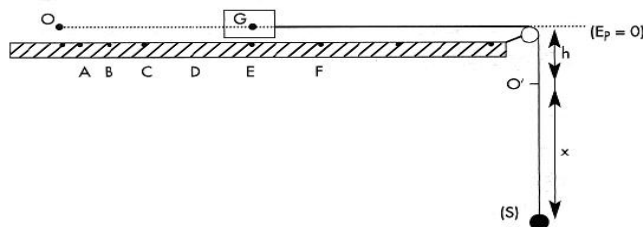


الاسم:  
الرقم:مسابقة في مادة الفيزياء  
المدة: ثلاث ساعات

***This exam is formed of four obligatory exercises in four pages  
The use of non-programmable calculators is allowed***

### **First Exercise ( 7 points) Verification of Newton's second**

In order to verify Newton's second law related to the dynamics of a solid in translation, we consider a puck of center of inertia G and of mass  $M = 200$  g, a horizontal air table, a solid (S) of mass  $m = 50$  g, an inextensible string and a pulley of negligible mass. We build the set up represented in the adjacent figure.



The part of the wire on the side of the puck is taut horizontally and the other part to the side of (S) is vertical.

The horizontal plane passing through G is taken as the gravitational potential energy reference.

At the instant  $t = 0$ , G is at O and the center of mass of (S) is at O', at a distance

$h$  below the reference. We release (S) without initial velocity, and, at the same time, the positions of G are recorded at successive instants separated by a constant time interval  $\tau = 50$  ms. At the instant  $t$ , G acquires a velocity  $\vec{V}$  and (S) is found at a distance  $x$  below O'.

Neglect all frictions and take  $g = 10$  m/s<sup>2</sup>.

- A- 1) Give the expression of the mechanical energy of the system (puck, string, (S), Earth) in terms of  $M$ ,  $m$ ,  $x$ ,  $h$ ,  $V$  and  $g$ . This energy is conserved. Why?
- 2) Deduce the expression of the acceleration of (S) in terms of  $g$ ,  $m$  and  $M$  and calculate its value.
- 3) Draw a diagram showing the forces acting on the puck and determine, using the relation  $\Sigma \vec{F} = M\vec{a}$ , the force  $\vec{T}$  exerted by the string on the puck.

B- By means of a convenient method, we determine the speed  $V$  of the puck. The results are tabulated as shown below:

Point	A	B	C	D	E
t in ms	50	100	150	200	250
V in cm/s	10	20	30	40	50

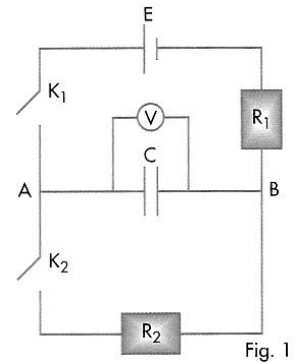
Determine, using the table, the linear momentums  $\vec{P}_B$  at B and  $\vec{P}_D$  at D and determine the ratio

$$\frac{\Delta \vec{P}}{\Delta t} = \frac{\vec{P}_D - \vec{P}_B}{\Delta t}$$

C- Compare  $\frac{\Delta \vec{P}}{\Delta t}$  and  $\vec{T}$ . Is Newton's second law thus verified? Justify.

## Second Exercise (6 points) Determination of the capacitance of a capacitor

In order to determine the capacitance  $C$  of a capacitor, we connect up the circuit of figure 1. This circuit is formed of the capacitor, a generator of e.m.f.  $E = 9 \text{ V}$  and of negligible internal resistance, two resistors of resistances  $R_1 = 200 \text{ K}\Omega$  and  $R_2 = 100 \text{ K}\Omega$  and two switches  $K_1$  and  $K_2$ .



### I- Charging the capacitor

The capacitor being initially uncharged, we close  $K_1$  and keep  $K_2$  open. The capacitor will be charged.

1) Derive the differential equation that describes the variation of the voltage  $v_C = v_{AB}$  across the capacitor.

- 2) Knowing that the solution of this differential equation has the form  $v_C = E(1 - e^{-\frac{t}{\tau_1}})$  expression of the constant  $\tau_1$  as a function of  $R_1$  and  $C$ .
- 3) Knowing that, at the instant  $t_1 = 20 \text{ s}$ ,  $v_C$  has a value of  $7.78 \text{ V}$ , calculate the capacitance  $C$  of the capacitor.

### II-Discharging the capacitor

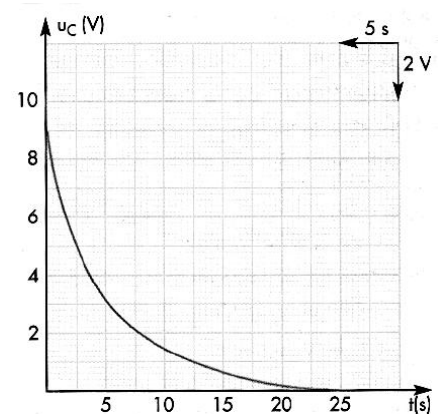
The capacitor being charged under a voltage of  $9 \text{ V}$ , we open  $K_1$  and close  $K_2$ .

The capacitor then discharges.

- 1) Draw a diagram of the circuit during that phase indicating the direction of the current.
- 2) Derive the differential equation that describes the variation of the voltages  $v_C = v_{AB}$  across the capacitor.
- 3) Knowing that the solution of this differential equation is of the

form  $v_C = E e^{-\frac{t}{\tau_2}}$ , deduce the expression of:

- a) the current  $i$  as a function of time. Take the direction of the current as a positive direction.
- b) the time constant  $\tau_2$  as a function of  $R_2$  and  $C$ .
- 4) A convenient apparatus allows us to trace the graph of the variation of  $v_C$  as a function of time. (fig. 2)



Determine from the curve the value of  $\tau_2$ . Deduce the value of  $C$ .

III- What conclusion can be drawn about the two values of  $C$ ? Comment.

### Third Exercise ( 6 points) Controlled nuclear reaction

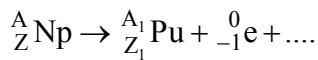
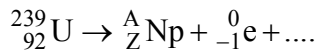
A chain nuclear reaction releases a considerable amount of energy. It may lead to an explosion if precautions were not taken. If this reaction is controlled inside a reactor, it may produce energy enough to function an electric power plant.

A- In a nuclear reactor of an atomic pile, the preparation of uranium 235, used as a fuel, takes place as follows:

- 1) The uranium nucleus  ${}_{92}^{238}\text{U}$  captures a fast neutron and is transformed into a uranium nucleus  ${}_{92}^{239}\text{U}$ .

Write the corresponding reaction.

- 2) The uranium nucleus 239 is radioactive, it is transformed into plutonium after two successive  $\beta^-$  dis-integrations according to the following reactions:



Complete these reactions and determine  $Z$ ,  $A$ ,  $Z_1$  and  $A_1$  specifying the supporting laws.

- 3) The radioactive plutonium nucleus (Pu) is an  $\alpha$  emitter. The daughter nucleus is the uranium 235 isotope. Some  $\alpha$  particles are ejected with a kinetic energy of 5.157 MeV each and others with a kinetic energy of 5.144 MeV each.
- Write the equation of the disintegration of (Pu) nucleus.
  - One of these  $\alpha$  disintegrations is accompanied by the emission of a photon  $\gamma$ . Calculate the energy of this photon and deduce the wavelength of the associated radiation.
- 4) Uranium 235 is fissionable. During one of these possible fission reactions, the mass defect is 0.2 u. Calculate, in MeV and in J, the energy liberated by the fission of one nucleus of uranium 235.

B- In that atomic pile, a mass of 0.4 kg of uranium 235 is consumed in one day. The efficiency of the transformation of nuclear energy into electric energy is 30%. Calculate the electric power of this pile.

Given:

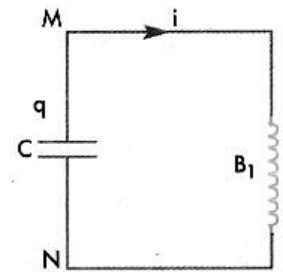
- $1 \text{ u} = 1,67 \times 10^{-27} \text{ kg} = 931,5 \text{ MeV}/c^2$
- $c = 3 \times 10^8 \text{ m/s}$
- Molar mass of  ${}^{235}\text{U} = 235 \text{ g}\cdot\text{mol}^{-1}$
- Avogadro's constant:  $N = 6,02 \times 10^{23} \text{ mol}^{-1}$
- $1 \text{ MeV} = 1,6 \times 10^{-13} \text{ J}$
- Plank's constant  $h = 6,63 \times 10^{-34} \text{ J}\cdot\text{s}$ .

## Fourth exercise (7½points) Electric oscillations

Consider a capacitor of capacitance  $C = 2 \times 10^{-10}$  F carrying a charge  $Q = 2 \times 10^{-9}$  C and two coils:  $B_1$  of inductance  $L_1 = 5 \times 10^{-4}$  H and of negligible resistance and  $B_2$  of inductance  $L_2 = 5 \times 10^{-4}$  H and of resistance  $r$ .

### I- Ideal oscillating circuit ( $L_1, C$ )

At the instant  $t_0 = 0$ , taken as the origin of time, we connect the capacitor across the terminals of  $B_1$  (figure 1). An ideal oscillating circuit is thus formed. Denote by  $q$  the electric charge, at the instant  $t$ , of the armature of the capacitor that is connected to M and by  $i$  the electric current at that instant, taken positive when it circulates in the direction indicated on figure 1.



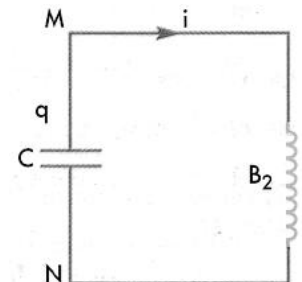
- 1) In this circuit,  $i$  and  $q$  are related by the expression  $i = -\frac{dq}{dt}$ .

Justify the (-) sign in this expression.

- 2) Apply the law of uniqueness of potential difference to derive the differential equation that describes the variation of the charge  $q$  as a function of time. Deduce the natural (proper) frequency  $f_0$  of this circuit.
- 3) The solution of the preceding differential equation has the form:  $q = Q \cos(2\pi f_0 t)$ .
  - a) Give the expression of the electric energy  $E_1$  of the capacitor at the instant  $t$ .
  - b) Give the expression of  $i$  as a function of time. Deduce the expression of the magnetic energy  $E_2$  of the coil at the instant  $t$ .
  - c) Show that the electromagnetic energy  $E = E_1 + E_2$  of the circuit is constant and deduce its numerical value.

### II- Damped oscillating circuit

- 1) Instead of connecting  $B_1$  to the capacitor at the instant  $t_0 = 0$ , we connect  $B_2$  (figure 2). Taking the same definitions for  $q$  and  $i$ , derive the differential equation that describes the variation of  $q$  with time.



- 2) Find  $\frac{dE}{dt}$  the derivative with respect to time of the electromagnetic energy  $E$  of the circuit.

- 3) Derive the relation between  $\frac{dE}{dt}$  and  $ri^2$  and comment on this relation in terms of

energy transfer.

- 4) The circuit thus formed is used as a detector of radio waves. The most convenient wave to this circuit is the one whose frequency is equal to the natural frequency  $f_0$  of the circuit.
  - a) In what particular electric state would the circuit be when the most convenient wave is received?
  - b) Calculate then the wavelength of the corresponding wave.  
Given: speed of light in air:  $c = 3 \times 10^8$  ms<sup>-1</sup>.

**Question I (07 points)**

<b>A-1.</b>	$ME = \frac{1}{2} M v^2 + \frac{1}{2} m v^2 - m g(h + x)$ The forces of friction are neglected, then the mechanical energy of the system is conserved.	<b>1</b> <b>0.5</b>
<b>A-2.</b>	$a = \frac{m}{(M + m)} \times g$ $a = 2m/s^2.$	<b>1</b> <b>0.5</b>
<b>A-3.</b>	The forces acting on the puck are: its weight $\vec{w}$ , $\vec{N}$ and the tension $\vec{T}$ . $\vec{w} + \vec{N} + \vec{T} = M\vec{a}$ $T = Ma = 0.2 \times 2 = 0.4N.$	<b>1</b> <b>1</b>
<b>B</b>	$\frac{\Delta \vec{P}}{\Delta t} = \frac{\vec{P}_D - \vec{P}_B}{\Delta t} = \frac{0.04}{0.1} \vec{i} = 0.4\vec{i} (kg.m/s^2)$	<b>1</b>
<b>C</b>	This result is compatible with Newton's 2nd law: $\sum \vec{F}_{ext} = \frac{\Delta \vec{P}}{\Delta t}$	<b>1</b>

**Question II (07 points)**

<b>A-1.</b>	$E = u_C + R_1 C \frac{du_C}{dt}.$	<b>1</b>
<b>A-2.</b>	$E + \left(1 - \frac{R_1 C}{\tau_1}\right) E e^{-\frac{t}{\tau_1}} = E$ then $1 - \frac{R_1 C}{\tau_1} = 0$ , thus $\tau_1 = R_1 C.$	<b>1</b> <b>0.5</b>
<b>A-3.</b>	$C = -\frac{t_1}{R_1 \ln\left(1 - \frac{7.78}{9}\right)} \approx 5 \times 10^{-5} F = 50\mu F$	<b>1</b>
<b>B-1</b>	Circuit	<b>0.5</b>
<b>B-2</b>	Law of uniqueness of voltages: $u_C = u_{AB} = u_{R2}.$ Then, $u_C + R_2 C \frac{du_C}{dt} = 0.$ $C = \frac{\tau_2}{R_2} = \frac{5}{100 \times 10^3} = 5 \times 10^{-5} F = 50\mu F$	<b>1</b>
<b>B-3.a)</b>	So, $i = -C \frac{du_C}{dt} = \frac{CE}{\tau_2} e^{-\frac{t}{\tau_2}}$	<b>0.5</b>
<b>B-3.b)</b>	We get: $E e^{-\frac{t}{\tau_2}} \left(1 - \frac{R_2 C}{\tau_2}\right) = 0$ Then $\left(1 - \frac{R_2 C}{\tau_2}\right) = 0$ , thus $\tau_2 = R_2 C.$	<b>0.75</b>
<b>B-4</b>	At $t = \tau_2$ : $u_C = 0.37 \times E = 0.37 \times 9 = 3.33 V$ & $\tau_2 = 5 s.$ $C = \frac{\tau_2}{R_2} = 5 \times 10^{-5} F = 50\mu F$	<b>0.25</b> <b>0.75</b>
<b>C</b>	The results are compatible with each other and the difference is due an experimental or measurement errors.	<b>0.25</b>

Question III (06 points)		
<b>A-1.</b>	${}^{238}_{92}\text{U} + {}^1_0\text{n} \longrightarrow {}^{239}_{92}\text{U}.$	<b>0.25</b>
<b>A-2.</b>	$A = 239 \text{ \& } Z = 93;$ The equation becomes ${}^{239}_{92}\text{U} \longrightarrow {}^{239}_{93}\text{Np} + {}^0_{-1}\text{e} + {}^0_0\bar{\nu} + \gamma$	<b>0.5</b>
	$A_1 = 239 \text{ \& } Z_1 = 94;$ The equation becomes: ${}^{239}_{93}\text{Np} \longrightarrow {}^{239}_{94}\text{Pu} + {}^0_{-1}\text{e} + {}^0_0\bar{\nu} + \gamma$	<b>0.5</b>
<b>A-3.a)</b>	${}^{239}_{94}\text{Pu} \longrightarrow {}^{235}_{92}\text{U} + {}^4_2\text{He} + \gamma$	<b>0.25</b>
<b>A-3.b)</b>	$E_\gamma = KE_{\alpha_1} - KE_{\alpha_2} = 0.013\text{MeV} = 2.08 \times 10^{-15}\text{J};$	<b>0.5</b>
	$\lambda = \frac{hc}{E_\gamma} = \frac{6.63 \times 10^{-34}\text{J}\cdot\text{s} \times 3 \times 10^8\text{m/s}}{2.08 \times 10^{-15}\text{J}} = 9.562 \times 10^{-11}\text{m}.$	<b>0.5</b>
<b>A-4)</b>	$E_\ell = \Delta m c^2 = 0.2 \times 931.5\text{MeV} = 186.3\text{MeV} = 2.98 \times 10^{-11}\text{J}$	<b>0.75</b>
<b>B-</b>	$N = \frac{m}{M} \times N_A = \frac{0.4 \times 10^3\text{g}}{238\text{g}\cdot\text{mol}^{-1}} \times 6.02 \times 10^{23}\text{mol}^{-1} = 1.025 \times 10^{24}.$	<b>0.75</b>
	$E_{t\ell} = N \times E_\ell = 3.05 \times 10^{13}\text{J};$	<b>1</b>
	$P_{\text{nuclear}} = \frac{E_{t\ell}}{\Delta t}$	<b>0.5</b>
	$P_{\text{electrical}} = \eta \times P_{\text{nuclear}} = 0.3 \times 353\text{MW} = 106\text{MW}$	<b>0.5</b>

Question IV (7.5 points)		
<b>A-1.</b>	The charge $q$ decreases	<b>0.25</b>
<b>A-2.</b>	Law of uniqueness of voltages: $u_{MN} = u_{MN}$ ; we get: $q'' + \omega_0^2 q = 0$ ;	<b>0.5</b>
	where $\omega_0^2 = \frac{1}{L_1 C}$ ;	<b>0.5</b>
	$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{L_1 C}}$	<b>0.25</b>
	$f_0 = 5 \times 10^5 \text{ Hz}$	
<b>A-3.a)</b>	$E_1 = \frac{q^2}{2C} = \frac{Q^2}{2C} \cos^2(2\pi f_0 t)$	<b>0.5</b>
<b>A-3.b)</b>	$E_2 = \frac{1}{2} L_1 i^2 = \frac{1}{2} L_1 Q^2 (2\pi f_0)^2 \sin^2(2\pi f_0 t)$	<b>0.5</b>
<b>A-3.c)</b>	$E = E_1 + E_2 = \frac{Q^2}{2C} \cos^2(2\pi f_0 t) + \frac{1}{2} L_1 Q^2 \times \frac{1}{L_1 C} \sin^2(2\pi f_0 t) = \frac{Q^2}{2C}$	<b>1</b>
	$E = 10^{-8} \text{ J}$ .	<b>0.25</b>
<b>B-1.</b>	Law of uniqueness voltages: $u_{MN} = u_{MN}$ , so $u_C = u_r + u_L$ ; Thus, $\frac{d^2 q}{dt^2} + \frac{r}{L_2} \frac{dq}{dt} + \frac{1}{L_2 C} q = 0$	<b>0.75</b>
<b>B-2.</b>	Then: $\frac{dE}{dt} = \frac{1}{C} q q' + L_2 i i'$	<b>0.5</b>
<b>B-3</b>	$\frac{dE}{dt} = -i \left( \frac{q}{C} + L_2 q'' \right)$	<b>0.75</b>
	Using the differential equation, we get: We get, $\frac{dE}{dt} = -i \left( \frac{q}{C} + L_2 q'' \right) = -r i^2$ .	<b>0.25</b>
	The decrease in the electromagnetic energy is converted into thermal energy due to Joule's effect.	
<b>B-4.a)</b>	Current resonance	<b>0.5</b>
<b>B-4.b)</b>	$\lambda = \frac{c}{f} = c \times 2\pi\sqrt{LC} = 600 \text{ m}$	<b>1</b>