![INSA Institut National des Sciences Appliquées Lyon]

FIMI
SCAN 1st
Year 2019-2020

Exam 3 — Physics

December 20, 2019, — Duration : 1 hour 30 min

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.*

Do not forget to state your name on the last page before returning it back with your paper

EXERCISE 1 : Electric locomotive (≈ 7 pts)

An electric locomotive is supplied by a DC current through the electric contact between a pantograph and a catenary (**Erreur ! Source du renvoi introuvable.**). The catenary is an electric wire through which a forward current is sent from an electric sub-station toward the locomotive's engine whereas the backward current returns back to the sub-station through the rails.

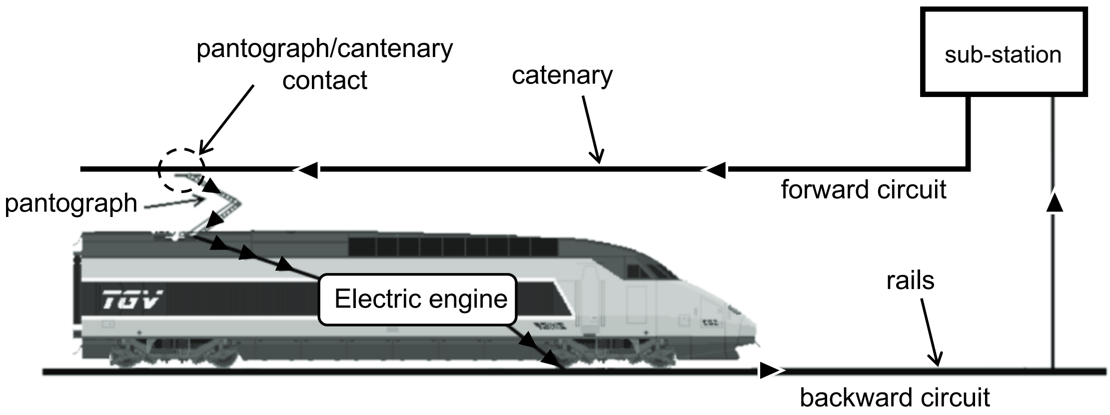

Figure 1 Scheme of the supply circuit of an electric locomotive involving a single sub-station

We will study here the supply circuit of such an electric engine involving two sub-stations (namely S_1 and S_2) separated by a distance L. A simplified electric model of the sub-stations/electric engine circuit is depicted in Figure 2. Each sub-station (S_1 and S_2) is modeled as an ideal high voltage source (electromotive force E) between the catenary (points A & B) and the rails (nodes F and G). The rails are considered to be grounded.

Therefore, the electric engine is connected to the sub-stations between the catenary/pantograph contact (node C) and the wheels/rails contacts (node H). We will consider that the electric engine has to be supplied with a DC current I = 800 A so that it can be modeled as an ideal current source between nodes C and H.

Let x be the distance between the locomotive and S_1 sub-station. The catenary resistances lying between the sub-stations and the engine (R_1 and R_2) is accounted given the linear resistance of the catenary **r** = 5.10^{-5} $\Omega.m^{-1}$ (***r*** is a resistance per unit length). The electric resistance of the rails is negligible so that they can be modeled as electric wires.

Given the catenary resistance, a voltage drop exists between the sub-stations and the engine so that the voltage difference across the motor (U_e) is lower than the e.m.f. of the substation. Let ΔU be the voltage drop between S_1 and the engine. In order to supply the engine properly, ΔU has to be lower than ΔU_{crit} = 45 V.

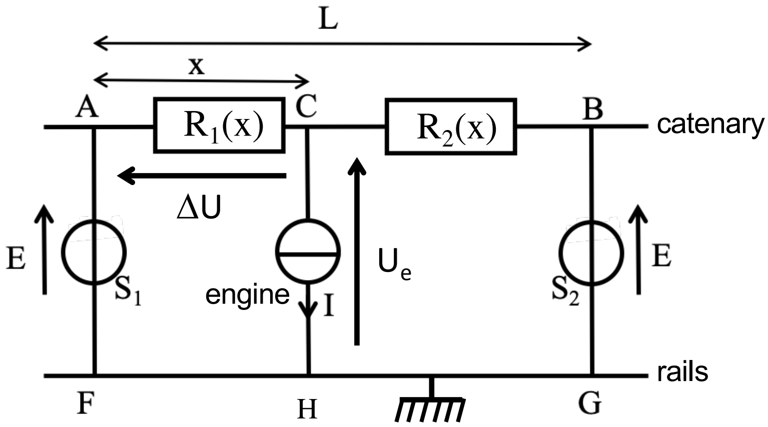

Figure 2 Simplified scheme of the supply circuit involving 2 sub-stations

1) Find the expression of the catenary resistances R_1 and R_2 as the locomotive travels between S_1 and S_2 as function of x.
2) Using an annotated scheme in which you will properly introduce any relevant physical quantities, find the expression of the voltage drop ΔU as function of *r, x, L* and *I* using a method of your choice.
3) Determine the position for which the ΔU *is maximal and give its expression,* namely ΔU_{max}. Provide comments this results.
4) Given the above results, what is the maximal length L_{max} we can afford between the two substations?

Bonus: How could we improve the supply circuit to further increase the distance between adjacent sub-stations (***E*** and ***I*** remaining unchanged)?

EXERCICE 2: RL Circuit (≈ 5 pts)

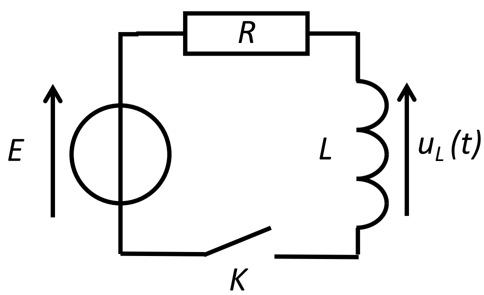

Figure 3 : RL circuit

We consider the circuit depicted in Figure 3 consisting in an ideal voltage source of e.m.f. **E** = 5V in series with a resistor **R** = 1kΩ, an inductor **L** = 1mH and a switch **K**. After being **opened** for a very long time (i.e. so that the steady-state was reached), the switch is suddenly **closed** at time **t** = 0s.

After analyzing the initial conditions, find the expression of the voltage across the inductor $u_L(t)$ (for t<0 and t>0) and provide its graphical representation using appropriate time and voltage scales. Provide details on your resolution methodology. You may introduce any other physical quantity you may find relevant.

EXERCICE 3: Neon Lamp (≈ 8 pts)

A Neon lamp N is connected to a supply circuit consisting in a real voltage source (e.m.f. ***E*** and internal resistance ***R***) in series with a switch **K** in parallel with a capacitor ***C*** (Figure 4).

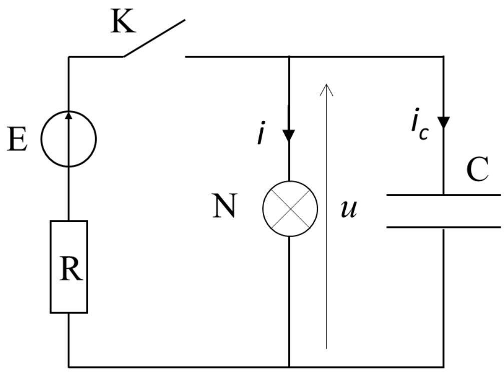

Figure 4 : Scheme of the circuit

The current-voltage characteristic (in passive sign convention) of the Neon lamp is given in Figure 5. As it is turned OFF, the lamp behaves as an open switch (infinite resistance). As soon as the voltage difference u across it exceeds a turn-on voltage (U_{ON}), the lamp is switched ON and behaves as an ohmic conductor of resistance r_e. If u is lowered below a turn-off voltage (U_{OFF}), the lamp is switched OFF and behaves again as an open switch.

LAST NAME : ***First Name :*** ***Group :***

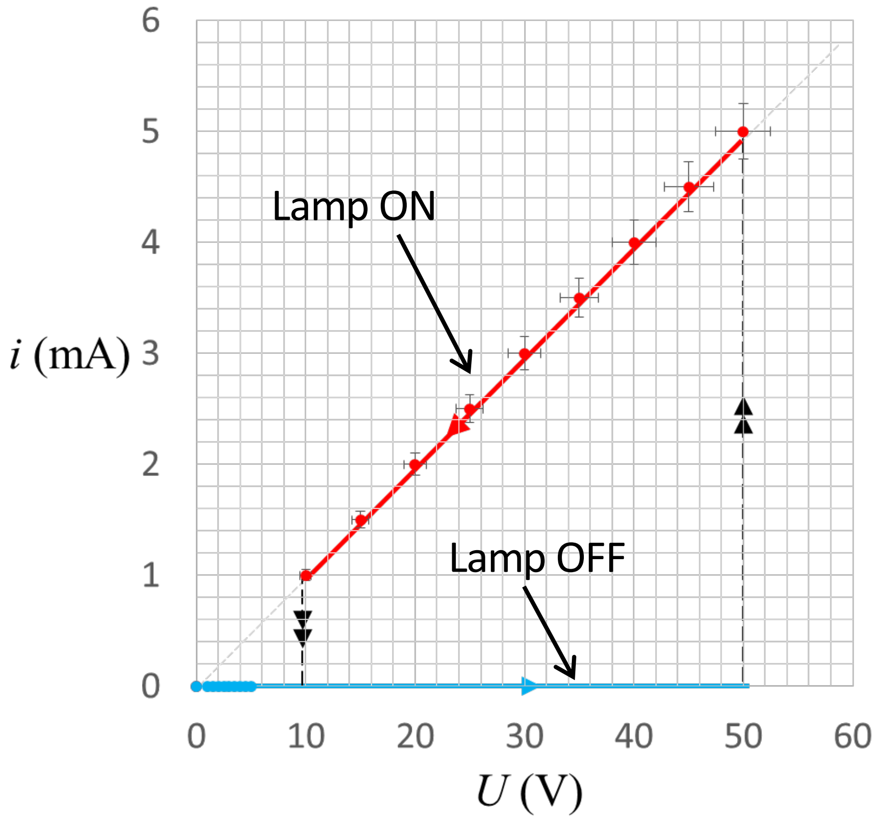

Figure 5 : Current-Voltage characteristic of the neon lamp (passive sign convention)

Numerical values : E = 100 V ; R = 1 MΩ ; C = 1 nF

1) Using the I-V curve of Figure 5, determine the values of U_{ON}, U_{OFF} *and the* resistance r_e. Provide the uncertainty on r_e.

For the next questions, we will only use the main values of $\boldsymbol{r_e}$ for numerical applications.

For t < 0 the lamp is turned off and the capacitor is discharged. At *t* = 0 the switch (K) is closed.

2) Give the equivalent scheme of the circuit at t=0 and find the initial conditions.
3) Establish the differential equation followed by *u(t)* and solve it. What is the time constant τ describing the time evolution of *u(t)*? Give its numerical value.
4) Do you think that a steady state is possible? Justify.
5) Determine t_{ON} the time at which the lamp will turn ON and give its numerical value.
6) As the lamp is turned ON, give the equivalent scheme of the circuit. Setting the new origin of time t=0 as the moment at which the lamps is turned ON, find the new differential equation followed by *u(t)* together with the initial conditions.

BONUS: Comment on the evolution of *u(t)* after the lamp is turned ON. Is a steady state achievable?