Physics exam 2 – Semester 1
December 16, 2022. Duration: 2 h

No document allowed. No mobile phone. Non-programmable 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: Analysis of an I-V curve [5 pts.]

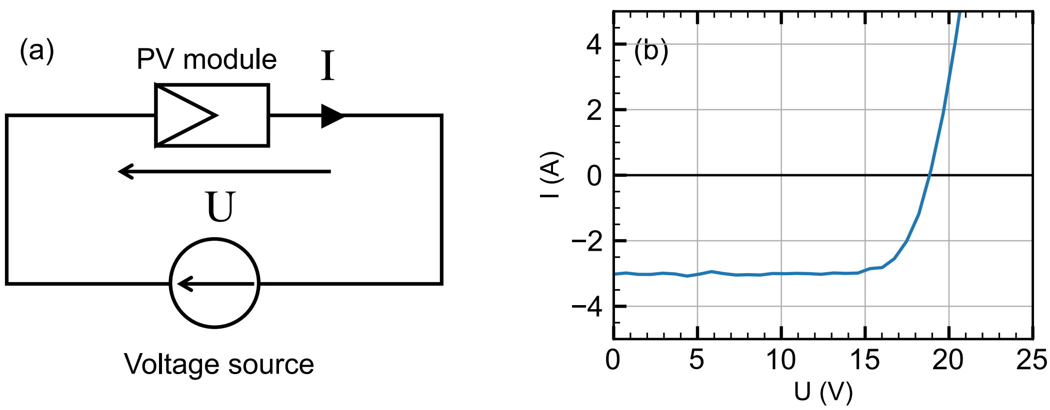

Figure 1: (a) Scheme of the experimental setup to study the PV module. (b) Current-Voltage characteristic of the PV module.

One wants to determine the current-voltage characteristic of a photovoltaic (PV) module. To this aim the experimental setup depicted in Figure 1-a is used. A DC voltage source is used to apply a voltage difference U across the terminals of the illuminated PV module while the current I flowing in the circuit is measured. Given the convention chosen in Figure 1-a for U and I, we obtain the curve shown in Figure 1-b.

1. State the convention used in the proposed setup to study the PV module.
2. The scheme of the experimental setup show in Figure 1-a is missing the different meters (i.e. voltmeter/ammeter) used to measure U and I. Propose an improved scheme featuring the meters including their +/− polarity.
3. Determine the electrical power absorbed by the PV module at 10 V and 20 V. Conclusion?
4. Determine *approximately* the maximum electrical power that can be delivered by the PV module.
5. The module has an area of A=0.50 m^2 and was illuminated under a solar irrandiance G_m=1000 W m^{-2}. Determine the power efficiency of the module $\eta = \frac{P_{max}}{P_{lum}}$ where P_{max} is the maximum power delivered by the module and P_{lum} is the power received through illumination.

Exercise 2: Static study of a bike transmission chain [7 pts.]

In this exercise we study the equilibrium of a bike in a configuration representative of a time-trial start (Figure 1-a). Lateral fall is prevented by persons maintaining the cyclist. In order to have the fastest possible reaction at the start, the cyclist applies a force on the upper pedal while keeping the brakes on, preventing any movement of the chain. We will consider here only the equilibrium of the bicycle drive represented in figures 1-b and 1-c.

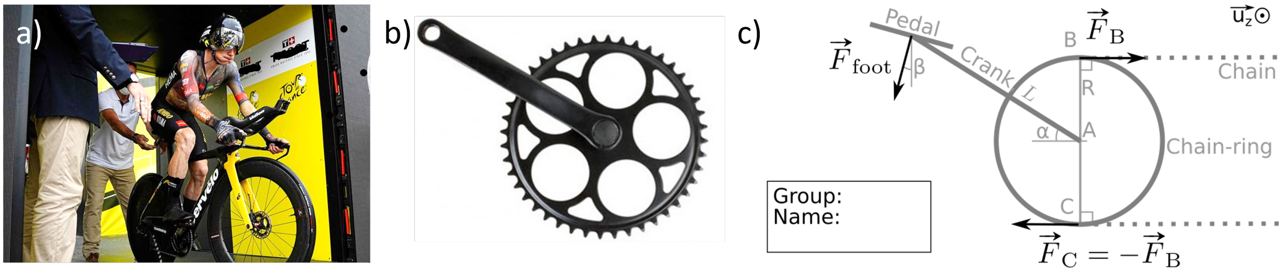

Figure 2: a) Picture of a cyclist at the start of a time trial. b) Picture of a bicycle drive ("pédalier" in French). c) Scheme of the bicycle drive. Some of the forces are represented.

The bicycle drive is made of two pedals – on which the feet act – linked by a crank to the chain-ring:

- the crank is a bar of length $L = 170mm$, we denote α the angle (not oriented) between the bar and the horizontal axis.
- the chain-ring (or chain wheel), which is fixed to the crank, is a circular part of center A and radius $R = 100mm$. It converts the pedals' motion into a circular motion about its axis, noted Az.
- the cyclist applies a force noted $\vec{F}_{\text{foot}}$ on the center of the upper pedal; the angle (not oriented) between this force and the vertical axis is noted β. We assume that the cyclist does not push on the other pedal, which is therefore not represented on the scheme for clarity.
- The set of forces that the chain applies on the chain-ring is equivalent to a pair of forces $\vec{F}_B$ and $\vec{F}_C$ of identical magnitude, horizontal and applied on B and C.

We consider that the pedal and the crank's masses are negligible compared to the mass m of the chain-ring. Friction is neglected.

1. Fill the scheme on figure 1-c with all force acting on the system {bicycle drive}. Do not forget to give the test text back with your work (write your name and group).
2. Determine the moment of the force due to the foot on the pedal about point A.
3. Determine the moment about point A resulting from the forces due to the chain.
4. Show that the force due to the chain on B can be written as $||\vec{F}_B|| = \gamma ||\vec{F}_{\text{foot}}||$. Give the expression of γ.
5. Determine the components of all other forces applied on the system, as functions of the problem data.

Exercise 3: Kinematics [8 pts.]

The movement of a point mass is parameterized in cylindrical coordinates by:

$$r = a, \quad \theta = 3bt^2, \quad z = abt^2$$

1. What are the dimensions of constants a and b ?
2. Describe the shape of this trajectory (you may use a scheme). What is the change in z when the point mass does one full turn?
3. Determine the velocity and acceleration vectors in cylindrical coordinates.
4. Determine the unit tangent vector $\vec{u_T}$ of the Frenet-Serret frame.
5. Determine the distance travelled by the point mass from $t = 0$ to $t_1 > 0$, as a function of a, b and t_1.
6. *(Bonus) What is the radius of curvature of the trajectory?*