-Voltage characteristics of the unknown battery

<u>Numerical values</u> :

<u>Note</u> : In the following calculations, the most pessimistic case was systematically

considered by rounding up (resp. down) maximal (resp. minimal) values to the nearest graduation available on the graph : 0.2 V for voltages and 0.1 A for currents. Uncertainties will therefore be over-estimated since we did not considered rounding to the nearest half-graduations.

The extreme values of e can be obtained from the intercepts of the 2 curves at $D \simeq (4.0\,V, 0\,A)$ and $B \simeq (5.0\,V, 0\,A)$:

$$e_{min} = 4.0\,V \text{ and } e_{max} = 5.0\,V$$

Therefore :

$$e = \frac{1}{2}(e_{max} + e_{min}) = 4.50\,V$$

$$\Delta e = \frac{1}{2}(e_{max} - e_{min}) = 0.50\,V$$

Finally, keeping 2 significant digits, rounding e to the closest $0.1\,V$ and Δe to the upper $0.1\,V$:

$$\boxed{e = (4.5 \pm 0.5)\ V}$$

0.5 Pt
e with uncertainties

Using the same methodology, the minimal slope (s_{min}) thus $r_{max} = s_{min}^{-1}$ can be deduced from the 2 intercepts at $A \simeq (0\,V, 2.3\,A)$ and $B \simeq (5.0\,V, 0\,A)$:

$$r_{max} = \frac{1}{s_{min}} = \frac{5.0\,V}{2.3\,A} \simeq 2.17\,\Omega$$

The maximal slope (s_{max}) thus $r_{min} = s_{max}^{-1}$ can be deduced from the 2 extreme points $C \simeq (0\,V, 3.0\,A)$ and $D \simeq (4.0\,V, 0\,A)$:

$$r_{min} = \frac{1}{s_{min}} = \frac{0.4\,V}{3.0\,A} \simeq 1.33\,\Omega$$

usingr_{min} and r_{max} :

$$r = \frac{1}{2}(r_{max} + r_{min}) \simeq 1.75\Omega$$

$$\Delta r = \frac{1}{2}(r_{max} - r_{min}) \simeq 0.43\Omega$$

Finally, keeping 2 significant digits by rounding r to the nearest $0.1\,\Omega$ and Δr to the upper $0.1\,\Omega$:

0.5 Pt
r with uncertainties

$$\boxed{r = (1.8 \pm 0.5)\ \Omega}$$

3. (a) As we connect the battery to the load resistor, both device share the same voltage across their terminals with I being the current flowing into the loop. **Q3 : 1.0 Pt**
The operating point therefore stands at the intersection point between the $I - V$ curve of the battery (in ASC) and the $I - V$ curve of the resistance (in PSC) given $U_b = R_0\,I$
Taking into account the uncertainties,two extreme operating points can be determined from Fig. 2 :

$$\boxed{OP_1 \simeq (3.2\,V; 0.6\,A) \text{ and } OP_2 = (3.6\,V; 0.7\,A)}$$

0.5 Pt
operating points

(b) The power dissipated in the resistor writes : $P = R_0\,I^2$. From the 2 operating points we can determine the minimun (maximum) power :

$$P_{min} = R_0\,I_{min}^2 = (5\,\Omega)\cdot(0.6\,A)^2 = 1.80\,W$$

$$P_{max} = R_0\,I_{max}^2 = (5\,\Omega)\cdot(0.7\,A)^2 = 2.45\,W$$

leading to :

$$\boxed{P = (2.1 \pm 0.4)\ W}$$

0.5 Pt
Power and uncertainties

4. From a dimensional analysis : $[C_b] = I \cdot T$. The discharge time t_d is therefore homogenous to the ratio between the capacity C_b and a current intensity. Taking the minimum and maximum operating current determined previously : **Q4 : 1.0 Pt**

$$t_d^{min} = \frac{C_b}{I_{max}^{op}} = 4.28\,h$$

$$t_d^{max} = \frac{C_b}{I_{min}^{op}} = 5.00\,h$$

leading to :

$$\boxed{t_d = (4.6 \pm 0.4)\ h}$$

0.5 Pt

The energy dissipated over the discharging time writes (with t_d in seconds) : $E_d = P_d \cdot t_d$

The minimal/maximal enegy dissipated then write :

$$E_d^{min} = P_d^{min} \cdot t_d^{min} \text{ and } E_d^{max} = P_d^{max} \cdot t_d^{max}$$

Using the previous values :

$$E_d^{min} \simeq 32.9\,kJ \text{ and } E_d^{max} = 39.8\,kJ$$

Finally :

$$\boxed{E_d = (36.3 \pm 3.4)\ kJ}$$

0.5 Pt