3rd Physics exam - SCAN FIRST
January 7, 2022 (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 : Exploiting a photovoltaic panel $[\approx 8\,\text{pts.}]$

The current-voltage characteristic $I-U$ of a photovoltaic panel obtained in active sign convention under a given illumination is shown in Fig. 1-a (see appendix). Fig. 1-b shows the corresponding electrical power $P = U \cdot I$ provided by the panel. This panel is used to supply the following devices connected in **parallel** :

- A DC motor, featuring a counter electromotive force $E = 15.26\,\text{V}$ and an internal resistance $R_M = 7.70\,\Omega$
- A lighting system to be designed from low voltage bulbs, supposed to be passive linear dipoles. Each bulb is labelled with 6 V/0.1 A. The system can be designed by combining any number of bulbs in series and/or in parallel. The lighting system is assumed to be equivalent to an electrical resistance denoted R_E.

The photovolatic panel will be referred as the "PV panel" in the following.

1) From Fig. 1 determine the operating point under which the PV panel delivers the maximum electrical power. Estimate the uncertainties of this operating point.

2) **Open question :** How many lamps and how should we combine them so that the PV panel supplies the motor **and** the lighting system **close** to its maximum power operating point (see circuit diagram in Fig. 2)? In series? In parallel? A combination of the two? Give the equivalent resistance R_E of the lighting system thus obtained.

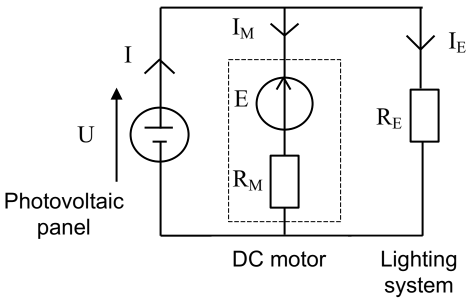

FIGURE 2 – Circuit diagram

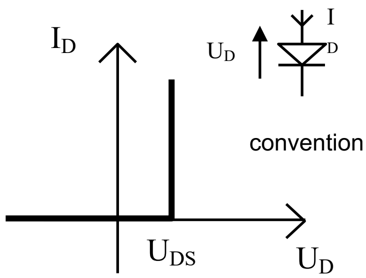

FIGURE 3 – $I-U$ curve of the ideal diode

From now on we will consider that R_E is equal to $25.7\,\Omega$.

3) Using circuit transformation, determine the equivalent Thevenin model of the parallel association {motor+lighting system} and plot its $I-U$ curve on the same graph than the $I-U$ characteristics of the PV panel (Fig. 1-a). Determine the operating point (no uncertainty required, just round the values to the nearest graduation).

We want to add a light indicator consisting of a light-emitting diode (LED) assumed to be ideal, with a threshold voltage $U_{DS} = 1.50\,\text{V}$ (the characteristic of the LED is given in Fig. 3), associated with a resistor R_D. The direct current flowing through the diode should reach a value $I_D = (20.0 \pm 2.0)\,\text{mA}$.

4) Complete the scheme of Fig. 2 adding the light indicator in parallel to the DC motor and the lighting system.

5) Taking into account the operating point of the PV panel, determine the value of R_D (together with its uncertainty) for the LED to operate properly.

Exercise 2 : Circuit in transient regime $[\approx 12\,\textbf{pts.}]$

Consider the circuit shown in Fig. 4-a consisting of an ideal voltage source of e.m.f. E, a switch, two resistors R_1 and R_2, and a real coil modeled by an inductance L and a internal resistance r. It is assumed that the switch has remained open for a long time.

At time $t = 0$, the switch is closed (Fig. 4-b).

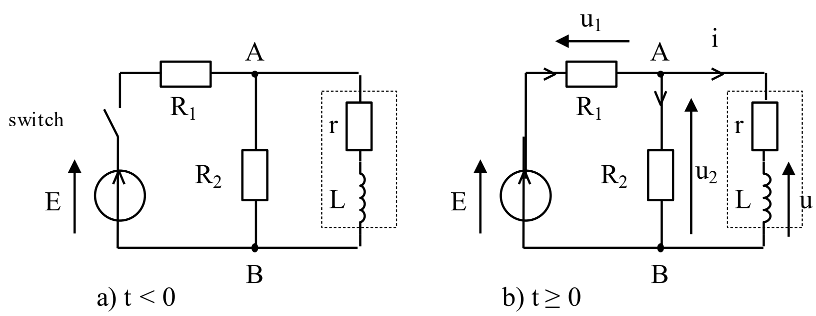

FIGURE 4 – Circuit in transient regime

1) What are the values of i, u_1, u_2 and u (see Fig. 4-b) just after closing the switch (at $t = 0+$) ?

2) Using Kirchhoff's laws, towards which values would i, u_1, u_2 and u tend in steady state (asymptotic behavior) ?

3) Using successive transformations (Thevenin/Norton), determine the equivalent Thevenin model of the circuit feeding the real coil. The characteristics of this model (equivalent e.m.f. E_{TH} and equivalent resistance R_{TH}) will be clearly specified.

From now on, we will consider the circuit consisting of the equivalent Thevenin source (E_{TH}, R_{TH}) in series with the real coil (L, r).

4) Establish the differential equation verified by the current i flowing through the coil, deduce the expression of the time constant τ of the circuit. Solve this differential equation to find the expressions of $i(t)$, then that of $u(t)$.

5) Plot qualitatively the evolution of $i(t)$ and $u(t)$

6) We give : $E = 5\,\text{V}$, $R_1 = 1\,\text{k}\Omega$, $R_2 = 2.2\,\text{k}\Omega$ and $r = 13\,\Omega$. Experimentally we observe that u is equal to 37 % of its maximum value for $t_0 = 85.6\,\mu\text{s}$. Deduce the value of L.

7) Determine the energy stored by the coil L between $t = 0$ and $t = +\infty$ (detailing and justifying the calculations).

Appendix 1 - NAME : ....

To be returned with your paper!

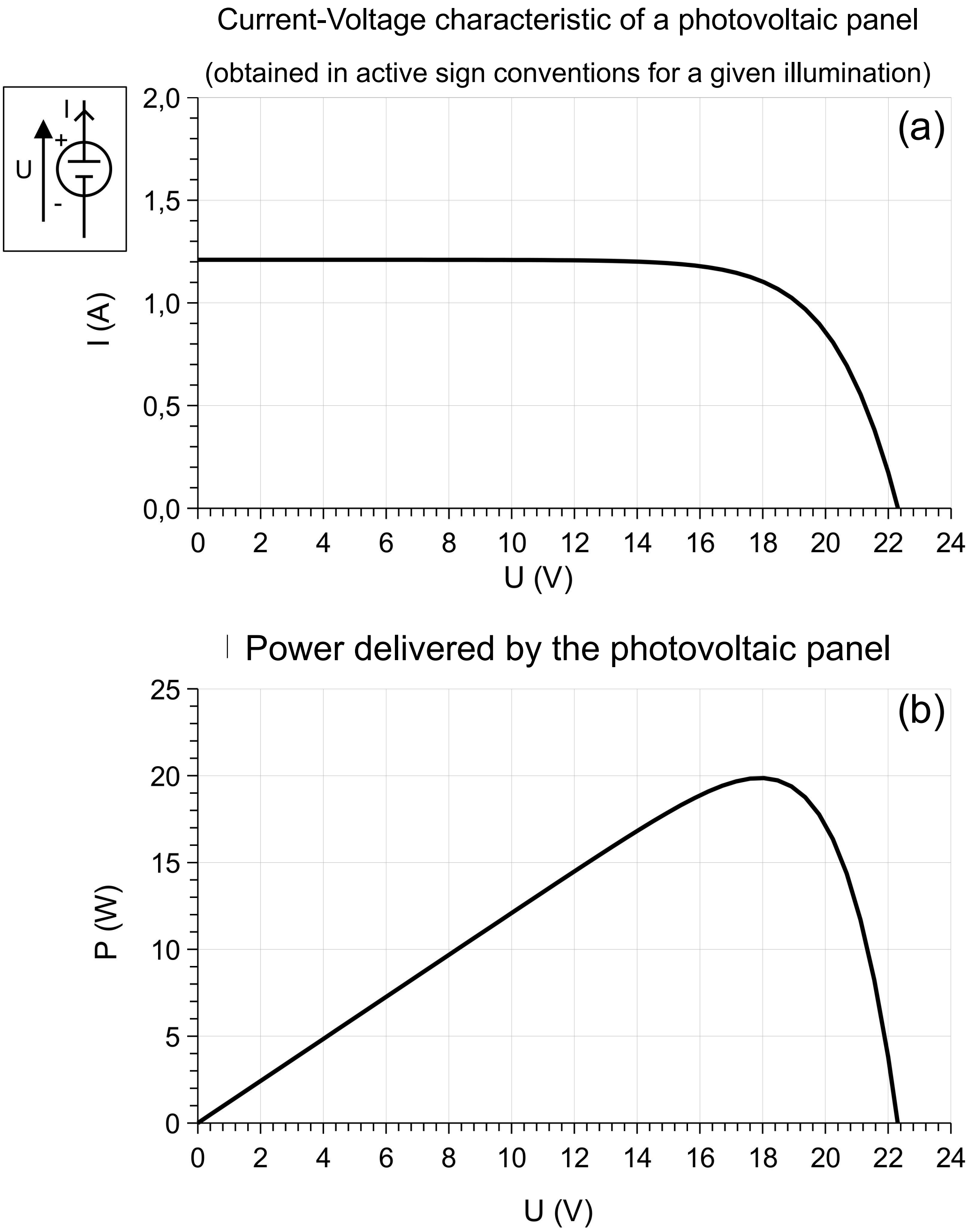

FIGURE 1 – (a) Current-Voltage and (b) Power-Voltage characteristics of a photovoltaic panel