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These files have been meticulously arranged by the 'Together We Can' team,
as we wish you the best of luck on your academic journey, filled with happiness and success

Join us in creating a better tomorrow,
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الاسم : الرقم :	مسابقة في الفيزياء المدة: ثلاث ساعات	

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

<u>First Exercise</u> (7 points) Clock pendulum

A- Free undamped oscillations

A simple pendulum is formed of a particle, of mass m = 100 g, fixed to the end A of a rod OA of negligible mass and of length OA = L = 25 cm.

This pendulum oscillates without friction about a horizontal axis (Δ) passing through O. The amplitude of oscillations is θ_m.

Take the reference level of the gravitational potential energy, the horizontal plane passing through A_o the equilibrium position of A. Take $g = 10\ m/s^2$ and $\pi^2 = 10$.

Determine the expression of the mechanical energy of the system (pendulum, Earth) in terms of m, g, L, θ and θ' where, θ and θ' are, respectively, the angular abscissa and the angular speed of the pendulum at any time t.

1) Derive the second order differential equation that describes the motion of the given pendulum.
2) What condition must θ_m satisfy so that the motion of the pendulum is angular simple harmonic?

Determine, in this case, the expression of the proper period T_o of the pendulum and calculate its value.

B- Driven oscillations

The pendulum of a clock can be taken as the preceding pendulum. When the oscillations are not driven, we notice that the amplitude decreases from 10° to 8° within 5 oscillations.

What causes this decrease in the amplitude?

Is the motion of the pendulum periodic or pseudo periodic? Why?

The oscillations of the pendulum are now driven by means of a convenient apparatus. Calculate the average power of this apparatus.

<u>Second Exercise</u> **(6 points)** **Determination of the wavelength of a laser light**

A- First method: By diffraction

The monochromatic light emitted by a laser source, of wavelength A, illuminates, under normal incidence, a very narrow slit F_1 of width $a_1 = 0.1$ mm cut in an opaque screen (E_1). The phenomenon of diffraction is observed on a screen (E_2) parallel to (E_1), found at a distance D = 4 m from it (fig. 1).

The central bright fringe on (E_2) has a linear width =5cm.

1) Describe the diffraction pattern observed on (E_2).
2) The phenomenon of diffraction shows evidence of a certain aspect of light. What is it?
3) Calculate the angular width of the central bright fringe.
4) Calculate the value of λ.

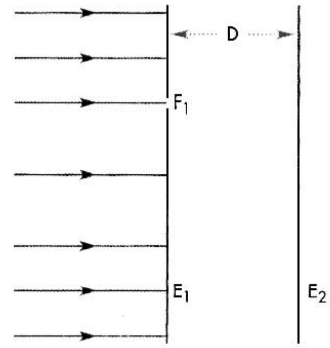


fig. 1

B- Second method: By interference of light

The positions of the laser source and of the screens are not modified. A second slit F_2 identical to F_1 and parallel to it is cut in (E_1) so that F_1 and F_2 are separated by a distance a 1 mm. We thus obtain the Young's slits apparatus (fig. 2).

We observe on (E_2) a system of interference fringes. The distance between the center O of the central bright fringe and that of the fourth bright fringe is 1 cm.

1) Due to what is the formation of the interference fringes?
2) Describe the aspect of the fringes observed on (E_2).
3) Consider a point M on (E_2) whose position is defined by its abscissa x relative to O.
   a) Write the expression of the optical path difference $\delta = F_2M - F_1M$ as a function of a, x and D.
   b) Deduce the expression giving the abscissas of the centers of the bright fringes.
   c) Calculate the wavelength λ.

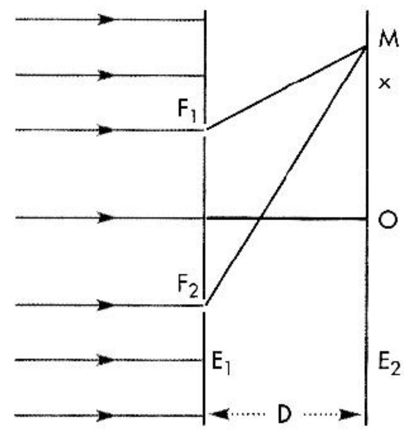


fig. 2

<u>Third Exercise</u> (6 ½ points) Energy levels of the hydrogen atom

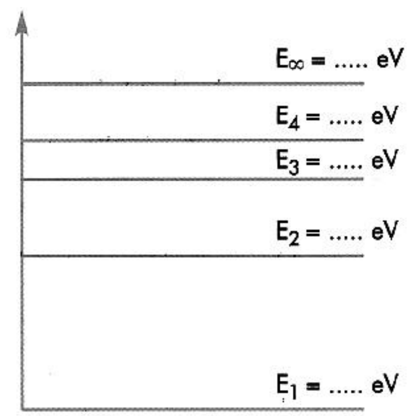
Given:

- Planck's constant: $h = 6.63 \times 10^{-34}$ J.s
- Speed of light in vacuum: $c = 3 \times 10^{8}$ ms^{-1}
- Mass of an electron: $m = 9.1 \times 10^{-31}$ kg
- $1eV = 1.6x10^{-19}J$
- Limits of the visible spectrum in vacuum: 400 nm $\leq \lambda \leq$ 800 m.

The quantized energy levels of the hydrogen atom are given by the formula:

$E_n = \frac{E_o}{n^2}$ where $E_o = 13{,}6$ eV and n is a whole number ≥ 1.

A- Line spectrum



1) Explain briefly what is meant by the term "quantized energy" and tell why the spectra (absorption or emission) of hydrogen are formed of lines.
2) Calculate the values of the energies corresponding to the energy levels n = 1, 2, 3, 4 and n = ∞. Redraw and complete the adjacent diagram.

B- Excitation of the hydrogen atom

The hydrogen atom is in its fundamental state.

1) Calculate the minimum energy of a photon that is able to:

   a) excite this atom; b) ionize this atom.

2) The hydrogen atom receives, separately, three photons of respective energies:

   a) 11 eV b) 12.75 eV c) 16 eV

   Specify in each case the state of the atom. Justify.

3) The hydrogen atom being always in the fundamental state, receives now a photon of energy E. An electron of speed $V = 7 \times 10^{5}$ ms^{-1} is thus emitted. Calculate E.

C- Dis-excitation of the hydrogen atom

The hydrogen atom is found now in the energy level n = 3.

1) Specify all the possible transitions of the atom when it is dis-excited.
2) One of the emitted radiations is visible. Calculate its wavelength in vacuum.

Fourth exercise (8 points) Characteristics of a coil

We intend to determine the inductance L and the resistance r of a coil by two methods.

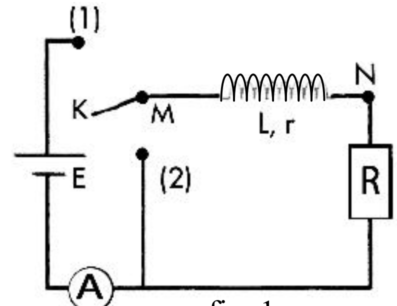


fig. 1

A- We place the coil in a circuit formed of: a resistor of resistance $R = 50\ \Omega$, a dry cell of e.m.f. $E = 6$ V and of negligible internal resistance, a switch K and an ammeter as indicated in figure 1.

1) We close the circuit by connecting K to position (1). The ammeter indicates a current i_1.
   a) Write, in the transient state, the expression of the voltage v_{MN} across the coil.
   b) In the steady state, the ammeter indicates $I_0 = 100$ mA. Which of the characteristics L or r of the coil may be determined? Justify and calculate its value.
2) At the instant $t_0 = 0$, taken as an origin of time, and within a very short time we turn K to position (2) during which we have no loss of energy.
   a) Derive the differential equation that governs the variation of the current i_2 in the new circuit.
   b) Verify that $i_2 = I_0 e^{-\frac{t}{\tau}}$ (where $\tau = \frac{L}{R+r}$) is a solution of this equation. Calculate then the value I of i_2 for $t = \tau$.
   c) The graph of figure 2 represents the variation of i_2 as a function of time.
   Determine, using the graph, the value of T. Deduce then the value of the other characteristic of the coil.

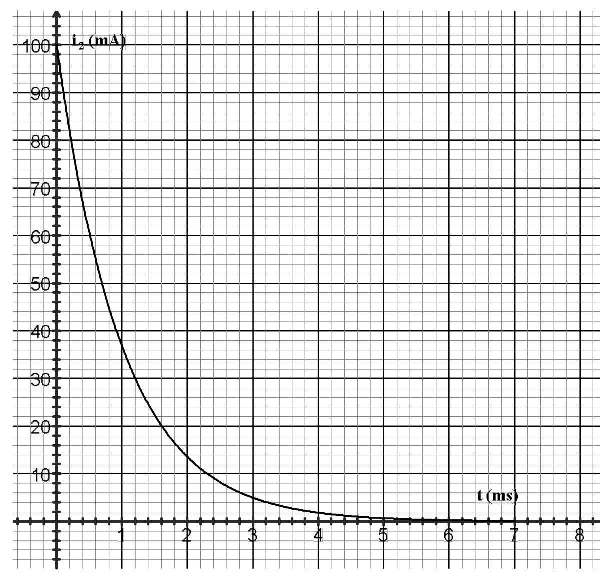


fig. 2

B- To confirm the values of r and L obtained in part A, we connect the coil, the resistor of resistance R and a capacitor of capacitance $C = 47\ \mu F$ all in series across the terminals of a low frequency generator delivering a sinusoidal voltage of frequency f (fig. 3)

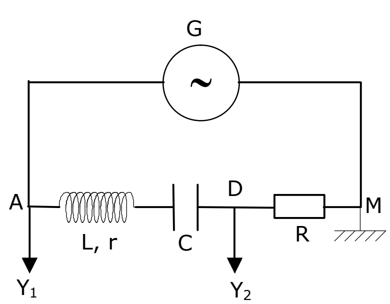


fig. 3

Horizontal sensitivity: 2 ms/div.

Vertical sensitivity on channel Y_1: 2 V/div.

Vertical sensitivity on channel Y_2: 5 V/div.

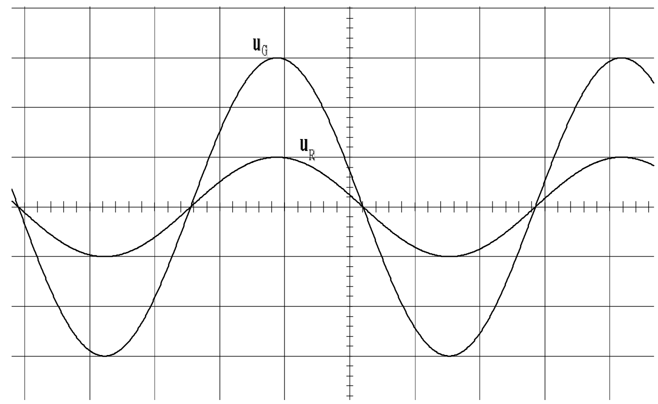


fig. 4

We display on the screen of the oscilloscope, the voltage $u_G = v_{AM}$ across the terminals of the generator on channel Y_1 and the voltage $v_R = u_{DM}$ across the resistor on channel Y_2. For a well determined value of f, we obtain the two oscillograms (waveforms) of figure 4.

1) The two oscillograms show evidence of a physical phenomenon. What is it? Justify.
2) Determine the value of f corresponding to this phenomenon and deduce the value of L.
3) Determine the maximum values V_m of the voltage v_G and I_m of the current i. Deduce the value of r knowing that, we have: $\frac{V_m}{I_m} = R + r$.

Solution

First Exercise (7 points)

A-1)

$$M.E = K.E + P.Eg = \frac{1}{2}I\theta'^2 + mgh;\; I = mL^2 \text{ et } h = L\text{-}L\cos\theta$$

(1.5 pts)

$$M.E = \frac{1}{2}mL^2\theta'^2 + mg(L\text{-}L\cos\theta)$$

2) The system (pendulum, Earth) is isolated. M.E is conserved:

$$\frac{M.E}{dt} = 0 \Rightarrow \frac{1}{2}mL^2 2\theta'\theta'' + mgL(\sin\theta)\theta' = 0$$

(1.25 pts)

$$\theta'' + \frac{g}{L}\sin\theta = 0$$

3) In the case of small amplitude, $\sin\theta \approx \theta$:

$\theta'' + \frac{g}{L}\sin\theta = \theta'' + \frac{g}{L}\theta$; it is of the form $\theta'' + \omega_o^2\theta = 0$, the motion is simple harmonic whose proper angular frequency $\omega_o = \sqrt{\frac{g}{L}}$ and proper period $T_o = 2\pi\sqrt{\frac{L}{g}} = 1s.$ (1.25 pts)

B-

1) The decrease is due to the friction. (0.5 pt)

2) The motion is pseudo-periodic because the amplitude decreases during the motion. (1 pt)

3) $\theta_{m1} = 10^o$ and $\theta' = 0$ rad $\Rightarrow M.E_{m1} = 3.798 \times 10^{-3}$ J

$\theta_{m2} = 8^o$ and $\theta' = 0$ rad $\Rightarrow M.E_{m2} = 2.433 \times 10^{-3}$ J

$\Delta M.E = M.E_2 - M.E_{m1} = -1.365 \times 10^{-3}$ J

$$P = \frac{|\Delta M.E|}{5xT} \approx \frac{|\Delta M.E|}{5xT_o} = 0.273 \text{ x}10^{-3}\text{ W}$$

(1.5 pts)

Second Exercise (6 ½ points)

A)

1) We observe alternately bright and dark fringes in a direction perpendicular to the slit.
The width of the central fringe is double of that those of the others fringes. (0.75 pt)

2) The phenomenon of diffraction shows the evidence that light has a wave nature. (0.25 pt)

3) $\alpha = \frac{L}{D} = 0.0125$ rd (1 pt)

4) $\theta_n = \frac{n\lambda}{a_1}$, for the first dark fringe, $\theta_1 = \frac{1\times\lambda}{a_1}$.

$$\alpha = 2x\theta_1 = \frac{2\lambda}{a_1} \Rightarrow \lambda = \frac{\alpha\times a_1}{2} = 0.625 \text{ x}10^{-6}\text{m}$$

(0.75 pt)

B-

1) The interference fringes are due to the superposition of light waves emitted by F_1 and F_2. (0.5 pt)

2) The interference fringes are rectilinear, parallel, equidistant and alternately bright and dark. (0.75 pt)

3)

a) $\delta = MF_2 - MF_1 = \frac{ax}{D}$. (0.25 pt)

b) The bright fringes are defined bye $\delta = k\lambda$ thus $x = k\frac{\lambda D}{a}$. (1 pt)

c) $k = 4$; $x = 0.01$ m $\Rightarrow \lambda = 4\frac{x.a}{D} = 0.625 \text{ x}10^{-6}$m. (0.75 pt)

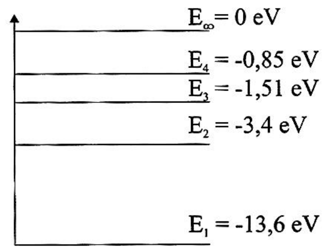
Third Exercise (6 ½ points)

A-

1) The energy is quantized because the energies corresponding to the different energy levels are discrete, that produces spectra constitute of the discontinuous lines. (1pt)

2) $E_n = -\frac{13.6}{n^2}$ (en eV)

$E_1 = E_o = -13.6$ eV;
$E_2 = -3.4$ eV;
$E_3 = -1.51$ eV;
$E_4 = -0.85$ eV
$E_\infty = 0$ eV. (1.5 pts)



B-

1) a) $E_2 - E_1 = -3.4 - (-13.6) = 10.2$ eV (0.5 pt) b) $E_\infty - E_1 = 13.6$ eV (0.5 pt)

2)

a) For E = 11 eV, we have $E_n - E_o = 11$, thus $-\frac{13.6}{n^2} = 2.6 \Rightarrow n = 2.28 \notin \mathbb{N}$, then the atom does not absorb the photon, it remains in the fundamental state. (0.5 pt)

b) For E = 12.75 eV, thus $n = 4 \in \mathbb{N}$ then the atom absorbs the photon and it passes to the excited level 4. (0.5 pt)

c) For E = 16 eV > 13.6 eV; the atom ionizes and the electron is emitted with K.E. (0.5 pt)

3) $E = |E_o| + KE_{(\text{in eV})} = 13.6 + 1{,}4 = 15$ eV (0.5 pt)

C)

1) The possible transitions are: a) $n = 3 \rightarrow n = 1$; b) $n = 3 \rightarrow n = 2$; c) $n = 2 \rightarrow n = 1$. (0.25 pt)

2) The de-excitation of the hydrogen atom ($n = 3 \rightarrow n = 2$) belongs to the series of Balmer which is visible.

$\frac{h.c}{\lambda} = (E_3 - E_2)_{\text{in J}} \Rightarrow \lambda = 0.656 \text{ x}10^{-6}$ m (0.75 pt)

Fourth exercise **(8 points)**

A- 1)

a) $v_{MN} = ri_1 + L\frac{di_1}{dt}$ (0.5 pt)

b)) In the steady state, $\frac{di}{dt} = 0$ and the voltage across the coil becomes $v_{MN} = r.I_o$.

$E = v_{MN} + v_R = r.I_o + RI_o = I_o(r+R) \Rightarrow R + r = \frac{E}{I_o} = 60\ \Omega \Rightarrow r = 10\ \Omega$ (1.25 pts)

2)

a) $0 = ri_2 + L\frac{di_2}{dt} + Ri_2 \Leftrightarrow L\frac{di_2}{dt} + (R+r)i_2 = 0$ (0.5 pt)

b) $i_2 = I_o e^{-\frac{t}{\tau}}$; $\frac{di_2}{dt} = -\frac{I_o}{\tau}e^{-\frac{t}{\tau}} \Rightarrow -L - \frac{I_o}{\tau}e^{-\frac{t}{\tau}} + (R+r)I_o e^{-\frac{t}{\tau}} = 0$. Thus $i_2 = I_o e^{-\frac{t}{\tau}}$ is a solution.

$t = \tau$; $I = 0.037$ A = 37 mA (1.25 pts)

c) On the graph, for $i_2 = 37$ mA, $t = \tau = 1$ ms = 10^{-3} s. $\tau = \frac{L}{R+r} \Rightarrow L = \tau(R+r) = 0.06$ H (1 pt)

B-

1) The phenomenon is the current resonance because v_G and i are in phase (v_R represents i). (1.25 pts)

2) $T_o = 5.3$ (div) x 2 = 10.6 ms, $f_o = 94$ Hz. (0.75 pt)

$f_o = \frac{1}{2\pi\sqrt{LC}} \Rightarrow L = \frac{1}{4\pi^2 f_o^2 C} = 59.7 \times 10^{-3}$ H = 59.7 mH (0.5 pt)

3) $V_{Rm} = 5$ V $\Rightarrow$ $I_m = 0,1$ A

$V_m = 3$ (div) x 2 = 6 V

$V_m = I_m(R+r) \Leftrightarrow (R+r) = \frac{V_m}{I_m} = 60 \Rightarrow r = 10\ \Omega.$ (1.5 pts)

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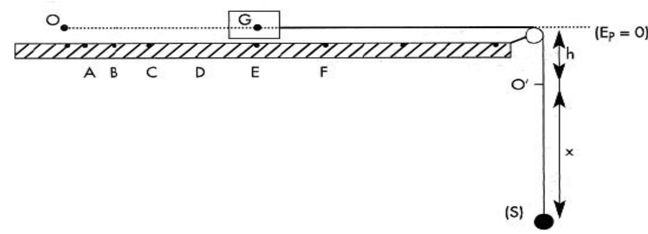
First Exercise (7 points) Verification of Newton's second



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 τ = 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 $g = 10\ m/s^2$.

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 $\sum\vec{F} = M\vec{a}$, 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.

<u>Second Exercise</u> (6 points) Determination of the capacitance of a capacitor

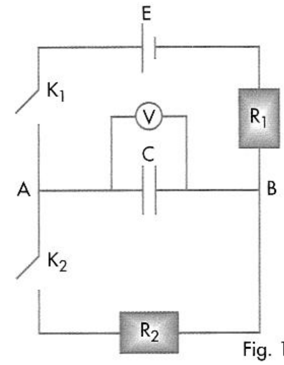


Fig. 1

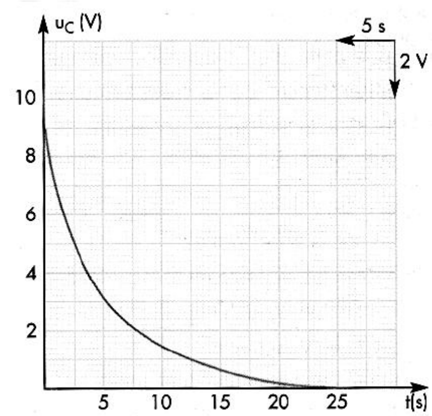
In order to determine the capacitance C of a capacitor, we connect up the circuit of figure 1. This circuit is formed of the capacitor, a generator of e.m.f. E = 9 V and of negligible internal resistance, two resistors of resistances R_1 = 200 KΩ and R_2 = 100 KΩ and two switches K_1 and K_2.

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 τ_1 as a function of R_1 and C.
3) Knowing that, at the instant t_1 = 20 s, v_C has a value of 7.78 V, calculate the capacitance C of the capacitor.

II-Discharging the capacitor



The capacitor being charged under a voltage of 9 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 τ_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 τ_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 ${}^{238}_{92}U$ captures a fast neutron and is transformed into a uranium nucleus ${}^{239}_{92}U$. Write the corresponding reaction.

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

$${}^{239}_{92}U \rightarrow {}^{A}_{Z}Np + {}^{0}_{-1}e + ...$$

$${}^{A}_{Z}Np \rightarrow {}^{A_1}_{Z_1}Pu + {}^{0}_{-1}e + ...$$

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

3) The radioactive plutonium nucleus (Pu) is an α emitter. The daughter nucleus is the uranium 235 isotope. Some α particles are ejected with a kinetic energy of 5.157 MeV each and others with a kinetic energy of 5.144 MeV each.

a) Write the equation of the disintegration of (Pu) nucleus.

b) One of these α disintegrations is accompanied by the emission of a photon γ. 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:

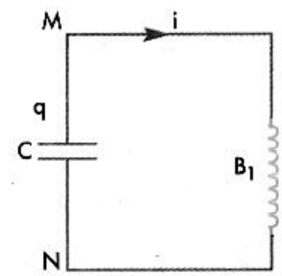
- 1 u = 1,67 x 10^{-27} kg = 931,5 MeV/c^2
- c = 3x10^8m/s
- Molar mass of ${}^{235}U$ = 235 g.mol^{-1}
- Avogadro's constant: N = 6,02 x 10^{23} mol^{-1}
- 1 MeV = 1,6 x 10^{-13} J
- Plank's constant h = 6,63 x 10^{-34} J.s.

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.

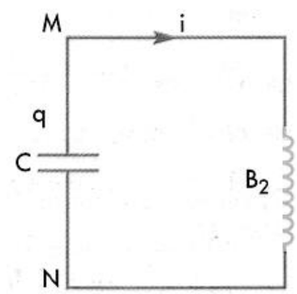
I- Ideal oscillating circuit (L_1, C)

At the instant $t_o = 0$, 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 t_o derive the differential equation that describes the variation of the charge q as a function of time. Deduce the natural (proper) frequency f_o of this circuit.
3) The solution of the preceding differential equation has the form: $q = Q \cos(2\pi f_o t)$.
   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 $t_o = 0$, 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 respective 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_o 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: $c = 3 \times 10^8\ ms^{-1}$.

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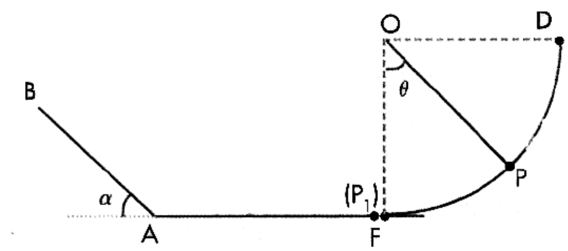
This exam is formed of four obligatory exercises in four pages
The use of non-programmable calculators is allowed

<u>First Exercise</u> (7 points) Conservation and non-conservation of the mechanical energy



Consider a material system (S) formed of an inextensible and mass less string of length l = 0.45 m, having one of its ends O fixed while the other end carries a particle (P) of mass m = 0.1 kg.
Take g = 10 m/s^2.
1) (S) is shifted from its equilibrium position by $\theta_m = 90°$, while the string is under tension, and then released without initial velocity.
Take the horizontal plane containing FA as a gravitational potential energy reference for the system [(S), Earth]. We neglect friction on the axis through O and air resistance.

a) Calculate the initial mechanical energy of the system [(S), Earth] when (P) was at D.
b) Determine the expression of the mechanical energy of the system [(S), Earth] in terms of l, m, g, V and θ, where V is the speed of (P) when the string passes through a position making an angle θ with the vertical.
c) Determine the value of θ, (0° < θ < 90°), for which the kinetic energy of (P) is equal to the gravitational potential energy of the system [(S), Earth].
d) Calculate the magnitude V_o of the velocity $\vec{V}_o$ of (P) as it passes through its equilibrium position.

2) Upon passing through the equilibrium position, the string is cut, and (P) enters in a head-on collision with a stationary particle (P_1) of mass ml= 0.2 kg. As a result, (P_1) is projected with a velocity $\vec{V}_1$ of magnitude V_1 = 2m/s. Determine the magnitude V of the velocity $\vec{V}$ of (P) right after impact knowing that $\vec{V}_o$, $\vec{V}_1$, and $\vec{V}$ are collinear.
Is the collision elastic? Justify your answer.

3) (P_1), being projected with a speed V_1 = 2m/s, moves along the frictionless horizontal track FA, and rises at A with the speed V_1, along the line of greatest slope of the inclined plane AB that makes an angle α = 30° with the horizontal.

a) Suppose now that the friction along AB is negligible. Determine the position of the point M at which (P_1) turns back.

b) In fact, AB is not frictionless; (P_1) reaches a point N and turns back, where AN = 20 cm. Calculate the variation in the mechanical energy of the system [(P_1), Earth] between A and N, and then deduce the magnitude of the force of friction (assumed constant) along AN.

Second Exercise (6 ½ points) Determination of the capacitance of a capacitor

In order to determine the capacitance C of a capacitor, we use the following components:

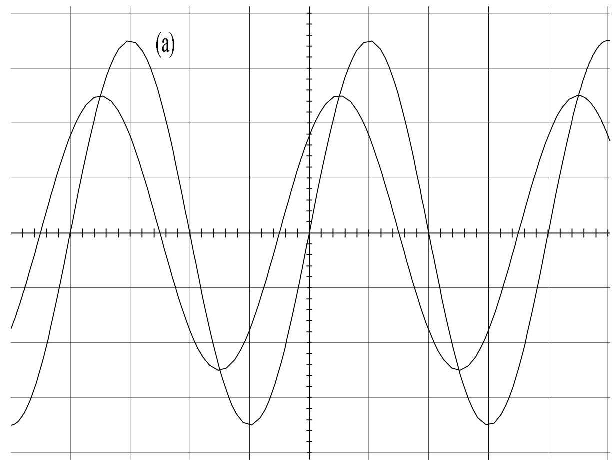
- a function generator (LFG) delivering an alternating sinusoidal voltage: $v = V_m \cos \omega t$ (v in V and tin s), a resistor of resistance R = 50 Ω, a coil of inductance L = 0.16 H and of negligible resistance, an oscilloscope and connecting wires. Take $0.32\,\pi = 1$.

A) In a first experiment, we connect the capacitor in series with the resistor across the LFG. The oscilloscope is used to display the voltage v across the LFG on the channel Yl and the voltage vR across the resistor on the channel Y2. The adjustments of the oscilloscope are:

vertical sensitivity: 2 V/division on both channels,

horizontal sensitivity: 5 ms/division.

1) Draw again a diagram of the circuit showing on it the connections of the oscilloscope.
2) The waveforms displayed are represented as in the adjacent figure:



a) Waveform (a) represents v. Why?

b) Determine the frequency of the voltage v and the phase difference between v and vR.

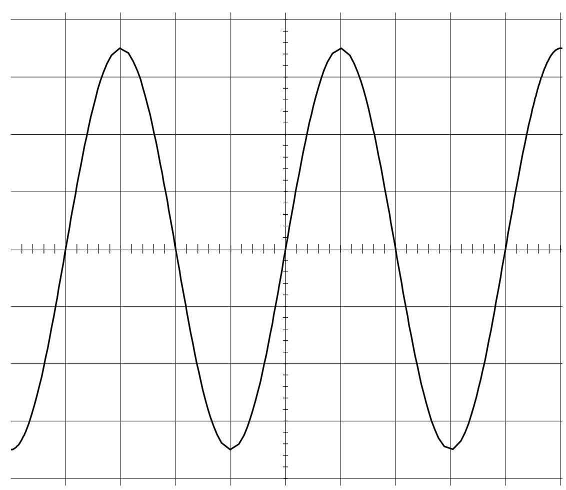
c) Using the numerical values of Vm and w, write the expressions of v and of vR as a function of time and deduce the expression of the instantaneous current i in the circuit.

d) Knowing that the voltage vC across the capacitor is $v_C = \frac{q}{C}$ show that uC is given by

$$v_C = \frac{3.2\text{x}10^{-4}}{C}\cos(\omega t - \frac{\pi}{4})$$

e) Determine the value of C using the law of addition of voltages by taking a particular value of the time t.

B) In a second experiment, we insert the coil in series with the previous circuit.
We thus obtain an RLC series circuit and we keep the same connections of the oscilloscope.
We observe only one waveform on the screen (the two waveforms are confounded).
The above result shows evidence of an electric phenomenon that took place.
Name this phenomenon and calculate again the value of the capacitance C.



Third exercise **(6.5 points)** **Radioactivity**

Given the masses of the nuclei: m($^{131}_{53}I$) = 130.87697 u; m($^{A}_{Z}Xe$) = 130.87538 u; mass of an electron = 5,5 x 10^{-4} u;

1 u = 931.5 MeV/c^2; 1 MeV = 1.6 x 10^{-13} J; h = 6,63 x 10^{-34} J.s et c = 3x10^8m/s

In order to detect a trouble in the functioning of the thyroid, we inject it with a sample of an iodine radionuclide $^{131}_{53}I$. This radionuclide has a period (half-life) of 8 days and it is a β^- emitter. The disintegration of the nuclide $^{131}_{53}I$ gives rise to a daughter nucleus $^{A}_{Z}Xe$ supposed at rest.

1) a) The disintegration of a nucleus of $^{131}_{53}I$ is accompanied by the emission of a γ radiation. Due to what is this emission?

b) Write the equation of the disintegration of $^{131}_{53}I$ nucleus.

c) Calculate the decay constant of the radionuclide. Deduce the number of the nuclei of the sample at the instant of injection, knowing that the activity of the sample, at that instant, is 1.5 x 10^5 Bq.

d) Calculate the number of the disintegrated nuclei at the end of 24 days.

2) a) Calculate the energy liberated by the disintegration of one nucleus of $^{131}_{53}I$.

b) Calculate the energy of a γ photon knowing that the associated wavelength is 3.55 x 10^{-12}m.

c) The energy of an antineutrino being 0.07 MeV, calculate the average kinetic energy of an emitted electron.

d) During the disintegration of the $^{131}_{53}I$ nuclei, the thyroid, of mass 40 g, absorbs only the average kinetic energy of the emitted electrons and that of γ photons. Knowing that the dose absorbed by a body is the energy absorbed by a unit mass of this body, calculate, in J/Kg, the absorbed dose by that thyroid during 24 days.

<u>Fourth exercise</u> (7½points) Effect of the resistance of a resistor in an electric circuit

According to the value of the resistance of the resistor in a circuit, the steady state is attained slower or faster, or the circuit may be (or may not be) the seat of ideal electric oscillations.
In this exercise, we intend to show the effect of the resistance of a resistor in some electric circuits.
Given a resistor (R) of adjustable resistance R, a coil (B) of inductance L = 0.64 H and of negligible resistance, a capacitor (C) of capacitance $C = 10^{-6}$ F, a generator (G) of negligible internal resistance and of electromotive force E, a switch (K), an oscilloscope with a memory and connecting wires.

A) Case of an R-L series circuit

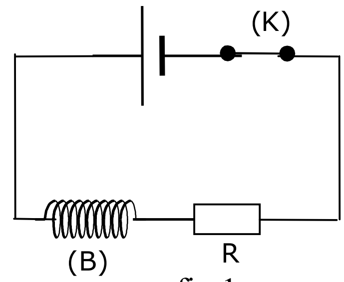


fig 1

We connect up the (R- L) series circuit of figure 1. The switch (K) is closed at t = 0.

1) Derive, in the transient state, the differential equation in $v_R = Ri$ associated with the considered circuit.
2) The expression $v_R = V_0(1-e^{-\frac{t}{\tau}})$ is a solution of this differential equation. Deduce the expression of U_0 and τ in terms of E, R and L.
3) Express, in terms of τ, the time t at the end of which the steady state is practically attained. What is then the value of the voltage across the coil?
4) a) Compare the values of t and of V_o corresponding to:
   i) $R_1 = 12\ \Omega$; ii) $R_2 = 60\ \Omega$; iii) $R_3 = 600\ \Omega$.
   b) Draw, on the same system of axes (t, v_R), the shape of the curve that represents v_R for each value of R.
   c) What is then the role of the value of R in the growth of the current towards the steady state?

B) Case of an R-C series circuit

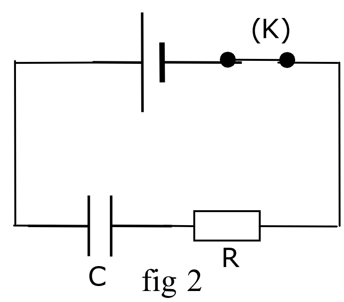


fig 2

We connect up the (R-C) series circuit of the figure 2. We close (K) at t = O.

1) Derive, in the transient state, the differential equation in $v_C = \frac{q}{C}$ associated with the considered circuit, q being the charge of the armature A of the capacitor.
2) The expression $v_C = V_C(1-e^{-\frac{t}{\tau'}})$ is a solution of this differential equation. Deduce the expressions of V_C and of τ' in terms of E, R and C.
3) a) Express, in terms of τ', the time t' at the end of which the steady state is practically attained. What is then the value of the voltage across the terminals of the resistor?
   b) Compare the values of t' and V_C corresponding to:
   i) $R_1 = 12\ \Omega$; ii) $R_2 = 60\ \Omega$; iii) $R_3 = 600\ \Omega$.
   c) Draw, on the same system of axes (t, v_c), the shape of the curve representing u_c for each value of R.
   d) What is then the role of the value of R in the decay of the current towards the steady state?

C) Case of an RLC series circuit

(C), being charged, is connected with (B) and (R) thus forming an RLC series circuit. This circuit is the seat of free electric oscillations.

The oscilloscope, connected across the terminals of (C), would display the variation of v_C as a function of time.

If R takes the value R = 0 and the switch (K) is closed at t = 0, we observe on the screen of the oscilloscope the waveform of figure 3.

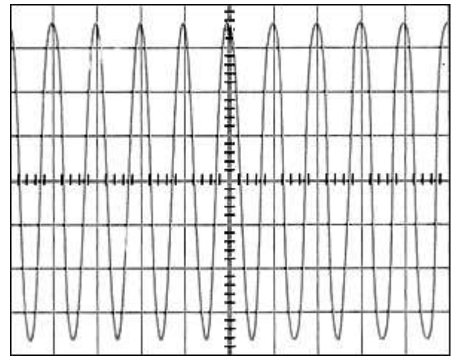


fig 3

If we give R a certain value and we close the switch at t = 0, we obtain the waveform of figure 4 without changing the adjustments of the oscilloscope.

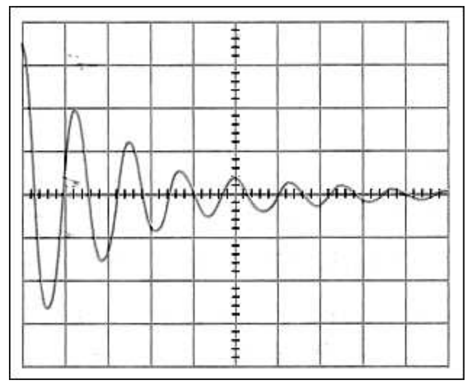


fig 4

1) Give the expression of the proper (natural) period T_0 of the RLC series circuit thus formed and calculate its value.

2) Determine, using the waveform of figure 3, the time base (horizontal sensitivity) used.

3) a) In which case are the oscillations undamped? Why?

b) Calculate the value of the pseudo-period T of oscillations.

4) Compare the values of T and T_0. Conclude.

Solution

First Exercise (7 points)

1)

a) At D: KE = 0 J car v = 0 m/s

$P.E_g = mgl = 0.1x10x0.45 = 0.45$ J

$M.E = KE + P.E_g = 0.45$ J (0.75 pt)

b)

$M.E = KE + P.E_g = \frac{1}{2}mv^2 + mgh$; et $h = l - l\cos\theta$

(0.75 pt)

$M.E = \frac{1}{2}mv^2 + mgl(1-\cos\theta)$

c) M.E of the system [(S), Terre] is conserved because friction is neglected.

$M.E = M.E_D = 0.45$ J.

$P.E_g = K.E = \frac{M.E}{2} = 0.45 \text{ J} \Rightarrow P.E_g = mgl(1-\cos\theta) = 0.45 \Rightarrow \theta = 60^o$ (1 pt)

d) $M.E = M.E_F = 0.45$ J ; $P.E_{gF} = 0$.

$K.E = \frac{1}{2}mV_o^2 = 0.45 \Rightarrow V_o = 3$ m/s (0.5 pt)

2) During collision, the linear momentum of the system (P, P_1) is conserved:

$m\vec{V}_o = m\vec{V} + m_1\vec{V}_1$

$\vec{V}_o$, $\vec{V}$ et $\vec{V}_1$ are collinear: $mV_o = mV + m_1V_1 \Rightarrow V = \frac{mV_o - m_1V_1}{m_1} = -1$ m/s (1 pt)

$K.E_i$ of the system before collision: $K.E_i = \frac{1}{2}mV_o^2 = 0.45$ J.

$K.E_f$ of the system before collision: $K.E_f = \frac{1}{2}mV^2 + m_1V_1^2 = 0.45$ J.

$K.E_i = K.E_f \Rightarrow$ the collision is elastic. (0.75 pt)

3)

a) At A, $P.E_{gA} = 0 \text{ J} \Rightarrow M.E_A = K.E_A = \frac{1}{2}m_1V_A^2 = 0.4$ J.

M.E of the system [(S), Terre] is conserved because friction is neglected, $M.E_A = M.E_M$

At M, $E_{cM} = 0 \text{ J} \Rightarrow E_{mM} = E_{pM} = m_1gAM\sin\alpha = 0.4 \Rightarrow AM = 0.4$ m. (1 pt)

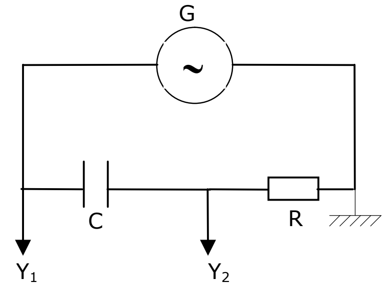
b) At N, $K.E_c = 0 \text{ J} \Rightarrow M.E_N = P.E_{gN} = m_1gAN\sin\alpha = 0.2$ J

$\Delta E_m = E_{mN} - E_{mA} = -0.20$ J

$\Delta E_m = W_{\vec{f}} = \vec{f}.\overline{AN} = -f \times AN \Rightarrow f = \frac{-\Delta E_m}{AN} = \frac{0.2}{0.2} = 1$ N (1.25 pts)

Second Exercise (6 ½ points)

1) (0.5 pt)



2)

a) $V_{m(a)} > V_{mb}$ (0.5 pt)

b) $T = 4(\text{div}) \times 5 = 20 \text{ ms} \Rightarrow f = \frac{1}{T} = 50 \text{ Hz}$

$T \rightarrow 4 \text{ div} \rightarrow 2\pi$

$0{,}5 \text{ div} \rightarrow \varphi \quad \Rightarrow \varphi = \frac{\pi}{4}$

v is lags behind i or v_R by $\frac{\pi}{4}$rad. (1.25 pts)

c) $\omega = 2\pi f = 100\pi$ rad/s

$v = 7 \cos 100\pi t$.

$V_{Rm} = 2{,}5(\text{div}) \times 2 = 5$ V

$v_R = 5 \cos(100\pi t + \frac{\pi}{4})$ and $i = \frac{v_R}{R} = 0{,}1 \cos(100\pi t + \frac{\pi}{4})$ (1.75 pts)

d) $i = \frac{dq}{dt} \Rightarrow q = \int i \, dt \Rightarrow u_C = \frac{q}{C} = \frac{1}{C}\int i \, dt = \frac{1}{C}\int[0{,}1 \cos(100\pi t + \frac{\pi}{4})] \, dt = \frac{3{,}2\text{x}10^{-4}}{C}\cos(\omega t - \frac{\pi}{4})$ (0.5 pt)

e) $v_G = v_R + v_C = Ri + v_C$

$7 \cos 100\pi t = 5 \cos(100\pi t + \frac{\pi}{4}) + \frac{3{,}2\text{x}10^{-4}}{C}\cos(\omega t - \frac{\pi}{4})$

for t = 0: $7 = 5\frac{\sqrt{2}}{2} + \frac{3{,}2\text{x}10^{-4}}{C} \text{x} \frac{\sqrt{2}}{2} \Rightarrow C = 64 \times 10^{-6} \text{ F} = 64 \ \mu\text{F}$. (1 pt)

B- The phenomenon is the current resonance.

$f = f_o = \frac{1}{2\pi\sqrt{LC}} \Rightarrow C = \frac{1}{4\pi^2 f_o^2 L} = 64 \text{ x}10^{-6} \text{ F} = 64 \ \mu\text{F}$ (1 pt)

Third exercise **(6.5 points)**

1)

a) The emission of γ ray is due to the de-excitation of the daughter nucleus. (0.25 pt)

b) ${}^{131}_{53}I \rightarrow {}^{A}_{Z}Xe + {}^{0}_{-1}e + {}^{0}_{0}\overline{\nu} + {}^{0}_{0}\gamma$

The law of conservation of charge number gives: 53 = Z – 1 thus Z = 54.

The law of conservation of mass number gives: 131 = A thus A = 131. (0.75 pt)

c) $\lambda = \frac{\ln 2}{T} = \frac{0.693}{T_{(s)}} = 10^{-6}$ s. (0.5 pt)

$A_o = \lambda N_o \Rightarrow N_o = \frac{A_o}{\lambda} = 1.5\times10^{11}$ nuclei (0.5 pt)

d) t = 24 days = 3 T, and the number of disintegrated at the end of 3T is: $N\text{-}N_o$

$N = \frac{N_o}{2^3} \Rightarrow N - N_o = 1.31\times10^{11}$ nuclei (1 pt)

2)

a) (1 pt)

$E = \Delta m \times c^2 = (m_{before} - m_{after})c^2 = (0.00104)\times931.5 = 0.96876$ MeV$=0.96876\times1.6\times10^{-13} = 1.55\times10^{-13}$ J

b) $E_{ph} = \frac{hc}{\lambda} = 5.6\times10^{-14}$ J = 0.35 MeV (0.75 pt)

c) The principe of conservation of energy gives:

$E = K.E(Xe) + E_{ph} + E(\overline{\nu}) + K.E(\beta^-)$

$0.96876 = 0 + 0.35 + 0.07 + K.E(\beta^-) \Rightarrow K.E(\beta^-) = 0.55$ MeV $= 0,88\times10^{-13}$ J (0.5 pts)

d) The energy absorbed by the thyroid during the disintegration of a single nucleus is:

$E_1 = 0.55 + 0.35 = 0.9$ MeV

For t = 24 days, $E_2 = E_1 \times 1.31\times10^{11} = 1.18\times10^{11}$ MeV $= 1.89\times10^{-2}$ J

$D = \frac{E_2}{mass} = \frac{1.89\times10^{-2}}{0.04} = 0.47$ J/kg (1.25 pts)

Fourth exercise (7½points)

1) $v_G = v_R + v_B$; $v_R = Ri \Rightarrow i = \frac{v_R}{R}$; $v_B = L\frac{di}{dt} = \frac{L}{R}\frac{dv_R}{dt}$

$E = v_R + \frac{L}{R}\frac{dv_R}{dt}$ (0.5 pt)

2)

$v_R = V_o(1-e^{-\frac{t}{\tau}})$; $\frac{dv_R}{dt} = \frac{V_o}{\tau}e^{-\frac{t}{\tau}} \Rightarrow E = V_o(1-e^{-\frac{t}{\tau}}) + \frac{L}{R}x(\frac{V_o}{\tau}e^{-\frac{t}{\tau}})$

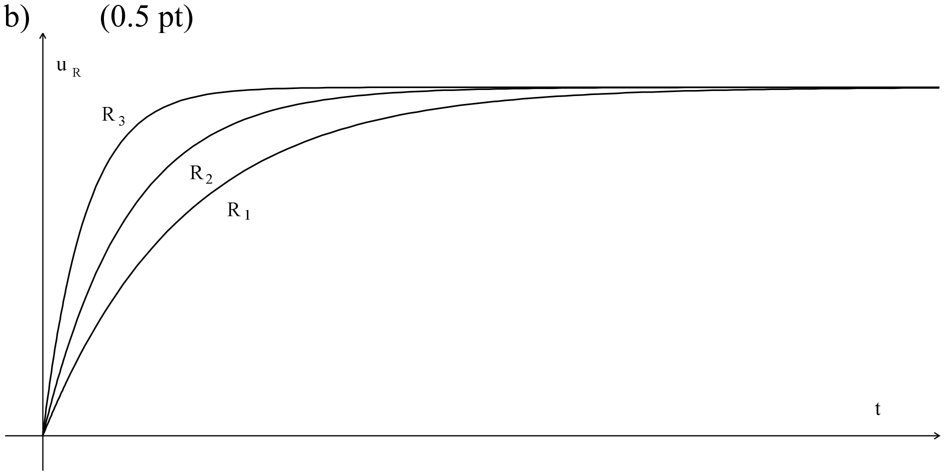
$E = V_o \times e^{-\frac{t}{\tau}}(\frac{L}{\tau \times R} - 1) + V_o \quad \forall\ t \Rightarrow$ (0.5 pt)

$E = V_o$; $\frac{L}{\tau \times R} - 1 = 0 \Rightarrow \tau = \frac{L}{R}$

3) The steady state is practically attained at the end of : $t = 5\tau$; $v_R \approx V_o$ (0.5 pt)

4) a)
i) $R_1 = 12\ \Omega$: $t_1 = 5\tau_1 = 0{,}267$ s; ii) $R_2 = 60\ \Omega$: $t_2 = 5\tau_2 = 0{,}053$ s ; iii) $R_3 = 600\ \Omega$: $t_3 = 5\tau_3 = 0{,}0053$ s
$V_o = E \quad \forall\ \tau$ (0.5 pt)

b) (0.5 pt)



c) When the resistor R increases, the steady state is attained more quickly. (0.25 pt)

B-

1) $v_G = v_R + v_C$; $v_R = Ri \Rightarrow i = \frac{dq}{dt} = C\frac{dv_C}{dt}$;

$E = RC\frac{dv_C}{dt} + v_C$ (0.5 pt)

2)

$$v_C = V_C(1-e^{-\frac{t}{\tau'}}); \ \frac{dv_C}{dt} = \frac{V_C}{\tau'}e^{-\frac{t}{\tau}} \Rightarrow E = V_C(1-e^{-\frac{t}{\tau'}}) + RCx(\frac{V_C}{\tau}e^{-\frac{t}{\tau}})$$

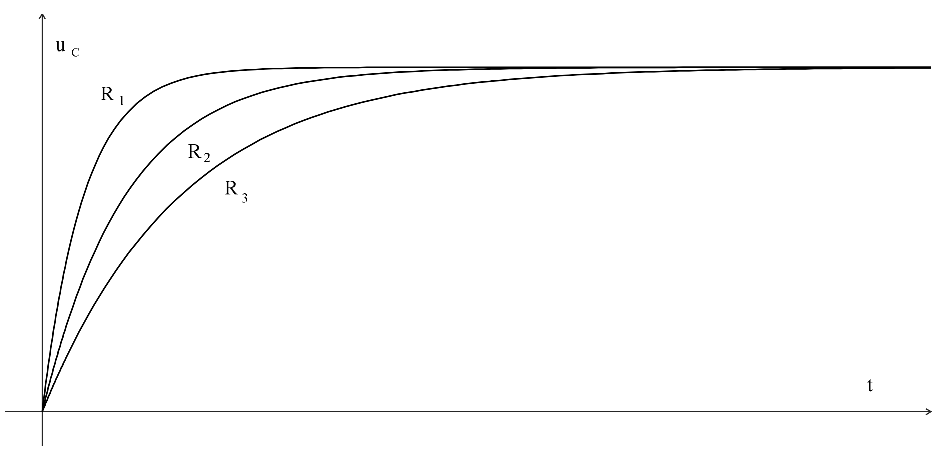
$$E = V_C \times e^{-\frac{t}{\tau'}}(\frac{RC}{\tau'} - 1) + V_C \quad \forall\ t \Rightarrow \qquad \text{(0.5 pt)}$$

$$E = V_C; \ \frac{RC}{\tau'} - 1 = 0 \ \Rightarrow \tau' = RC$$

3)
a) The steady state is practically attained at the end of: t' = 5τ'; $U_C \approx E$ (0.5 pt)

b) i) $R_1 = 12\ \Omega : t'_1 = 5\tau'_1 = 6 \times 10^{-5}$ s; ii) $R_2 = 60\ \Omega : t'_2 = 5\tau'_2 = 30 \times 10^{-5}$ s ;
iii) $R_3 = 600\ \Omega : t'_3 = 5\tau'_3 = 6 \times 10^{-6}$ s
$U_C = E \ \ \forall\ \tau$ (0.5 pt)

c) (0.5 pt)



d) When the resistor R increases, the steady state is attained more slowly.

C-
1) $T_o = 2\pi\sqrt{LC} = 5 \times 10^{-3}$ s = 5 ms. (0.75 pt)
2) T_o = 1(div) x S_h then S_h = 5 ms/div (0.25 pt)

3)
a) The oscillations are damped because the amplitude decreases with time. (0.5 pt)

b) T = 1,25(div) x 5 = 6,25 ms (0.25 pt)

4) $T > T_o$: the pseudo-period increases with the resistance of the circuit. (0.25 pt)

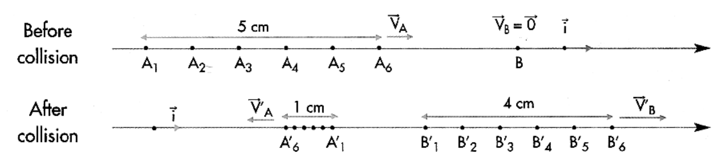
مسابقة في مادة الفيزياء
المدة: ثلاث ساعات

الاسم:
الرقم:

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

<u>First Exercise</u> (7 points) Collision and the laws of conservation

In order to study the collision between two bodies, we use a horizontal air table that is equipped with a launcher and two pucks (A) and (B) of respective masses $m_A = 0.2$ kg and $m_B = 0.3$ kg.



(A), thrown with the velocity $\vec{V}_A = V_A\,\vec{i}$, enters in a head-on collision with (B), initially at rest. (A) rebounds with the velocity $\vec{V}'_A = V'_A\,\vec{i}$, and (B) is projected with the velocity $\vec{V}'_B = V'_B\,\vec{i}$.
The figure below shows, in real dimensions, a part of the dot-prints, that register the positions of the centers of masses of (A) and (B), obtained when the time interval separating two successive dots is $\tau = 20$ ms.

A) Law related to the linear momentum

I) 1) Show, using the above dot-prints, that the velocities V_A, V'_A and V'_B are constant and calculate the algebraic values $\vec{V}_A$, $\vec{V}'_A$ and $\vec{V}'_B$.

2) Determine the linear momentums $\vec{P}_A$ and $\vec{P}'_A$ of the puck (A), before and after collision respectively and that $\vec{P}'_B$ of the puck (B) after collision.

3) Deduce the linear momentums, $\vec{P}$ and $\vec{P}'$, of the center of mass of the system [(A) and (B)] before and after collision respectively.

4) Compare $\vec{P}$ and $\vec{P}'$ then conclude.

II) 1) Name the forces acting on the system [(A), (B)].

2) What is the value of the resultant of these forces?

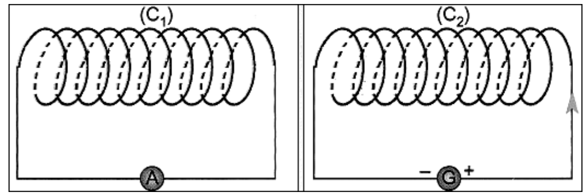
3) This result agrees with the conclusion of (I - 4). Why?

B) **Law related to the kinetic energy**

1) Calculate the kinetic energy of the system [(A), (B)] before and after collision.

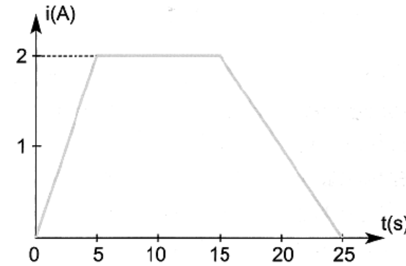
2) Deduce the nature of this collision.

Second Exercise (7 points) The transformer



The purpose of this exercise is to study the principle of functioning of an ideal transformer and its role.
Consider two coils, (C_1) of 1000 turns and (C_2) of 500 turns; the surface area of each of the turns of (C_1) and (C_2) is 100 cm^2.

A) Principle of functioning



The coil (C_1) is connected to a sensitive ammeter (A) and the coil (C_2) is connected across a generator thus forming two closed circuits. (Fig. 1)
The coil (C_2) carries then a current i that varies with time as shown in the graph of figure 2. As a resultat, (C_2) produces, through (C_1), a magnetic field $\vec{B}$ supposed uniform of magnitude $B = 2 \times 10^{-3}\, i$ (B in T and i in A).

1) Give the expression of the magnetic flux crossing (C_1) in terms of i.
2) Give the expression of e, the e.m.f. induced in (C_1).
3) Find the values of e for $0s \leq t \leq 25s$.
4) Trace the graph giving the variation of e as a function of time t for $0s \leq t \leq 25s$.
   Scale: on the time axis: 1cm → 5 s and on the axis of e: 1cm → 4 mV.
5) Draw again figure 1 and indicate, using Lenz's law, the direction of the current induced in (C_1), i the interval of time $0s \leq t \leq 5s$.

B) Role

The coils (C_1) and (C_2), disconnected from the preceding circuit, are used to construct an ideal transformer (T) using a convenient iron core. (C_1) and (C_2) are respectively the primary and the secondary.

1) We connect across (C_1) a sinusoidal alternating voltage of effective value $V_1 = 220$ V. A voltmeter, in AC mode connected across (C_2), reads a value V_2.
   a) Give a simplified diagram of (T).
   b) Does (T) act as a step-up or a step-down transformer? Justify your answer and calculate V_2.

2) A lamp, connected across the terminals of (C_2), carries a current of effective value $I_2 = 1$ A. Calculate the effective current I_1 carried by the coil (C_1).

Third exercise (6 points) **Nuclear fission**

Given: mass of a neutron: $m_n = 1.00866$ u

mass of a 235 uranium nucleus : $m(^{235}U) = 234.99342$ u

mass an iodine nucleus A: $m(^{A}I) = 138.89700$ u

mass of a 94 yttrium nucleus 94: $m(^{94}Y) = 93.89014$ u

$1\text{ u} = 1.66054\text{x}10^{27}\text{ kg} = 931.5\text{ MeV/c}^2$.

$1\text{ eV} = 1.6\text{x }10^{-19}\text{ J}$

In a nuclear power station, the fissionable fuel is made up of 235 uranium nuclei. The nuclei that undergo a nuclear reaction must have been bombarded with a thermal neutron.

1) One of the possible reactions that the uranium 235 undergoes has the form of:

$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{A}_{53}I + ^{92}_{Z}Y + 3^{1}_{0}n + \gamma$.

a) The 235 uranium nucleus is fissionable. Why?

b) The nuclear reaction that the 235 uranium nucleus undergoes is said to be provoked. A provoked reaction is one of two types of nuclear reactions. Name the other type and tell how it can be distinguished from the other.

c) Determine the values of A and Z specifying the supporting laws.

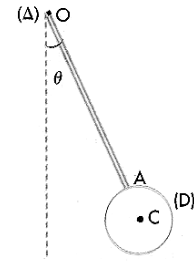
d) Calculate the energy liberated during the preceding reaction.

In what form does this liberated energy appear?

2) The nuclear power station converts 30% of the liberated energy into electrical energy.

Calculate the mass of 235 uranium consumed by the power station during one day if the electric power it supplies is $6\text{x}10^8$ W.

<u>Fourth exercise</u> (7½points) Clock pendulum



A clock pendulum may be represented by a homogeneous disk (D), of center C, fixed at the extremity A of a homogeneous rod OA.

A) Characteristics of the motion of the clock pendulum

In this part, friction is neglected.

The clock pendulum is a compound pendulum that may oscillate around a horizontal axis (Δ) passing through O (figure). During oscillations of small amplitude θ_m of proper period T_o, the pendulum passes through the equilibrium position with an angular speed of 0.3 rd/s.

Given: OA = 100 cm; g = 10 m/s^2; radius of the disk AC = 10 cm;

π = 3.14; mass of the rod = 0.5 kg; mass of the disk = 1 kg;

moment of inertia of the clock pendulum about (Δ) is: I = 1.38 kg.m^2.

1) a) Specify the equilibrium position of the pendulum.

b) Calculate the angular momentum of the pendulum while passing through the equilibrium position.

c) Determine the sum of the moments of the forces acting on the pendulum while passing through the equilibrium position.

d) Apply the theorem of angular momentum to determine the value of the angular acceleration of the pendulum while passing through the equilibrium position.

Deduce that the maximum angular speed of the pendulum is 0.3 rd/s.

2) a) Show that the center of mass G of the pendulum is at a distance OG = 90 cm from O.

b) Determine the mechanical energy of the system [pendulum, Earth) for any angular elongation θ. Take the horizontal plane passing through G_o, the center of mass of the pendulum in its equilibrium position, as a gravitational potential energy reference.

c) This mechanical energy is conserved. Why? Deduce the value of θ_m.

d) Determine the differential equation that describes the periodic motion of the pendulum. Calculate the value of T_o.

B) Driving the oscillations of the clock pendulum

In fact, the pendulum performs oscillations of pseudo-period T. If the motion of the pendulum is not driven, the oscillations tend to be damped.

1) Is the pseudo-period T greater, equal or smaller than T_o?
2) Why do the oscillations of the pendulum tend to be damped?
3) The driving of the oscillations is done by the very slow descending of a solid (S) of mass M = 2 kg. Every week, (S) descends by a height h = 1.5 m and is raised back to its initial position within 10 seconds by means of an electric motor.

Calculate the average power of the electric motor

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This exam is formed of four obligatory exercises in four pages
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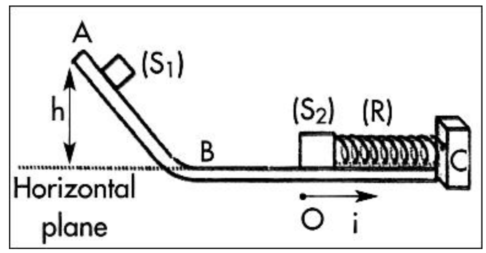
<u>First Exercise</u> (6 ½ points) Determination of the force constant of a spring

In order to determine the force constant k of a spring (R) of un-jointed turns, we consider:

- a frictionless track ABC found in a vertical plane,
- a spring (R) having one end fixed to a support C and its other end connected to a solid (S_2) of mass m_2 of negligible dimensions.
- a solid (S_1) of mass $m_1 = 0.1$ kg and of negligible dimensions held at A at height h = 0.8 m above the horizontal plane containing BC.



The horizontal plane containing BC is taken as the gravitational potential energy reference. Take $g = 10\ m/s^2$.

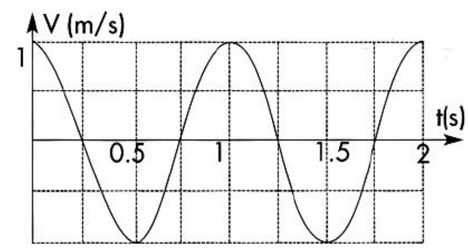
1- (S_1), released from rest at A, reaches (S_2) with a velocity $\vec{V}_1$. Show that the magnitude of $\vec{V}_1$ is $V_1 = 4$ m/s.

2- (S_1), collides with (S_2) and sticks to it, thus forming a particle (S). Determine, in terms of m_2, the expression of V_o the magnitude of the velocity $\vec{V}_o$ of (S) just after the impact.

3- The system [(S), (R)] forms a horizontal elastic pendulum, (S) oscillating around its equilibrium position at O.

a- Determine the differential equation that describes the motion of the oscillator. Deduce the expression of its proper period T_o.

b- Figure (2) represents the variation of the algebraic value of the velocity of (S) as a function of time.
The origin of time corresponds to the instant when the velocity of (S) is $\vec{V}_o$.



i- Give the value V_o of $\vec{V}_o$.
ii- Deduce the value of m_2.
iii- Give the value of T_o.
iv- Calculate k.

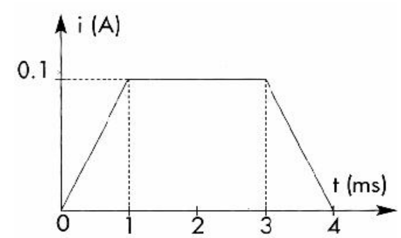
<u>Second Exercise</u> (7 points) Role and characteristics of a coil

Consider a coil (B) that bears the following indications: L = 65 mH and r = 20 Ω.

A- Role of a coil

In order to show the role of a coil, we connect the coil across a generator G_1 .

The variation of the current i carried by the coil as a function of time is represented in figure (1).



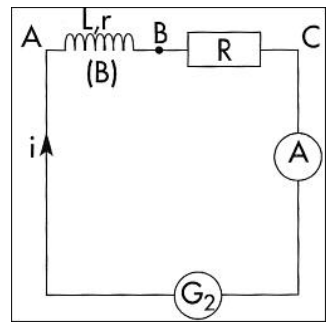
1- a- Give, in terms of L and i, the literal expression of the induced electromotive force e produced across the coil.

b- Determine the value of e in each of the following time intervals: [0; 1ms], [1 ms; 3 ms], [3 ms; 4 ms].

2- In what time interval would the coil act as a generator? Justify your answer.

B- Characteristics of the coil

In order to verify the values of L and r, we perform the two following experiments:



I- **First experiment:** The coil (B), a resistor of resistance R = 20 Ω and an ammeter of negligible resistance are connected in series across a generator (G_2) of electromotive force E = 4 V and of negligible internal resistance (figure 2). After a certain time, the ammeter reads I = 0.1 A. Deduce the value of r.

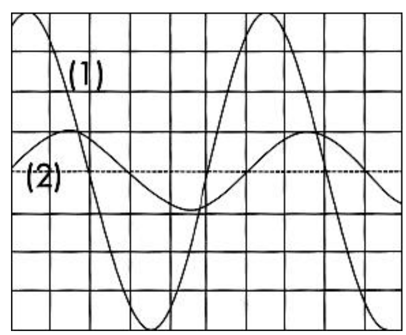
II- **Second experiment:** The ammeter is removed and G_2 is replaced by a generator G_3 delivering an alternating sinusoidal voltage.

1- Redraw figure (2) and show on it the connections of an oscilloscope that allows to display, on the channel (1), the voltage v_g across the generator and, on channel (2), the voltage v_R across the resistor.

2- The voltages displayed on the oscilloscope are represented on figure (3).

Given: vertical sensitivity on both channels: 2 V/division.

horizontal sensitivity: 1 ms/division.



a- The waveform (1) represents v_g. Why?

b- The voltage across the generator has the form:

$v_g = V_m\cos\omega t$. Determine U_m and ω.

c- Determine the phase difference φ between v_g and v_R.

d- Determine the expression of the instantaneous current i carried by the circuit.

e- Using the law of addition of voltages at an instant t, and using a particular value of t, deduce the value of the inductance L.

III- Compare the values found for r and L, with those indicated on the coil.

<u>Third exercise</u> (6 ½ points) The two aspects of light

To show evidence of the two aspects of light, we perform the two following experiments:

A- First experiment

We cover a metallic plate by a thin layer of cesium whose threshold wavelength is $\lambda_o = 670$ nm. Then we illuminate it with a monochromatic radiation of wavelength in vacuum $\lambda = 480$ nm. A convenient apparatus is placed near the plate in order to detect the electrons emitted by the illuminated plate.

1- This emission of electrons by the plate shows evidence of an effect. What is that effect?

2- What does the term "threshold wavelength" represent?

3- Calculate, in J and eV, the extraction energy (work function) of the cesium layer.

4- What is the form of energy carried by an electron emitted by the plate? Give the maximum value of this energy.

Given: Planck's constant: $h = 6.6 \times 10^{-34}$ J.s;
speed of light in vacuum: $c = 3 \times 10^{8}$ m/s;
1 eV= 1.6×10^{-19} J.

B- Second experiment

The two thin slits of Young's apparatus, separated by a distance a, are illuminated with a laser light whose wavelength in vacuum is $\lambda = 480$ nm. The distance between the screen of observation and the plane of the slits is D=2m.

1- Draw a diagram of the apparatus and show on it the region of the interference.

2- The conditions to obtain the phenomenon of interference on the screen are satisfied. Why?

3- Due to what is the phenomenon of interference?

4- **a-** Describe the aspect of the region of interference observed on the screen.

b- We count 11 bright fringes. The distance between the centers of the farthest fringes is l = 9.5 mm. What do we call the distance between the centers of two consecutive bright fringes? Calculate its value and deduce the value of a.

C- The two experiments show evidence of two aspects of light. Specify the aspect shown by each experiment.

<u>Fourth exercise</u> (7½points) Radioactivity of polonium 210

In order to study the radioactivity of polonium $^{210}_{84}Po$ which is an α emitter, we take a sample of polonium 210 containing N_o nuclei at the instant $t_o = 0$.

A- Determination of the half-life (period)

We measure, at successive instants, the number N of the remaining nuclei. We calculate the ratio N/N_o and the result is tabulated as in the following table:

t (in days)	0	50	100	150	200	250	300
N / N_o	1	0.78	0.61	0.47	0.37	0.29	0.22
$-\ln (N / N_o)$	0	0.25				1.24	

1- Draw again the above table and complete it by calculating at each instant $-\ln (N/N_o)$.
2- Trace the curve representing the variation of $f(t) = -\ln (N/N_o)$, as a function of time, using the scale: 1 cm on the abscissa represents 25 days; 1 cm on the ordinate represents 0.1.
3- a- Knowing that $Ln(N/N_o) = -\lambda t$, determine graphically the value of the radioactive constant λ of polonium 210.
b- Deduce the half-life of polonium 210.

B- Activity of polonium 210

1- Define the activity of a radioactive sample.
2- Give the expression of the activity A_o of the sample at the instant $t_o = 0$, in terms of λ and N_o. Calculate its value for $N_o = 5 \times 10^{18}$.
3- Give the expression, in terms of t, of the activity A of the sample.
4- Calculate the activity A:
a- at the instant t = 90 days.
b- When t increases indefinitely.

C- Energy liberated by the disintegration of polonium 210

1- The disintegration of a nucleus of polonium produces a daughter nucleus which is an isotope of lead $^{A}_{Z}Pb$. Determine A and Z.
2- Calculate, in MeV, the energy liberated by the disintegration of one nucleus of polonium 210.
3- The disintegration of a polonium nucleus may take place with or without the emission of a photon. The energy of an emitted photon is 2.20 MeV. Knowing that the daughter nucleus has a negligible velocity, determine in each case the kinetic energy of the emitted α particle.
4- The sample is put in an aluminum container. Thus, the α particles are stopped by the container whereas the photons are not.
Knowing that half of the disintegrations are accompanied by a γ emission, determine the power transferred to the aluminum container at the instant t = 90 days.

Numerical data:

Mass of a polonium 210 nucleus: 209.9828 u
Mass of lead (Pb) nucleus: 205.9745 u
Mass of an α particle: 4.0015 u
$1 u = 1.66 \times 10^{-27} kg = 931.5 MeV/c^2$.

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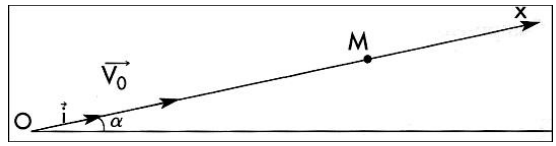
<u>First Exercise</u> (6 points) Graphical study of energy exchange

Consider an inclined plane that makes an angle α with the horizontal ($\sin \alpha = 0.2$) and a marble (B) of mass m = 100 g, taken as a particle. We intend to study the energy exchange between the system (marble, Earth) and the surroundings.



To do that, the marble (B) is given, at the instant $t_o = 0$, the velocity $\vec{V}_o = V_o \vec{i}$ along the line of greatest slope OX. Given $V_o = 4$ m.s^{-1} and g = 10 m/s^2.

The horizontal plane through point O is taken as the gravitational potential energy reference.

A- The forces of friction are supposed negligible.

1- Determine the value of the mechanical energy M.E of the system (marble, Earth).

2- At the instant t, the marble passes through a point M of abscissa OM = x. Determine, as a function of x, the expression of the gravitational potential energy $P.E_g$ of the system (marble, Earth) when the marble passes through M.

3-a) Trace, on the same system of axes, the curves representing the variations of the energies M.E and $P.E_g$ as a function of x.

Scale: - on the axis of abscissas: 1 cm represents 1 m;
- on the axis of energy: 1 cm represents 0.2 J.

b) Determine, using the graph, the speed of the marble for x = 3 m.

c) Determine, using the graph, the value of x_m of x for which the speed of (B) is zero.

B-1. In reality, the speed of the marble becomes zero at a point of abscissa x = 3 m. The forces of friction are no longer negligible. Calculate then the work done by the forces of friction between x = 0 and x = 3 m.

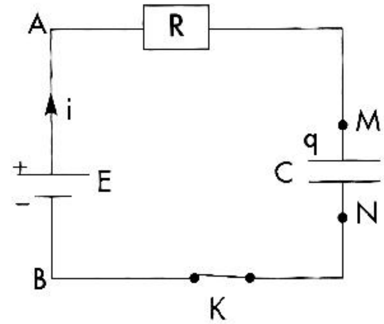
2. The system (marble, Earth) thus exchanges energy with its surroundings. In what form and by how much?

Second Exercise (7 points) Response of an RC series circuit

The object of this exercise is to distinguish the response of an RC series circuit when we apply across its terminals a constant voltage, from its response when it carries a constant current.

A- Case of a constant voltage

The circuit of the adjacent figure allows us to charge the capacitor of capacitance C = 10 μF through a resistor of resistance R = 100 kΩ, under a constant voltage E = 9V. Take the instant t = 0 the instant when the switch K is closed.



1- Denote by $u_C = u_{MN}$, the instantaneous value of the voltage across the terminals of the capacitor.

a- Show that the differential equation in u_C is of the form:

$$u_C + RC\frac{du_C}{dt} = E$$

b- Knowing that the solution of this equation has the form: $u_C = A(1 - e^{-\frac{t}{\tau}})$ determine A and τ.

c-Trace the shape of the curve that gives the variation of u_C as a function of time.

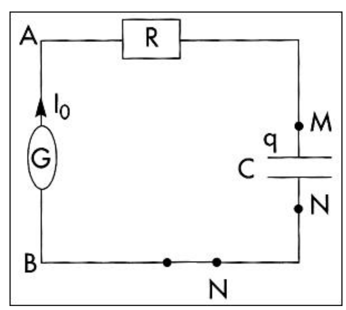
2- a- Determine the expression of the voltage $u_R = u_{AM}$ as a function of time.

b- Trace, on the same system of axes, the shape of the curve giving the variation of u_R as a function of time.

3- What is the value of the interval if time t_A at the end of which u_C becomes practically 9V?

B- Case of a constant current

The preceding capacitor being discharged is to be recharged through the same resistor by a generator giving a constant current I_o = 0.1 mA.



1-a- Show that the charge q can be written, in SI, in the form $q = 10^4$ x t.

b- The voltage $u_R = u_{AM}$ across the resistor remains constant. Determine its value.

c- Trace the shape of the graph representing u_R.

2-a- Determine the expression of the voltage $u_C = u_{MN}$ as a function of time.

b- Trace the shape of the graph representing u_C.

c- Determine the time interval t_B needed for the voltage u_C to attain the value 9 V.

C- Conclusions

1- Using the preceding graphs, specify the case where the voltage across the capacitor attains, in the steady state, a limiting value.

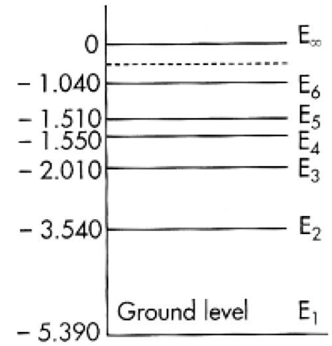
2- A camera is equipped with a flash that is formed of the preceding RC circuit. We intend to take the largest number of photos in a given time interval. To do so we have to charge the capacitor. Which one of the two preceding charging modes is more convenient? Why?

Third exercise (6 ½ points) The isotope $^{7}_{3}Li$ of lithium

As all the other chemical elements, the isotope $^{7}_{3}Li$ has properties that distinguish it from other chemical elements.

The object of this exercise is to show evidence of some properties of the isotope $^{7}_{3}Li$.

A- Emission spectrum of the lithium atom



The adjacent figure represents the energy levels of the lithium atom.

1-Calculate, in joule, the energy (E_1) of the atom when it is in the ground state and (E_5) when it is in the fifth state.

2-During the downward transition (de-excitation) from different energy levels to the ground level, the lithium atom emits some radiations.

a- Calculate the highest and the lowest frequency of the emitted radiations.

b- The corresponding emission spectrum is discontinuous. Why?

3- The lithium atom, being in the ground state, captures:

a- a photon whose associated radiation has a wavelength of λ = 319.9 nm. Show that the atom absorbs this photon. In what level would it be?

b- a photon of energy 6.02 eV. An electron is thus liberated. Calculate, in eV, the kinetic energy of that electron.

B- Nuclear reaction

A nucleus $^{A}_{Z}X$, at rest, is bombarded by a proton carrying an energy of 0.65 MeV; we obtain two α particles.

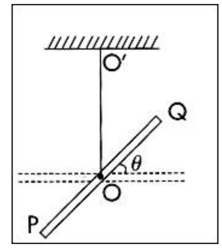
1- Is this nuclear reaction spontaneous or provoked? Justify your answer.
2- Determine the values of Z and A by applying the convenient conservation laws. Identify the nucleus X.
3- Calculate the mass defect due to this reaction and deduce the corresponding energy liberated.
4- Knowing that the two obtained α particles have the same kinetic energy E. Calculate E.

Given: $h = 6.62 \times 10^{-34}$ J x s; $c = 3 \times 10^{8}$ m.s^{-1}; 1 eV = 1.6×10^{-19} J;
1 u = 931.5 MeV/c^2;
mass of the nucleus of lithium: m (Li) = 7.01435 u;
mass of the a particle: m(α) = 4.00150 u;
mass of a proton: m_p = 1.00727 u.

Fourth exercise (7½points) **Moment of inertia of a rigid rod**

The object of this exercise is to determine, by two methods, the moment of inertia I_o of a rigid and homogeneous rod PQ of negligible cross-section, about an axis perpendicular to it through its mid-point O. In order to do that we consider the rod PQ of mass M = 375 g and of length l = 20 cm. We neglect all frictions. Take $g = 10\ m/s^2$ and $\pi^2 = 10$.

A- Case of a torsion pendulum

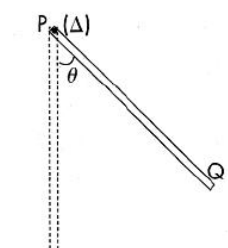


The rod PQ, being horizontal, its mid point O is fixed to a vertical torsion wire OO' whose torsion constant is $C = 5 \times 10^{-4}$ SI; the other end O' of the wire is fixed to a support. We thus obtain a torsion pendulum. The rod PQ, in the horizontal plane, is shifted from its equilibrium position around the vertical axis OO' by $\theta_m = 0.1$ rad in a direction taken as positive and is released from rest at the instant $t_o = 0$.
PQ thus oscillates around OO' in the horizontal plane around its equilibrium position.
At any instant t during its motion, the position of the rod is defined by its angular elongation θ with its equilibrium position.

1- a- Write, at the instant t, the expression of the mechanical energy M.E of the pendulum as a function of I_o, C, θ and the angular speed θ'.
   b- Calculate the value of M.E.
   c- Derive the second order differential equation that describes the motion of the pendulum.
   d- Prove that the expression of the proper period T_o can be written as $T_o = 2\pi\sqrt{\frac{I_o}{C}}$.

2- We measure the time t_1 for 10 oscillations; we find $t_1 = 100$ s. Calculate I_o.

B- Case of a compound pendulum



The rod PQ, alone, is now free to rotate in the vertical plane around a horizontal axis (Δ) passing through its extremity P.
The rod PQ is shifted by an angle $\theta_m = 0.1$ rad from its equilibrium position and is then released from rest at the instant $t_o = 0$. The rod PQ thus oscillates around its equilibrium position.
At any instant t, the position of the rod is defined by the angular elongation θ with its equilibrium position.
The horizontal plane containing (Δ) is taken as the gravitational potential energy reference.

1-a- Write the expression of the mechanical energy M.E of the system (rod, Earth) at any instant t as a function of M, g, l, θ, the angular speed and the moment of inertia I_1 of the rod about the axis (Δ).
   b- Calculate the value of M.E.
   c- Derive the second order differential equation that describes the motion of the rod.
   d- Prove that the expression for the proper period T_o' may be written as: $T_o' = 2\pi\sqrt{\frac{2I_1}{Mgl}}$

2- We measure the time t2 of 10 oscillations of the rod. We find $t_2 = 7.3$ s. Calculate I_1.

3- Knowing that $I_1 = I_o + \frac{Ml^2}{4}$, find again the value of I_o.

Take, for $\theta \leq 0.2$ rad, $\sin\theta = \theta$ rad and $(1-\cos\theta) = \frac{\theta^2}{2}$ (θ in rad).

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المدة : ثلاث ساعات | الرقم :

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First Exercise (7 points) Suspension system in a car

Certain tracks present periodic variations of its level .A car moves in a uniform motion on such a track that has regularly spaced bumps. The distance between two consecutive bumps is d and the speed of the car is V.
In order to study the effect of the bumps on the car , we consider the car and the suspension system as a mechanical oscillator (elastic pendulum) whose oscillation takes a time T.

A- Study of T

1. **Theoretical study**

Consider a horizontal elastic pendulum formed of a solid of mass m attached to a spring of constant k and of negligible mass; the other end of the spring is fixed to a support. The forces of friction are supposed to be negligible and the solid of center of mass G can move on a horizontal axis Ox.
When the solid is at rest , G coincides with the point O taken as origin of abscissa.
The solid is pulled from its equilibrium position by a distance x_m, and then released without initial velocity at the instant $t_o = 0$. The horizontal plane passing through G is taken as a gravitational potential energy reference
At any instant t , the abscissa of G is x and the algebraic measure of its velocity is v.

a) Starting from the expression of the mechanical energy of the system {pendulum -Earth}, determine the second order differential equation that characterizes the motion of the solid.
b) Deduce the expression of its proper period T_o .

2. **Experimental study**

In order to show the effects of the mass m of the solid and the constant k of the spring on the duration of one oscillation of a horizontal elastic pendulum, we use four springs of different stiffnesses and four solids of different masses.
In each experiment , we measure the time Δt for 10 oscillations using a stopwatch .

a) Effect of the mass m of the solid

In a first experiment , the four solids are connected separately from the free end of the spring whose stiffness is k = 10 N/m. The values of Δt are shown in the following table:

m (g)	50	100	150	200
Δt (s)	4.5	6.3	7.7	8.9

Determine, using the table, the ratio T^2 / m. Conclude.

b) Effect of the stiffness k of the spring.

In a second experiment , the solid of mass m = 100 g is connected successively from the free end of each of the four springs. The new values of Δt are shown in the following table :

k (N/m)	10	20	30	40
Δt (s)	6.3	4.5	3.7	3.2

Determine, using the table , the values of the product $T^2 \times k$. Conclude.

c) Expression of T

Deduce that T may be written in the form $T = A\sqrt{\frac{m}{k}}$ where A is a constant.

B) Oscillations of the car

1) The car ,with the driver alone ,form a mechanical oscillator whose proper period is around 1s .It moves with a speed V = 36 km / h on a path having equally spaced bumps .The distance between two consecutive bumps is d = 10 m. The car enters then in resonance.
   a) Specify the exciter and the resonator.
   b) Explain why does the car enter resonance.
   c) How can the driver avoid this resonance?
2)The driver, with four passengers , drives his car on the same path with the same speed of 36km/h. Would the car enter in resonance? Justify your answer.

<u>Second Exercise</u> (6 points) <u>Energy levels of the hydrogen atom</u>

The energies of the different energy levels of the hydrogen atom are given by the relation:

$$E_n = -\frac{13.6}{n^2} \quad \text{(in eV)} \qquad \text{where } n \text{ is a positive whole number.}$$

Given :
Planck's constant : $h = 6.63 \times 10^{-34}$ J.s ; $1 \text{ eV} = 1.60 \times 10^{-19}$ J ;
Speed of light in vacuum : $c = 3 \times 10^8$ m/s ; $1 \text{ nm} = 10^{-9}$ m.

A- Energy of the hydrogen atom

1) The energies of the atom are quantized. Justify this using the expression of E_n .
2) Determine the energy of the hydrogen atom when it is:
   a) in the fundamental state .
   b) in the second excited state.
3) Give the name of the state for which the energy of the atom is zero.

B - Spectrum of the hydrogen atom

1 - Emission spectrum

The Balmer's series of the hydrogen atom is the set of the radiations corresponding to the downward transitions to the level of n = 2.

The values of the wavelengths in vacuum of the visible radiations of this series are :

411 nm ; 435 nm ; 487 nm ; 658 nm.

a) Specify, with justification, the wavelength λ_1 of the visible radiation carrying the greatest energy.
b) Determine the initial level of the transition giving the radiation of wavelength λ_1 .
c) Deduce the three initial levels corresponding to the emission of the other visible radiations.

2 - Absorption spectrum

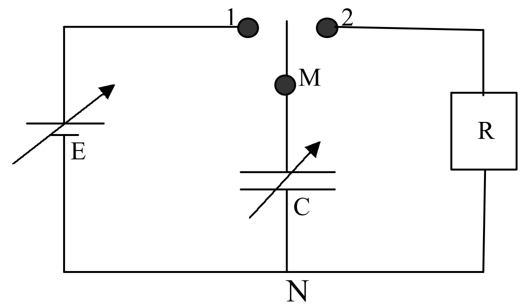
A beam of Sunlight crosses a gas formed mainly of hydrogen . The study of the absorption spectrum reveals the presence of dark spectral lines.

Give , with justification, the number of these lines and their corresponding wavelengths.

C - Interaction photon - hydrogen atom

1) We send on the hydrogen atom , being in the fundamental state, separately, two photons of respective energies 3.4 eV and 10.2 eV .
   Specify, with justification , the photon that is absorbed .
2) A hydrogen atom found in its fundamental state absorbs a photon of energy 14.6 eV.The electron is thus ejected.
   a. Justify the ejection of the electron.
   b. Calculate, in eV, the kinetic energy of the ejected electron.

Third Exercise (7 points) Saving life capacitor



A heart suffering from disordered muscular contractions is treated by applying electric shocks using a convenient apparatus.

In order to study the functioning of this apparatus , we use a source of DC voltage of adjustable value E , a double switch , a resistor of resistance R and a capacitor (initially neutral) of adjustable capacitance C. We connect the circuit represented in the adjacent figure.

A. Theoretical study

1. The switch is turned to position (1).

a) Give the name of the physical phenomenon that takes place in the capacitor.

b) Specify the values of the current in the circuit and the voltage u_{MN} after few seconds.

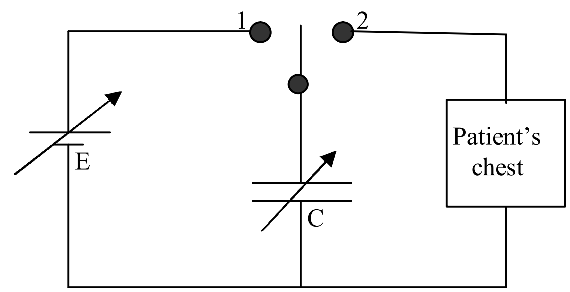
2. The switch is now turned to position (2) at an instant taken as $t_o = 0$.

a) Derive , at the instant t , the differential equation giving the variation of the voltage $u_C = u_{MN}$ as a function of time.

b) The expression $u_C = A\,e^{-\frac{t}{\tau}}$, where A and τ are constants , is a solution of that equation. Determine the expressions of A and τ in terms of E, R and C.

c) Derive the expression giving the current i during the discharging as a function of time.

B. Using the apparatus



The energy needed to save the life of a patient during an electric shock is 360 J. This energy is supplied by discharging the capacitor through the patient's chest (ribcage) considered as a resistor of resistance 50 Ω during a time t_1 that can be controlled by the switch.

The capacitance of the capacitor is adjusted on the value C = 1 millifarad and is charged under the voltage E = 1810 V.

1) Determine the energy stored in the capacitor at the end of the charging process.

2) The discharging starts at the instant $t_o = 0$ .At the instant t_1 , the energy delivered to the patient amounts to 360J ,the switch is then opened .

a) Calculate the energy that remains in the capacitor at the instant t_1.

b) Using the results of the above theoretical study; determine:

i) the value of t_1 .

ii) the current at the end of the electric shock.

Fourth Exercise (7½ points) Coil in an electric circuit

Consider a generator of DC voltage (E ; r), a coil (L ; R_1), a resistor of resistance $R_2 = 100\ \Omega$, two lamps (C_1) and (C_2), an oscilloscope and a switch k.

A - Qualitative study

In order to study the role of a coil in an electric circuit, we connect up the circuit that is represented in figure 1.

We close k..One of the two lamps gives bright light first. Explain the phenomenon responsible for the delay in the brightness between the two lamps.

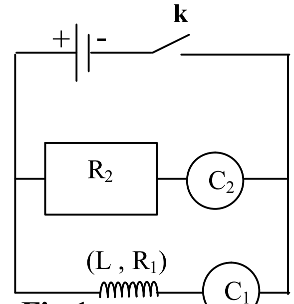


Fig.1

B- Quantitative study

In order to determine the characteristics (L ; R_1) of the coil and (E, r) of the generator, we connect up the circuit represented in figure 2.

Take $R = R_1 + R_2 + r$ the total resistance of the circuit.

I – Analytical study of the growth of the current

We close the switch k at the instant $t_0 = 0$.

At any instant t, the circuit carries an electric current i.

1) Applying the law of addition of voltages, derive the first order differential equation of the variation of the current as a function of time.

2) The solution of this differential equation is of the form:
$i = a + be^{-t/\tau}$ where a, b and τ are constants.
Determine the expressions of a, b and τ in terms of R, E and L.

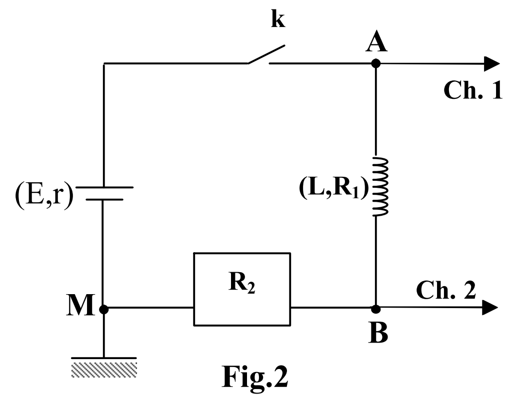


Fig.2

3) Deduce that $i = \frac{E}{R}(1 - e^{-t/\tau})$

II- Determination of the values of E, r, R_1 and L

An oscilloscope, connected as shown in figure 2, allows us to display the variation of the two voltages represented in the curves (a) and (b) of figure 3.

1) a) Specify the voltage u_1 displayed on channel 1.
b) Determine the expression of u_1 as a function of t.

2) a- Specify the voltage u_2 displayed on channel 2.
b- Give the expression of u_2 as a function of t.

3) a- Give the values of u_1 and u_2 at the instant $t_0 = 0$.
b- Deduce the value of E.

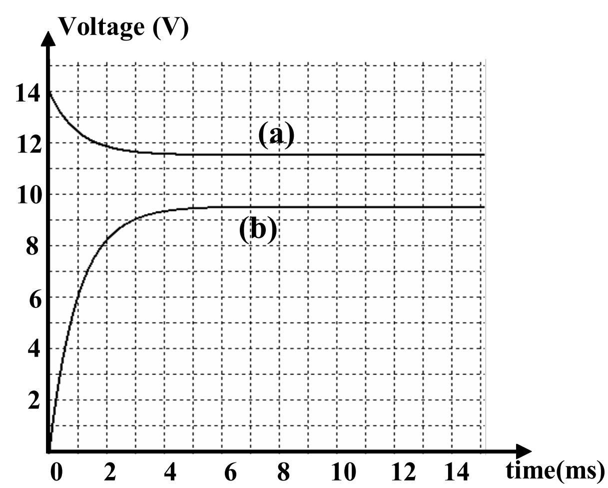


Fig.3

4) Using the curves (a) and (b), determine :
a- the value of τ.
b- the values of r and R_1.

5) Calculate L .

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First exercise :

A) 1 – a) $M.E = \frac{1}{2}kx^2 + \frac{1}{2}mv^2$;

No friction the M.E is conserved $\Rightarrow \frac{dM.E}{dt} = 0$

$\Rightarrow kxv + mvx'' = 0 \Rightarrow x'' + \frac{k}{m}x = 0$

b) $\omega_0^2 = \frac{k}{m} \Rightarrow \omega_0 = \sqrt{\frac{k}{m}}$; $T_0 = \frac{2\pi}{\omega_0} \Rightarrow T_0 = 2\pi\sqrt{\frac{m}{k}}$

2 – a) $\frac{T^2}{m} = 4$ (S.I) $\Rightarrow \frac{T^2}{m} = \text{const.}$

b) $T^2 \times k = 4$ (S.I) $\Rightarrow T^2 \times k = \text{const}$

c) T is proportional $\sqrt{m}$ to and T is inversely proportional to $\sqrt{k}$

$\Rightarrow T = A\sqrt{\frac{m}{k}}$

B) 1 – a) Exciter is the bumps and the resonator is the car

b) The car is submitted to pulses periodically of period :

$T' = \frac{d}{V} = 1\text{sec}$; $T_0 = 1$ sec ; $T' = T_0 \Rightarrow$ Resonance

b) Mass increases $\Rightarrow T_0$ increases $\Rightarrow T_0 \neq T'$

Second exercise :

A) 1 – E_1 = -13.6 eV ; E_2 = -3.4 eV ; E_3 = -1.51 eV ; E_∞ = 0

⇒ The values of energies are discontinous.

2 – a) $E_{fund.}$ corresponding to n = 1 ⇒ $E_{fund.}$ = -13.6 eV

b) Second excited state corresponding to n = 3 ⇒ E_3 = -1.51 eV.

3 – Ionize state

B) 1 – a) E = $\frac{hc}{\lambda}$ or E is inversely prop. to λ ⇒ λ_1= 411 nm

b) $\frac{hc}{\lambda} = E_i - E_f \Rightarrow \frac{hc}{\lambda} = (\frac{-13.6}{n^2} + \frac{13.6}{4})\ 1.6 \times 10^{-19}$ J ;

For $\lambda = \lambda_1$; n = 6

c) The other three levels is : n = 5 ; n = 4 ; n = 3 to n = 2

2 – The dark lines of the absorption spectrum corresponding to the bright lines of same wavelength of the emission spectrum .

We have 4 bright lines ⇒ we have 4 dark lines of wavelengths :

411 nm ; 487 nm ; 658 nm

C) 1 - $-13.6 + 3.4 = -10.2 = \frac{-13.6}{n^2} \Rightarrow n = 1.15$;

not a whole no ⇒ not absorbed

$-13.6 + 10.2 = -3.4 = \frac{-13.6}{n^2} \Rightarrow$ n = 2 (whole no) ⇒ absorbed

2 - a) The energy of the photon is greater than the ionization energy

b) K.E = -13.6 + 14.6 = 1 eV

Third exercise :

A) 1 – a) Charging of the capacitor

b) $i = 0$; $u_C = E$.

2 – a) $u_C = Ri = -RC\frac{du_C}{dt}$

$\Rightarrow u_C + RC\frac{du_C}{dt} = 0$

b) At t = 0 ; $u_C = A = E$; Derive u_C and substitute $\Rightarrow \tau = RC$

c) $i = -C\frac{du_C}{dt} \Rightarrow i = \frac{E}{R}e^{-\frac{t}{\tau}}$

B) 1 – $E = \frac{1}{2}CU^2 \Rightarrow E = 1638$ J

2 – a) $E_{rem.} = 1638 - 360 = 1278$ J

b) i) $E_{rem.} = \frac{1}{2}Cu_C^2 \Rightarrow u_C = 1599$ V ;

$u_C = E\,e^{-\frac{t}{\tau}} \Rightarrow t = 6.2$ ms

ii) $i = \frac{E}{R}e^{-\frac{t}{\tau}} \Rightarrow i = 32$ A

Fourth exercise

A) on closing the switch i increases , the coil opposes this increase (self-induction)

B) I – 1 – $u_{AM} = u_{AB} + u_{BM} \Rightarrow E - ri = R_1\, i + L\dfrac{di}{dt} + R_2\, i \Rightarrow E = Ri + L\dfrac{di}{dt}$

2 – a) At t = 0 ; $i = 0 = a + b \Rightarrow a = -b$

$E = R(a + b e^{-\frac{t}{\tau}}) + \dfrac{Lb}{\tau} e^{-\frac{t}{\tau}} \Rightarrow E = R a + b e^{-\frac{t}{\tau}} (R - \dfrac{L}{\tau}) \Rightarrow a = \dfrac{E}{R}$ and $R - \dfrac{L}{\tau} = 0$

$\Rightarrow \tau = \dfrac{L}{R}$ and $b = -\dfrac{E}{R}$

b) $i = \dfrac{E}{R} - \dfrac{E}{R} e^{-\frac{t}{\tau}} = \dfrac{E}{R} (1 - e^{-\frac{t}{\tau}})$

B) II – 1 – a) $u_1 = u_{AM}$

b) $u_1 = E - ri = E - r\dfrac{E}{R} (1 - e^{-\frac{t}{\tau}})$

2 – a) $u_2 = u_{BM}$

b) $u_2 = R_2 i = R_2 \dfrac{E}{R} (1 - e^{-\frac{t}{\tau}})$

3 – a) At $t_0 = 0$; $u_2 = 0$ and $u_1 = 14$ V

b) At $t_0 = 0$; $u_1 = E - ri = E \Rightarrow E = 14$ V

4 – a) At $t = \tau$; $u_2 = 0.63\, u_{max} = 0.63 \times 9.5 = 6$ V. From the curve (b) $\tau = 1$ ms

b) At the steady state : $u_1 = 11.5$ V ; $u_1 = E - r\, I_{max}$ with $I_{max} = \dfrac{u_{2\max}}{R_2} = \dfrac{9.5}{100} = 95\times10^{-3}$A

$\Rightarrow 11.5 = 14 - 95\times10^{-3}\, r \Rightarrow r = 26\ \Omega$. At the steady state : $u_1 = 11.5 = (R_1 + R_2)\, I_{max}$

$\Rightarrow R_2 + R_1 = \dfrac{11.5}{95\times10^{-3}} = 121\ \Omega \Rightarrow R_2 = 21\ \Omega$

5 - $\tau = \dfrac{L}{R}$; $R = 21 + 26 + 100 = 147\ \Omega \Rightarrow L = \tau R = 147 \times10^{-3}$ H

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امتحانات شهادة الثانوية العامة
فرع العلوم العامة

دورة سنة 2004 الإستثنائية

مسابقة في الفيزياء
المدة: ثلاث ساعات

الاسم:
الرقم:

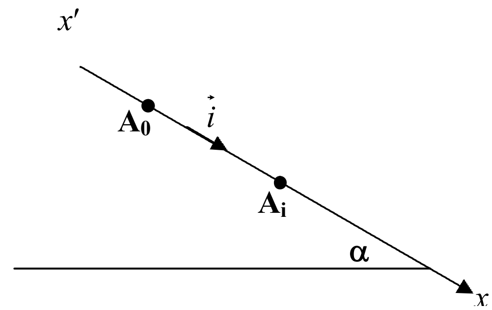
This exam is formed of four obligatory exercises in four pages numbered from 1 to 4.
The use of a non programmable calculator is allowed.

First exercise (6.5 pts) Determination of a force of friction

In order to determine the value of the force of friction between a moving body of mass M = 0.50 kg and a table inclined by an angle $\alpha = 30°$ with respect to the horizontal, we release the body from a point A_0 without initial velocity at the instant $t_0 = 0$ that is taken as the origin of time and we record the different positions A_i of the projection of its center of mass on the table at instants separated by a constant time interval τ = 60 ms, the points A_i being held by the axis $x'x$ of motion of unit vector $\vec{i}$

Take g = 9.8m/s^2

The recordings allow us to obtain the following table.



Instant	$t_0 = 0$	$t_1 = \tau$	$t_2 = 2\tau$	$t_3 = 3\tau$	$t_4 = 4\tau$	$t_5 = 5\tau$	$t_6 = 6\tau$
Position	A_0	A_1	A_2	A_3	A_4	A_5	A_6
Abscissa x (mm)	0	$A_0A_1 = 7.20$	$A_0A_2 = 28.9$	$A_0A_3 = 64.9$	$A_0A_4 = 115$	$A_0A_5 = 181$	$A_0A_6 = 259$
Speed V (m/s)	0	0.24		0.72		1.20	
Linear momentum P(kg.m/s)	0	0.12		0.36		0.60	

1) Complete the above table by calculating, at the instants t_2 and t_4, the speeds V_2 and V_4 and the values P_2 and P_4 of the linear momentum of the body.

2) Trace the curve representing the variation of P as a function of time , using the scale : 1cm on the axis of abscissas represents 0.06 s and 1 cm on the axis of ordinates represents 0.05 kg.m/s .

3) Show that the relation between the linear momentum $\vec{P} = P\vec{i}$ and the time t has the form $\vec{P} = \boldsymbol{b}\, t\vec{i}$ where ***b*** is a constant.

4) Calculate ***b*** in SI units.

5) **a.** Show that the inclined table exerts on the body a force of friction $\vec{f}$ supposed constant and parallel to the axis $x'x$.

b. Calculate the value f of $\vec{f}$.

Second exercise (7.5 pts) **Identification of some electric components**

We intend to identify each of two electric components D_1 and D_2, one of them being a capacitor of capacitance C, and the other a coil of inductance L and of resistance r. In order to do that, we consider a function generator (LFG) delivering an alternating sinusoidal voltage whose effective value is kept constant throughout the whole problem, an oscilloscope, a resistor of resistance $R=10\,\Omega$, and connecting wires.

We connect up the circuit represented in figure (1); the component D may be either D_1 or D_2. The figures (2) and (3) show the waveforms of each of the voltages u_{AM} and u_{BM}

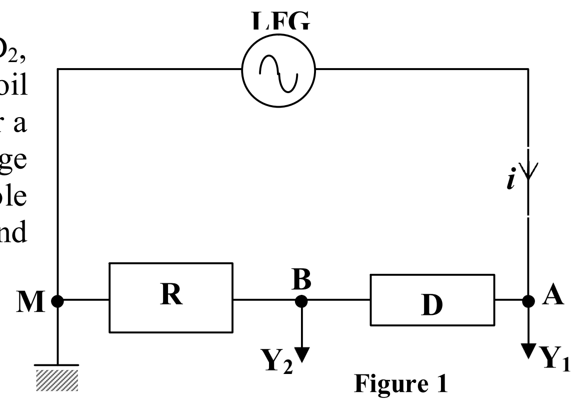


Figure 1

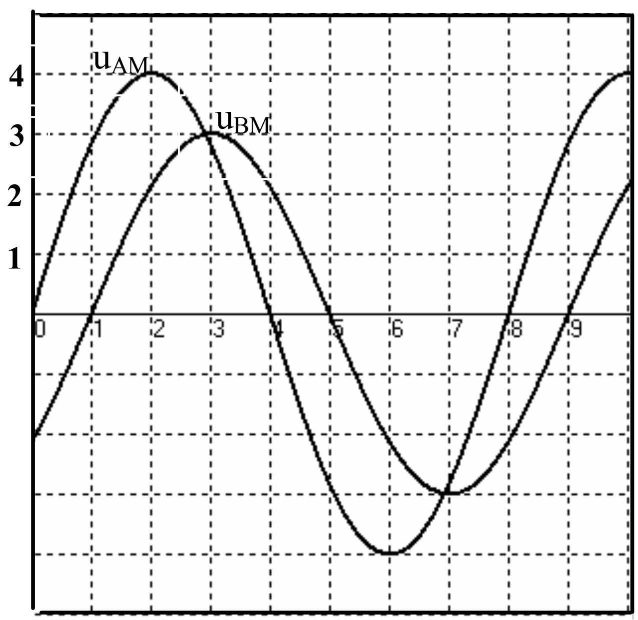


Figure 2

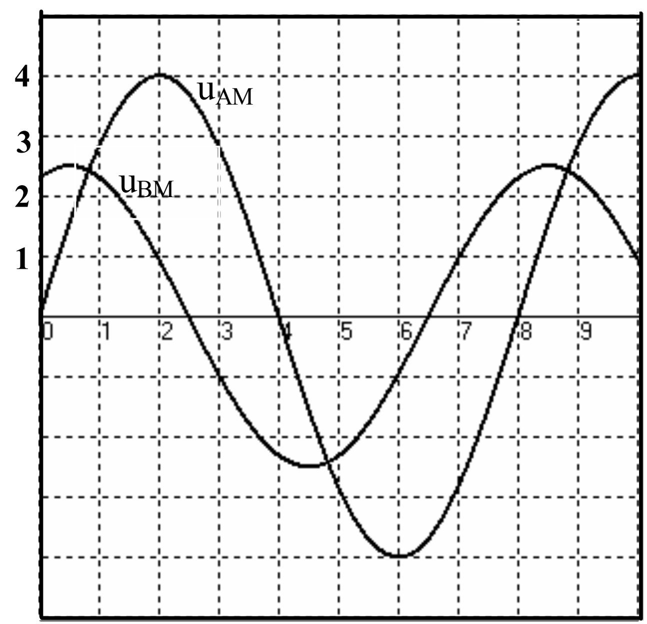


Figure 3

Given:

Horizontal sensitivity : 1ms/division
Vertical sensitivity on (Y_1) : 2 V/division
Vertical sensitivity on (Y_2) : 1V/division

A- Nature of D_1 and of D_2

The waveform of figure (2) corresponds to the case when the component D is D_1.
D_1 is then the coil. Why?

B- Characteristics (L, r) of the coil

1. **a)** Determine the period of the voltage delivered by the LFG and deduce its angular frequency ω
   b) Determine the maximum values of the voltages u_{AM} and u_{BM}
   c) Calculate the phase difference φ between the voltage u_{AM} and the current $\boldsymbol{i}$ carried by the circuit.
2. Knowing that the current $\boldsymbol{i}$ is given by the expression $\boldsymbol{i} = I_{1m} \cos \omega t$,determine:
   a) the expression of each of u_{BM} ,u_{AB} and u_{AM} as a function of time.
   b) calculate I_{1m}.
3. By applying the law of addition of voltages, determine the values of r and L by giving ωt two particular values.

C- Capacitance C of the capacitor

D_2 is now connected between A and B, the expression of the voltage u_{AB} is, in this case: $u_{AB} = \frac{I_{2m}}{C\omega}\sin\omega t$.

1. Verify that the expression of the current is: $i = I_{2m}\cos\omega t$.

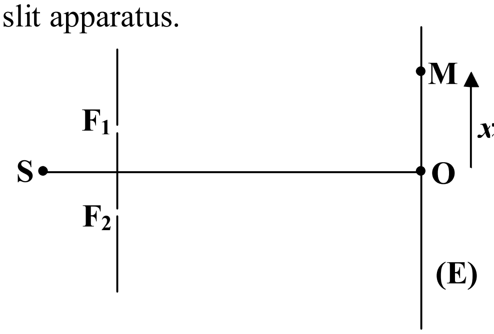
2. Show that the expression of u_{AM} is : $u_{AM} = 8\cos(\omega t - \frac{3\pi}{8})$

3. Determine the value of C.

<u>Third exercise</u> (6.5pts). <u>Interference of light</u>

Consider a source S of monochromatic light of wavelength λ and a glass plate of parallel faces of thickness ***e*** and of index n =1.5.
The object of this exercise is to determine λ and ***e*** using Young′s double slit apparatus.

A- Value of λ



Young′s double slit apparatus is formed of two very thin and parallel slits F_1 and F_2, separated by a distance a = 0.15 mm, and a screen of observation (E) placed parallel to the plane of the slits at a distance D = 1.5 m from this plane.

1) Upon illuminating F_1 by S and F_2 by another independent source S′ synchronous with S, we do not observe a system of interference fringes. Why?

2) We illuminate F_1 and F_2 with S, placed equidistant from F_1 and F_2 we observe on (E) a system of interference fringes.

a) Describe this system.

b) At point O of the screen, equidistant from F_1 and F_2, we observe a bright fringe. Why?

c) It can be shown that for a point M of (E), of abscissa x = OM, the optical path difference in air or in vacuum is given by $\delta = F_2M - F_1M = \frac{ax}{D}$.

Determine the expression of x_k corresponding to the k^{th} bright fringe and deduce the expression of the interfringe distance ***i***.

3) We count 11 bright fringes over a distance d = 5.6 cm. Determine the value of λ.

B) Value of e

Now, we place the glass plate just behind the slit F_1.

The optical path difference at point M becomes: $\delta' = \frac{ax}{D} - e(n-1)$.

1. Show that the interfringe distance ***i*** remains the same.

2. a) The central bright fringe is no longer at O. Why?

b) The new position O′ of the central bright fringe is the position that was originally occupied by the fifth dark fringe before introducing the plate. Determine the thickness ***e*** of the plate.

Fourth exercise (7 pts) — Studying the radionuclide $^{198}_{79}Au$

Given:

molar mass of $^{198}_{79}Au$: 198 g ;
Avogadro′s number : 6.022×10^{23} mol^{-1};
mass of the electron: 5.50×10^{-4} u;
speed of light in vacuum $c = 3\times10^{8}$m/s;
1 u = 931.5 MeV / c^2 = 1.66×10^{-27}kg ;
1 eV = 1.6×10^{-19}J;
mass of the gold nucleus Au : 197.925 u ;
mass of the mercury nucleus Hg : 197.923 u;
mass of the proton m_p = 1.00728 u ;
mass of the neutron m_n= 1.00866 u.

A- Comparison between the density of the gold nucleus and that of the gold atom

1) a) Calculate the mass of the gold atom $^{198}_{79}Au$.

b) Compare the mass of the gold atom $^{198}_{79}Au$ with that of its nucleus.

2) The average radius of the gold atom is $r = 16\times10^{-11}$ m. The average radius of a nucleon is $r_o = 12\times10^{-16}$ m. Compare the density of the gold atom with that of its nucleus. Give a conclusion about the distribution of mass in the atom.

B- Stability of the gold nucleus

1. a) Give the constituents of the nucleus $^{198}_{79}Au$.

b) If the gold nucleus $^{198}_{79}Au$ is broken into its constituting nucleons, show that the sum of the masses of the nucleons taken separately at rest is greater than the mass of the nucleus taken at rest.
Due to what is this increase in the mass?

2. Knowing that a nucleus is considered stable when its binding energy per nucleon is larger or equal to 8 MeV, give a conclusion about the stability of the nucleus $^{198}_{79}Au$.

C- Studying the disintegration of the gold nucleus $^{198}_{79}Au$

When the gold nucleus $^{198}_{79}Au$, at rest, disintegrates it gives a daughter nucleus (mercury nucleus $^{A}_{Z}Hg$) of negligible speed. We were able to detect the emission of a γ photon of energy 0.412 MeV and a β^- particle of kinetic energy 0.824 MeV.

1. Write the equation of this disintegration reaction and, specifying the laws used ,determine *A* and *Z*.

2. a) Specify the physical nature of the γ radiation.

b) Due to what is the emission of this γ radiation ?

3. a) Show , by applying the law of conservation of total energy, the existence of a new particle accompanying the emission of β^-.

b) Give the name of this particle.

c) Deduce its energy in MeV.

4. Calculate the speed V of the relativistic particle β^- knowing that its kinetic energy is given by:

K.E (relativistic) = $mc^2(\gamma-1)$ with $\frac{1}{\gamma} = \sqrt{1-\frac{V^2}{c^2}}$

First exercise :

1) $V_2 = \dfrac{A_1A_3}{2\tau}$ **(1/4pt.)** $\Rightarrow V_2 = \dfrac{57.7}{0.12} = 481 mm/s$ **(1/4 pt.)**

$V_4 = \dfrac{A_3A_5}{2\tau}$ **(1/4 pt.)** $\Rightarrow V_4 = \dfrac{116.1}{0.12} = 967 mm/s$ **(1/4 pt.)**

$P_2 = MV_2$ **(1/4 pt.)**

$P_2 = 0.24$ kgm/s. **(1/4 pt.)**

$P_4 = MV_4$; $P_4 = 0.48$ kg.m/s. **(1/4 pt.)**

2) Trace the curve **(1pt.)**

3) The curve is a straight line passing through the origin ; P= b t **(1/4pt.)**

But $\vec{P} = \overrightarrow{mV}$ and $\vec{V} = V\vec{i}$; $\vec{P} = P\vec{i}$; thus $\vec{P} = bt\vec{i}$. **(1/4pt.)**

4) $b = \dfrac{P_5 - P_1}{4\tau} = 2kgm/s^2$. **(1/2 pt.)**

5) a) $\dfrac{d\vec{P}}{dt} = b\vec{i} = 2\vec{i}$ **(1/4pt)**

Newton's second law, applied on the moving body, is written as: $\dfrac{d\vec{P}}{dt} = \sum\vec{F}$. **(1/4 pt.)**

If there are no forces of friction , we have:

$\sum\vec{F} = m\vec{g} + \vec{N}$; $\vec{N}$ being the normal reaction exerted by the table on the body. $\sum\vec{F} = mg\sin\alpha\,\vec{i} - mg\cos\alpha\,\vec{j} + N\vec{j}$

The motion takes place along $\overrightarrow{x'x}$, we have $-mg\cos\alpha\,\vec{j} + N\vec{j} = \vec{0}$; thus $\sum\vec{F} = mg\sin\alpha\,\vec{i} = 0.5\times9.8\times0.5\vec{i} = 2.45\vec{i}$.

In this case: $\dfrac{d\vec{P}}{dt}$ is not equal to $\sum\vec{F}$.

The force of friction $\vec{f}$ must exist. **(11/4pt.)**

b) $\sum\vec{F} = (mg\sin\alpha - f)\,\vec{i} = \dfrac{d\vec{P}}{dt} = 2\vec{i}$.

Thus : $mg\sin\alpha - f = 2 \Rightarrow f = 2.45 - 2 = 0.45$ N. **(1 pt.)**

Second exercise :

A- Figure (2) correspond to the case of the coil since u_{AM} is leading u_{BM} which represents the image of the current **(1/2 pt)**

B) 1) a) T=8div×1ms/div=8ms= 8×10^{-3}s. **(1/4pt)**

$\omega = 2\pi / T$; $\omega = 785$rad/s **(1/4 pt)**

b) $(U_{AM})_{max}$ = 4 div× 2 V/div = 8 V **(1/4pt)**

$(U_{BM})_{max}$ = 3 div ×1 V/div = 3 V **(1/4pt)**

c) $\varphi = \dfrac{2\pi \times 1div}{8div} = \dfrac{\pi}{4} rad$ **(1/4pt)**

2) a) u_{BM}=Ri=R I_{1m} cosω t **(1/4pt)**

u_{AB}= ri+Ldi/dt = r I_{1m} cosω t -Lω I_{1m} sinω t **(1/2pt)**

$u_{AM} = 8\cos(\omega t + \dfrac{\pi}{4})$ **(1/4pt)**

b) R I_{1m} =3V $\Rightarrow$ I_{1m}= 0.3A **(1/4pt)**

3) $8\cos(\omega t + \dfrac{\pi}{4})$ = (r+R) I_{1m} cosω t - Lω I_{1m} sinω t

for ω t = 0 we have: $8\cos\dfrac{\pi}{4}$ = (r+R) $I_{1m} \Rightarrow$ r = 8.85Ω . **(3/4pt)**

for $\omega t = \dfrac{\pi}{2}$ we have : $-8\sin\dfrac{\pi}{4} = -L\omega\ I_{1m} \Rightarrow$ L = 24 mH. **(3/4pt)**

C-1) i = dq/dt = Cdu_{AB}/dt = I_{2m} cosω t **(1/2pt)**

2) ($U_{AM})_{max}$= 8V ; u_{AM} lags i by β . $\beta = \dfrac{1.5\times 2\pi}{8} = \dfrac{3\pi}{8}$ rad.

$\Rightarrow u_{AM} = 8\cos(\omega t - \dfrac{3\pi}{8})$ **(11/4pt)**

3) $8\cos(\omega t - \dfrac{3\pi}{8}) = \dfrac{I_{2m}}{C\omega}\sin\omega t + RI_{2m}\cos\omega t$.

for $\omega t = \dfrac{\pi}{2}$ we have : $8\sin\dfrac{3\pi}{8} = \dfrac{I_{2m}}{C\omega}$

with RI_{2m} = 2.5 V we have : I_{2m} = 0.25 A. $\Rightarrow$ C = 43 μF. **(11/4pt).**

Third exercise :

- **A-1)** because the two sources are not coherent **(1/2 pt)**

2)a) We observe straight fringes that are:

- Rectilinear **(1/4 pt)**
- Parallel to the slits **(1/4 pt)**
- equidistant **(1/4pt)**

alternately bright and dark **(1/4pt)**

b) Light waves reach o in phase (or their optical path difference at Ois zero). **(1/2 pt)**

c) The abscissa of a bright fringe satisfies the relation : $\delta = \frac{ax}{D} = K\lambda$

(K is a whole number) $\Rightarrow$ the abscissa of the k^{th} bright fringe is :

$x_K = K\frac{\lambda D}{a}$. **(1/2 pt)**

$i = (K+1)\frac{\lambda D}{a} .- K\frac{\lambda D}{a} = \frac{\lambda D}{a}$ **(3/4pt.)**

3) $d = 10\ i = 10\ \frac{\lambda D}{a}$ **(1/2pt.)** $\Rightarrow \lambda = \frac{ad}{10D}$ **(1/4pt.)**

$\Rightarrow \lambda = 0.56\ \mu m$. **(1/2pt.)**

B) 1) $\delta' = \delta - e(n-1) = \frac{ax}{D} - e(n-1) = K'\lambda$ **(1/2pt)**

Bright fringe $\Rightarrow \delta' = K'\lambda$ **(1/4 pt)**

$\Rightarrow x_{k'} = K'\frac{\lambda D}{a} + \frac{e(n-1)D}{a}$

$\Rightarrow \Rightarrow i' = (K+1)\frac{\lambda D}{a} .- K\frac{\lambda D}{a} = \frac{\lambda D}{a} = i$ (the same) **(1/4 pt)**

2) a) $\delta' = \frac{ax}{D} - e(n-1)$ for $x = 0 \Rightarrow \delta' = - e(n-1) \neq 0$ **(1/4pt)**

$\Rightarrow$ the central bright fringe is not at O **(1/4pt.)**

b) The abscissa xo of the central bright fringe is such that $\delta' = 0 \Rightarrow x_o = 9\ \frac{i}{2}$ **(1/2 pt)**

$\delta' = 0 \Rightarrow x_0 = \frac{e(n-1)D}{a} \Rightarrow e = 9\lambda \Rightarrow e = 5.04\ \mu m$ **(1/2pt)**

Fourth exercise:

A-1) a) $m_{atom} = \frac{198}{6.022\times10^{23}} = 32.879\times10^{-23}$g **(1/4 pt)**

b) $m_{nucleus} = 197.925\times1.66\times10^{-24}$g $= 32.855.\ 10^{-23}$g. $\Rightarrow$ $m_{atom.} \approx$ $m_{nucleus}$

(1/4pt)

2) $\rho_{atom} = \frac{m_{atom}}{V_{atom}} = \frac{m_{atom}}{\frac{4}{3}\pi r^3} = 19.16\times10^3$Kg/m^3**(1/2pt)**

$\rho_{nucleus} = \frac{m_{nucleus}}{V_{nucleus}} = \frac{m_{nucleus}}{A\times\frac{4}{3}\pi r_0^3} = 2.3\times10^{17}$Kg/m^3. **(1/2pt)**

$\rho_{nucleus} = 10^{13}\rho_{atom}$ **(1/4 pt)**

The matter forming the atom is concentrated in the nucleus. **(1/4pt)**

B-1) a) 79 protons and 119 neutrons **(1/4 pt)**

b) 79 m_p + 119 mn = 199.605 u **(1/4pt)**

$m_{nucleus}$ = 197.925 u < 199.605 u. **(1/4 pt)**

the binding energy. or the energy transformed into mass **(1/4 pt)**

2) $E_l = \Delta m\times c^2$ **(1/4 pt)**

$\Delta m = Zm_p + (A-Z)m_n - m_{nucleus} = 1.68066$ u **(1/4pt)**

E_l = 1565.535 MeV **(1/4 pt)** $\Rightarrow$ E_l/A = 7.9 MeV **(1/4 pt)**

E_l/A < 8 MeV **(1/4 pt)** $\Rightarrow$ The ${}^{198}_{79}Au$ nucleus is unstable. **(1/4 pt)**

C- 1) ${}^{198}_{79}Au \rightarrow {}^{198}_{80}Hg + {}^{0}_{-1}e + \gamma$ **(1/2pt)**

The laws of conservation of mass number A and charge number Z. **(1/4 pt)**

2) a) The γ radiation is an electromagnetic wave. **(1/4 pt)**

b) The daughter nucleus Hg being in an excited state, it undergoes a downward transition giving the γ radiations. **(1/4pt)**

3) a) $E_{total\ before} = E_{total\ after}$

$\sum(K.E + E_{mass})_{before} = \sum(K.E + E_{mass})_{after}$

$(m_{Au}c^2 + 0) = (m_{Hg}c^2 + 0) + (m_{e^-}c^2 + K.E_{e^-}) + E(\gamma)$

$[m_{Au} - (m_{Hg} + m_{e^-})]c^2 = K.E_{e^-} + E(\gamma) \Rightarrow 1.351$ MeV > 1.236 MeV $\Rightarrow$ Thus the need to assume the production of a new particle. **(1/2 pt)**

b- Antineutrino **(1/4 pt)**

c) E = 1.351 – 1.236 = 0.115 MeV **(1/4 pt)**

4) $E_{mass} = mc^2 = 0.00055\times931.5 = 0.512$ MeV.

$Ec = (\gamma - 1)\ m\ c^2 \Rightarrow 0824 = (\gamma - 1)\ 0.512$

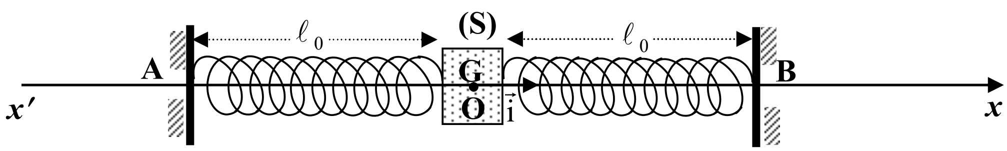
$\Rightarrow \gamma = 2.6 \Rightarrow V = 2.7\times10^8$ m/s **(1 /2 pt)**

مسابقة في الفيزياء المدة: ثلاث ساعات	الاسم : الرقم :

This exam is formed of 4 obligatory exercises in four pages numbered from 1 to 4
The use of non-programmable calculators is allowed

First Exercise: (7 pts) Study of a horizontal mechanical oscillator

A solid (S), of mass m = 140 g, may slide on a straight horizontal track. The solid is connected to two identical springs of un-jointed turns, of negligible mass, fixed between two supports A and B.
Each of these springs has a stiffness (force constant) k = 0.60 N/m, and a free length ℓ_0.
We denote by O the position of the center of mass G of (S) when the oscillator [(S) + two springs] is in equilibrium, each spring having then the length ℓ_0 (figure).



The solid is shifted from this equilibrium position along the direction $x'x$, by a distance of 4.2 cm, and then released without initial velocity at the instant $t_o = 0$. During its oscillations, at any instant t, the abscissa of G is x and the algebraic value of its velocity is V, O being the origin of abscissas.
The horizontal plane through G is taken as a gravitational potential energy reference.

I – Theoretical study

In this part, we neglect friction.
The solid (S) performs ,in this case, oscillations of amplitude X_{mo} = 4.2 cm.

1) a) Show that the expression of the elastic potential energy of the oscillator is $P.E_e = kx^2$.
b) Write the expression of the mechanical energy M.E of the system [oscillator, Earth] as a function of m, V, x and k.
2)a) Derive the differential equation that governs the motion of (S).
b) Deduce the expression of the proper period T_o of the oscillator in terms of m and k.
c) Calculate the value of T_o. Take $\pi = 3.14$

II – Experimental study

In reality, the value of the amplitude X_m decreases during oscillations, each of duration T.
Some values of X_m are tabulated as below.

Instant	0	T	2T	3T	4T	5T
Amplitude X_m(cm)	X_{mo}= 4.20	X_{m1}= 2.86	X_{m2}=1.95	X_{m3} = 1.33	X_{m4}= 0.91	X_{m5}= 0.62

1) Draw the shape of the curve representing the variation of the abscissa x of G as a function of time.

<u>Scale</u>: on the axis of abscissas 1cm represents $\frac{T}{2}$ and on the axis of ordinates 1 cm represents 1cm.

2) The duration of 5 oscillations is measured and found to be 10.75 s.

- ***a)*** Calculate T.
- ***b)*** Compare T and T_o.
- ***c)*** What is then the type of oscillations?

3) The decrease in the mechanical energy of the system [oscillator, Earth] is due to the existence of a force of friction of the form $\vec{f} = -h\vec{V}$ where $\vec{V} = V\vec{i}$ and h is a positive constant.

a) From the above table of values, verify that:

$$\frac{X_{m1}}{X_{mo}} \approx \frac{X_{m2}}{X_{m1}} \approx .....\approx A \quad \text{where A is a positive constant.}$$

b) Knowing that A is given by the expression $A = e^{\frac{-hT}{2m}}$, calculate h.

4) In order to compensate for the loss in the mechanical energy of the system, an apparatus (D) allows, at regular time intervals, to provide energy to the oscillator.

- ***a)*** Determine the average power furnished by (D) between the instants t = 0 and t = 5 T.
- ***b)*** What is then the type of oscillations?

<u>Second Exercise:</u> (7 ½ pts) <u>Flash of a camera</u>

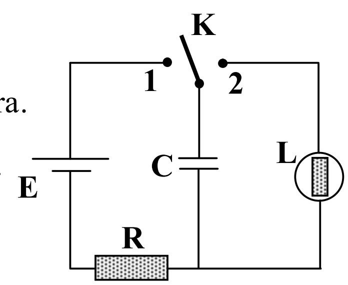


Figure 1

In this exercise, we intend to show evidence of the functioning of the flash of a camera. The simplified circuit of the flash of a camera is formed of an apparatus taken as a source of DC voltage of E = 300 V, a capacitor of capacitance C = 200 μF, a resistor of resistance R = 10 kΩ, a lamp (L), considered as a resistor of resistance r = 1 Ω and a double switch K (figure 1).

I – Charging the capacitor

The capacitor is initially neutral. The double switch is turned to position 1 at the instant $t_o = 0$. The capacitor starts charging (figure 2)

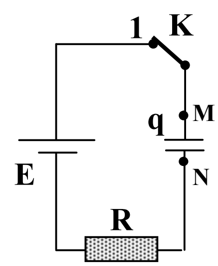


Figure 2

1) *a)* Derive , at an instant t ,the differential equation that governs the variation of the voltage $u_c = u_{MN}$,as a function of time ,during the charging of the capacitor.

b) The solution of this equation, at an instant t, has the form: $u_c = A + B\,e^{\frac{-t}{\tau}}$ where A, B and τ are constants. Determine these constants in terms of E, R and C.

2) Calculate the energy W stored by the capacitor at the end of charging.

II- Discharging the capacitor

The capacitor being completely charged, the double switch is turned to position 2.

The capacitor starts to discharge through the lamp (L).

The instant of closing the circuit is taken as an origin of time. At an instant t, the voltage across the capacitor is $u_c = u_{MN} = E\, e^{\frac{-t}{rC}}$ and the circuit carries then a current i (figure 3) .

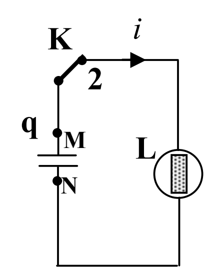


Figure 3

1. Justify the direction of the current in figure (3).
2. Knowing that $i = -\frac{dq}{dt}$

a) determine the expression of the current i as a function of time,
b) calculate the maximum value of i,
c) determine the duration t_1 at the end of which the current reaches 70 % of its maximum value.
d) calculate, at the instant t_1, the voltage u_C across the capacitor.

3. a) Assuming that the energy released by the capacitor by the end of the duration t_1 is converted totally into light in the lamp, determine the average power received by the lamp during t_1.

   b) The flash lamp emits light as long as the average power it receives is greater or equal to 6.4×10^4 W. Knowing that the duration of the flash is t_1, justify the emission of the flash between the instants 0 and t_1.

Third exercise : (7 pts) Photoelectric Effect

The experiments on photoelectric emission performed by Millikan around the year 1915, intended to determine the kinetic energy K.E of the electrons emitted by metallic cylinders of potassium (K) and cesium (Cs) when these cylinders are illuminated by monochromatic radiation of adjustable frequency ν.
The object of this exercise is to determine, performing similar experiments, Planck's constant (h), as well as the threshold frequency ν_o of potassium and the extraction energy W_o of potassium and that of cesium.

I - ***1)*** What aspect of light does the phenomenon of photoelectric effect show evidence of ?
2) A monochromatic radiation is formed of photons. Give two characteristics of a photon.
3) For a given pure metal, the incident photons of a monochromatic radiation provoke photoelectric emission. Give the condition for this emission to take place.

II- In a first experiment using potassium, a convenient apparatus is used to measure the kinetic energy K.E of the electrons corresponding to frequency ν of the incident radiation. The obtained results are tabulated in the following table:

ν (Hz)	K.E (eV)
6×10^{14}	0.25
7×10^{14}	0.65
8×10^{14}	1.05
9×10^{14}	1.45
10×10^{14}	1.85

Given : $1 eV = 1.60 \times 10^{-19}$ J.

1- Using Einstein's relation about photoelectric effect , show that the kinetic energy of an extracted electron may be written in the form : $K.E = a\nu + b$.

2- ***a)*** Plot , on the graph paper, the curve representing the variation of the kinetic energy K.E versus ν , using the following scale:
- on the axis of abscissas: 1cm represents a frequency of 10^{14}Hz
- on the axis of ordinates: 1 cm represents a kinetic energy of 0.5 eV.

b) Using the graph, determine:
i) the value, in SI, of h , the Planck's constant.
ii) the threshold frequency ν_o of potassium.

3- Deduce the value of the extraction energy W_o of potassium.

III- In a second experiment using cesium, we obtain the following values: K.E = 1 eV for $\nu = 7 \times 10^{14}$Hz.
1) Plot, with justification ,on the preceding system of axes, the graph of the variation of K.E as a function of ν.
2) Deduce from this graph the extraction energy W'_o of cesium.

Fourth exercise : (6 pts) Fuel and a power plant

The object of this exercise is to compare the masses of different fuels used in power plants producing the same electric power.
The power plant, of electric power $P = 3 \times 10^9$ W, has an efficiency supposed to be 30 % whatever the nature of the fuel used be.

A. Energy furnished by the fuel

Calculate, in J, the energy furnished by the fuel during 1 day.

B. I. Thermal power plant

The power plant uses fuel-oil. The combustion of 1kg of this fuel-oil liberates 4.5×10^7 J of energy.

Calculate, in kg, the mass m_1 of fuel-oil consumed during 1 day.

II. Power plant using nuclear fission

In the power plant , we use uranium enriched with ^{235}U. One of the fission reactions is :

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{94}_{38}Sr + {}^{140}_{54}Xe + 2\,{}^{1}_{0}n $$

1) In order that fission reaction may take place, the neutron used must satisfy a condition. What is it?
2) The fission of uranium 235 nucleus liberates energy of 189 MeV.
   a) In what form does this energy appear?
   b) Calculate , in kg, the mass m_2 of uranium 235 necessary for the power plant to function during 1 day.

III. Power plant using nuclear fusion?

The thermonuclear fusion reaction has not yet been controlled. If such controlling becomes within reach , we may provoke reactions like those taking place in the Sun.
The balanced fusion reaction of hydrogen in the Sun may be written as :

$$ 4\,{}^{1}_{1}H \rightarrow {}^{4}_{2}He + 2\,{}^{A}_{Z}X $$

1) Identify the particle ${}^{A}_{Z}X$ specifying the laws used.
2) What condition must be satisfied for this fusion to take place?
3) Determine, in J, the energy liberated in the formation of a helium nucleus.
4) Calculate, in kg, the mass m_3 of hydrogen necessary for the power plant to function 1 day.

C. Suggest the mode that is the most convenient for the production of electric energy for a country .
Justify your answer.

Given :
1 u = 931.5 MeV/c^2 = 1.66 × 10^{-27} kg ; 1 MeV = 1.6 × 10^{-13}J ;
Masses of nuclei and particles ${}^{1}_{1}H$: 1.00728 u ; ${}^{4}_{2}He$: 4.00150 u ; ${}^{A}_{Z}X$: 0.00055 u ; ^{235}U : 235.04392 u.

Solution

First exercise

I-

1-a) PEe= $1/2kx^2 + 1/2kx^2 = kx^2$ **(1/2pt)**

b) $M.E = K.E + P.Ee = ½\, m V^2 + kx^2$ **(1/2pt)**

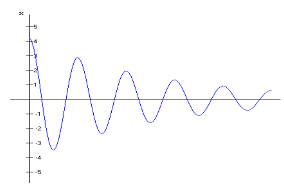
2- a) M.E = cte => $\frac{dM.E}{dt} = 0 = mV\ \ddot{x} + 2kxV$ => $\ddot{x} + \frac{2k}{m}x = 0$ **(1/2pt)**

b) The differential equation is of the form $\ddot{x} + \omega_o{}^2 x = 0$ where $\omega_o = \sqrt{\frac{2k}{m}}$ is the proper angular frequency of the motion.

The proper period is $T_o = \frac{2\pi}{\omega_o} = 2\pi\sqrt{\frac{m}{2k}}$. **(1pt)**

c) $T_o = 2\pi\sqrt{\frac{0{,}14}{2 \times 0{,}6}} =$ 2,145 s. **(1/2pt)**

II- 1) The shape of the curve **(1/2pt)**



2) a) $T = \frac{10{,}75}{5} =$ 2,150 s **(1/2pt)**

b) T= 2,150 s et T_o= 2,145s => $T > T_o$ **(1/4pt**

c) Oscillations are free damped **(1/4pt)**

3) a) $A = \frac{2{,}86}{4{,}2} =$ 0,68 **(1/2pt)**

b) $\ln A = -\frac{h}{2m}T$. **(1/2pt)** Thus : h = 0,05 Kg/s **(1/2pt)**

4- a) $M.E = ½\, m V^2 + kx^2$. At maximum abscissa, $V = 0$, thus $M.E = k(X_m)^2$

At t = 0, $M.E_0 = k(X_{m0})^2 = 1{,}0584.10^{-3}$J.

At t = 5T, $M.E_5 = k(X_{m5})^2 = 0{,}0231.10^{-3}$J.

The decrease in the mechanical energy of the system is $|\Delta M.E| = 1{,}0584.10^{-3} - 0{,}0231.10^{-3} = 1{,}0353.10^{-3}$ J.

Thus : $P_{av} = \frac{|\Delta M.E|}{5T} = \frac{1{,}0353 \times 10^{-3}}{5 \times 2{,}15} = 0{,}096.10^{-3}$W. **(1 1/4 pt)**

b) The oscillator performs driven oscillations. **(1/4 pt)**

Second exercise

I- 1- a) $E = Ri + u_C$, avec $i = dq/dt = Cdu_C/dt$; we have : $E = R\,Cdu_C/dt + u_C$. **(1 pt)**

b- $u_C = A + B\,e^{-\frac{t}{\tau}}$; $du_C/dt = -\frac{B}{\tau}e^{-\frac{t}{\tau}}$ => $E = -RC\frac{B}{\tau}e^{-\frac{t}{\tau}} + A + Be^{-\frac{t}{\tau}}$ =>

$Be^{-\frac{t}{\tau}}(1-\frac{RC}{\tau}) + (A - E) = 0 \quad \forall t$ => $(1-\frac{RC}{\tau}) = 0$ => τ **= RC** et $A - E = 0$ => .

A= E . On the other hand at $t = 0$, $u_C = 0$ => $A + B = 0$ => **B = - E** **(11/2pt)**

2- $W = ½\,C\,(u_C)^2 = ½\,CE^2$ => $W = 9$ J **(1/2pt)**

II- 1) $u_{MN} > 0$ => the current has the direction from high to low potential. **(1/2 pt)**

2) a) $i = -\frac{dq}{dt} = -C\frac{du_C}{dt} = C\frac{E}{rC}e^{\frac{-t}{rC}} = \frac{E}{r}e^{\frac{-t}{rC}}$ **(1/2pt)**

b) $I_{max} = \frac{E}{r} = 300$ A. **(1/2pt)**

c) At the end of the duration t_1, we have : $i = 0,7\,I_{max} = 0,7\frac{E}{r}$ => $\frac{E}{r}e^{-\frac{t_1}{rC}} = 0,7\frac{E}{r}$

=> $e^{-\frac{t_1}{rC}} = 0,7$ ou $\frac{t_1}{rC} = 0,356$ => $t_1 = 7.10^{-5}$s **(1pt)**

d) if $t = t_1 = 7.10^{-5}$s , the voltage across the capacitor is :

$u_C = E\,e^{-\frac{t_1}{rC}} = 300 \times e^{-0,35} = 211,41$ V . **(1 pt)**

3- a) The energy stored in the capacitor at the instant t_1 is then : $W_1 = ½\,C\,(u_C)^2 = 10^{-4}(211,41)^2 = 4,5$ J.

$\Delta W = W - W_1 = 4,5$ J **(1/2pt)**

$P_m = \frac{\Delta W}{t_1} = 6,4.10^4$ W.

b) The lamp receives a power equal to the power of its normal functioning, it produces then a flash. **(1/2pt)**

Third exercise

1-1) Corpuscular aspect. **(1/2pt)**

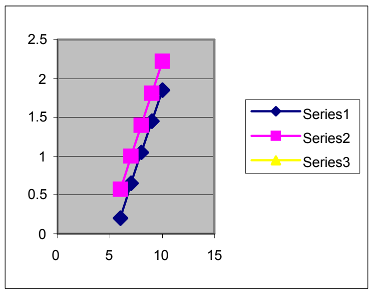
2) Zero mass; speed in vacuum = c ; zero charge ; energy = h ν .**(1/2pt)**

3) If hν ≥ W_O or λ ≤ λ_O or ν ≥ ν_S) **(1/2pt)**

II-1- Einstein's relation gives : h ν = W_O + K.E

We can write : K.E = h ν - W_O = a ν + b où a = h et b = -W_O **(1/2pt)**

2- a) Representation **(1pt)**



b) i- K.E = f(ν) is a straight line not passing through the origin having a slope h..

$$h = \frac{K.E_2 - K.E_1}{\nu_2 - \nu_1} = \frac{(1{,}85 - 0{,}25) \times 1{,}6.10^{-19}}{10.10^{14} - 6.10^{14}} = 6{,}4.10^{-34}\text{ J.s}$$ **(11/2pt)**

ii- If the electron is extracted without velocity (K.E = 0), The metal is illuminated with a radiation of frequency equal to threshold frequency $\nu_O = \frac{W_O}{h}$. The threshold frequency corresponds to the intersection of the obtained line with the axis of abscissa. Graphically we find $\nu_O = 5{,}5.10^{14}$Hz. **(1pt)**

3) On a : $\nu_O = \frac{W_O}{h} \Rightarrow W_O = h\,\nu_O = 6{,}4.10^{-34} \times 5{,}5.10^{14} = 3{,}52.10^{-19}$J = 2,2 eV **(1/2).**

III- 1) In order to plot the curve for cesium, it is enough to locate the point (7.10^{14}Hz ; 1eV) in the system of axes then draw a straight line parallel to the previous line. **(1/2pt)**

2) In order to determine the extraction energy of cesium, we produce the line until it meets the axis of K.E; we find W'_O = 1,9 eV. **(1/2pt)**

Fourth exercise

A- The energy consumed by the plant during 1 s is: $\frac{100\times 3.10^{9}}{30} = 10^{10}$ W

The energy consumed by the plant during 1 day is: $E = 10^{10}\times 24\times 3600 = 864.10^{12}$J. **(1/2pt)**

B - I – The mass of fuel-oil needed for functioning 1 day is : $m_1 = \frac{864.10^{12}}{45.10^{6}} = 19{,}2.10^{6}$ kg. **(1/2pt)**

II. 1) The energy of the neutron is of the order of 0.1 eV (or slow neutron or thermal neutron) **(1/4pt)**

.

2) a) The energy liberate appears in the form of kinetic energy of the neutrons and the nuclei. **(1/4pt)**

b) In order to liberated a nuclear energy of 189 MeV, we need a mass of uranium equal to 235,04392 u. In In order to liberated a nuclear energy E, we need a mass of uranium

$$m_2 = \frac{235{,}04392\times 1{,}66.10^{-27}\times 864.10^{12}}{189\times 1{,}6.10^{-13}} = 11 \text{ kg.}$$ **(1pt)**

III-1) The laws of conservation of Z and of A give : Z = 0 and A = 1. The emitted particle is positron. **(3/4pt)**

2) The nuclei must have a large kinetic energy (in the order of 0.1 MeV or a temperature of the medium about 10^8K). **(1/4pt)**

3) The energy liberated is given by $E_3 = \Delta m.c^2$

$\Delta m = 4\times 1{,}00728 - 4{,}0015 - 2\times 0{,}00055 = 0{,}02652$ u

$\Delta m = 0{,}02652\times 931{,}5$ MeV/c^2 = 24,70338 MeV/c^2.

thus : $E_3 = 24{,}7$ MeV $= 39{,}52.10^{-13}$J. **(1pt)**

4) In order to liberate nuclear energy of $39{,}52.10^{-13}$J , We need a mass of hydrogen equal to $4\times 1{,}00728$ u.
In order to liberate the energy E, we need a mass of hydrogen.

$$m_3 = \frac{4\times 1{,}00728\times 1{,}66.10^{-27}\times 864.10^{12}}{39{,}52.10^{-13}} = 1{,}5 \text{ kg.}$$ **(1pt)**

C- $m_3 < m_2 < m_1$: for the same production of energy, we find that the consumption of hydrogen is 7 times less than that of uranium and 13.10^{6} times less than fuel-oil.

Fusion does not result in radioactive nuclei

_ Hydrogen is much more abundant in nature then uranium

_ Fusion is more energetic than fission

_ Fusion does not produce toxic gases **(1/2pt)**

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

This exam is formed of 4 exercises in 4 pages numbered from 1 to 4.
The use of non-programmable calculators is allowed.

First exercise (7 pts) Moment of inertia of a disk

Consider a homogeneous disk (D) of mass m = 400 g and of radius R =10 cm.
The object of this exercise is to determine, by two methods, the moment of inertia I_0 of (D) about an axis (Δ_0) perpendicular to its plane through its center of mass G.
Neglect all friction. **Take:** $0{,}32\pi = 1$; $g = 10\ m/s^2$; $\sin\theta = \theta_{(rd)}$ for small θ .

A- First method

The disk (D) is free to rotate about the horizontal axis (Δ_0), that is perpendicular to its plane through its center G (fig.1). This disk starts from rest, at the instant $t_0 = 0$, under the action of a force $\vec{F}$ of constant moment about (Δ_0) and of magnitude M = 0,2 m.N. At the instant $t_1 = 5$ s, (D) rotates then at the rotational speed $N_1 = 80$ turns/s.

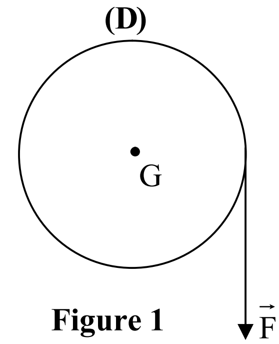


Figure 1

1) a- Give the names of the external forces acting on (D) and represent them on a diagram.
b- Show that the resultant moment of these forces, about (Δ_0), is equal to the moment M of the force $\vec{F}$.
c- Specify, using the theorem of angular momentum, the nature of the motion of (D).
2) a- Find the expression of the angular momentum *a* of the disk, about (Δ_0) , as a function of t.
b- Determine the value of I_0 .

B – Deuxième méthode

The disk (D) is free to oscillate about a horizontal axis (A), perpendicular to Its plane through a point O of its periphery
We denote by I the moment of inertia of (D) about (A).We shift (D), from its equilibrium position , by a small angle θ_0 and then we release it without initial velocity , at the instant $t_0 = 0$.
The position of (D) is defined, at any instant t , by the angle θ that the axis OZ makes with OG .
$\theta' = \frac{d\theta}{dt}$ represents the angular velocity of (D) at the instant t (fig. 2).
The horizontal plane passing through the point 0 is taken *as* a gravitational potential energy reference.

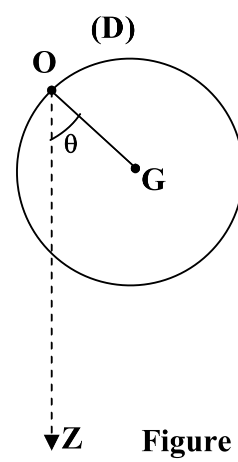


Figure 2

1) determine, at the instant t, the mechanical energy of the system [(D),Earth], in terms of I , m , g , R , θ and θ'.
2) Derive the second order differential equation that describes the oscillatory motion of (D).
3) Deduce the expression of the period T of the oscillations of (D) in terms of I , m , g and R .
4) The time taken by the compound pendulum thus formed to perform 10 oscillations is 7.7s. Determine the value of I.
5) mowing that I_0 and I are related by the relation $I = I_0 + mR^2$, find again the value of I_0 .

Second exercise (7 pts) Identification of an electric component

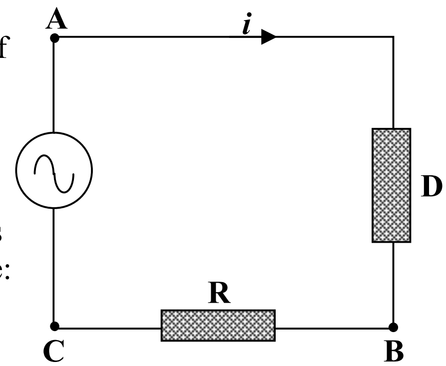


Figure 1

We intend to exploit a waveform and identify an electric component (D) of physical characteristic X. (D) may be:
- a resistor of resistance $X = R_1$
- or a capacitor of capacitance X = C
- or a coil of inductance X = L and of negligible resistance. In order to do that, we connect (D) in series with a resistor of resistance R = 400 across a generator delivering across its terminals an alternating sinusoidal voltage:

$$u_g = u_{AC} = 4\sqrt{2}\cos(100\pi t), \text{ (u in V et t in s) (fig.1).}$$

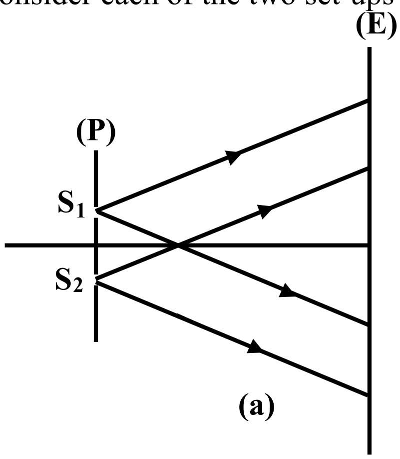
The circuit thus carries an alternating sinusoidal current *i*. An oscilloscope, conveniently connected, displays the waveforms time, of the voltage $u_{AC} = u_g$ on channel 1 and that of the voltage (fig.2). The vertical sensitivity on channel 2 is 2V/div.

1) Redraw the figure 1 showing the connections of the oscilloscope.
2) a- Calculate the value of the period T of the voltage u_g.
   b- Determine the horizontal sensitivity of the oscilloscope.
3) a- The waveform of usc represents the "image" of the current *i*. Why?
   b- Specify the nature of the component (D). Justify your answer.
4) a- Determine the phase difference between u_{AC} and u_{BC}.
   b- Determine the maximum value I_m of the current *i*.
   c- Write the expression of *i* as a function of time .
5) Show that u_{AB} may be written in the form: $u_{AB} = \frac{0{,}1}{100\pi X}\sin(100\pi t + \frac{\pi}{4})$
6) Applying the law of addition of voltages, determine X by giving t a particular value.

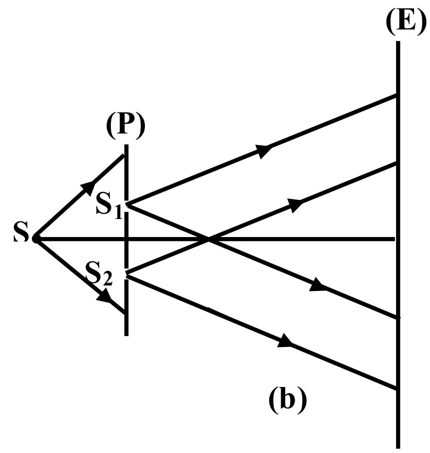
Third exercise (6 ½ pts) Interference of light

A- Conditions to obtain a phenomenon of interferences

We are going to use Young's double slit and two identical lamps.
Consider each of the two set-ups (a) and (b) drawn.



(a)



(b)

In the set-up (a), each of the slits S_1 et S_2 is illuminated by a lamp; the two lamps emit the same radiation.
In the set-up (b), S_1 et S_2 are illuminated by a lamp placed at S next to a very narrow slit parallel to S_1 and S_2; the lamp emits the same preceding radiation.
Dans le dispositif (b), S_1 et S_2 sont éclairées par une lampe placée en S et munie d'une fente très fine parallèle à S_1 et S_2 ; la lampe émet la même radiation précédente.

1- The radiation emitted by the sources S_1 and S_2 in the two set-ups (a) and (b) have a common property. What is it?

2- One property differentiates the radiations issued from S_1 and S_2 in the set-up (a) from those issued from S_1 and S_2 in the set-up (b). Specify this property.

3- The set-up (b) allows us to observe the phenomenon of interference. Why ?

B- Interference in air

We intend to perform a series of experiments about interference using Young's slits apparatus. The slits are in a plane (P), separated by a distance a , and the pattern of interference is observed on a screen (E) found at a distance D from (P).

I- Interference in air

Consider many light filters, each allowing the transmission of a specific monochromatic radiation. For each radiation of wavelength in air, we measure the distance x = 5i along which five interfringe distances extend. The results obtained are tabulated as in the table below.

λ(*en nm*)	470	496	520	580	610
x = 5i (en mm)	11,75	12,40	13,00	14,50	15,25
i (en mm)					

1) a- Complete the table.

b) i- Show that the expression of i as a function of λ is of the form $i = \alpha\lambda$ where α is a positive constant.

ii- Calculate α.

iii- Deduce the value of the ratio $\frac{D}{a}$.

2) We move (E) by 50 cm away from (P). we find that, for the radiation of wavelength λ = 496 nm

In air, five interfringe distances extend over a distance of 18.6 mm. Determine the value of D.

3) Deduce the value of a.

II – Interference in water

The radiation used now has a wavelength λ = 520 nm in air. The preceding apparatus is immersed completely in water whose index of refraction is n. The distance between the planes (E) and (P) is D and the distance between the slits is a.

1- The value of the wavelength λ of a luminous radiation changes when it passes from a transparent medium into another. Why?

2-The interference fringes in water seem closer than in air. Why?

3- In water, five interfringe distances extend over a distance of 9.75 mm. Determine the value of n.

Quatrième exercice (7 pts) The technetium 99

A - A bit of history...

In 1937, Pierrier and Sêgre obtained, for the first time, an isotope of technetium ${}^{99}_{43}Tc$ by bombarding the nuclei of molybdenum ${}^{98}_{42}Mo$ with an isotope of hydrogen ${}^{A}_{Z}H$ according to the following reaction :

$${}^{98}_{42}Mo + {}^{A}_{Z}H \longrightarrow {}^{99}_{43}Tc + {}^{1}_{0}n$$

Determine Z and A specifying the laws used.

B- Production of technetium 99 at the present time and its characteristic

The isotope ${}^{99}_{43}Tc$ is actually obtained in a generator molybdenum/technetium, starting from the isotope ${}^{99}_{42}Mo$ of molybdenum. This molubdenum is a β^- emitter.

1) Write the equation corresponding to the decay of ${}^{99}_{42}Mo$.
2) Determine, in MeV, the energy liberated by this decay.
3) Most of the technetium nuclei obtained are in an exited state [${}^{99}_{43}Tc^*$]

a- i) Complete the equation of the following downward transition: ${}^{99}_{43}Tc^* \longrightarrow {}^{99}_{43}Tc + \ldots\ldots.$

ii) Specify the nature of the emitted radiation.

b- The energy liberated by this transition, of value 0.14 MeV, is totally carried by the emitted radiation; the nuclei [${}^{99}_{43}Tc^*$] and ${}^{99}_{43}Tc$ are supposed to be at rest.

i) Determine, in u, the mass of the ${}^{99}_{43}Tc^*$ nucleus.

ii) Calculate the wavelength of the emitted radiation.

C- Using technetium 99 in medicine

The isotope ${}^{99}_{43}Tc$ is actually often used in medical imaging. The generator molybdenum/technetium is known, in medicine, by the name " technetium cow". Also, the daily preparation of the medically needed technetium 99, of half-life T_1 = 6 hours, starting from its "parent" the molybdenum of half-life T_2 = 67 hours, allows a weekly supply.

1) Why is it preferable, in medical service that requires the use of technetium 99, to keep a reserve of molybdenum 99 and not a reserve of technetium 99 ?
2) Determine the number of technetium 99 nuclei obtained from a mass of 1g of molybdenum 99 at the end of 24 hours. Deduce the mass of these technetium nuclei.

Given : Masses of nuclei and particles: ${}^{99}_{42}Mo$ = 98,88437 u; ${}^{99}_{43}Tc$ = 98,88235 u; ${}^{0}_{-1}e = 55\times10^{-5}u$.

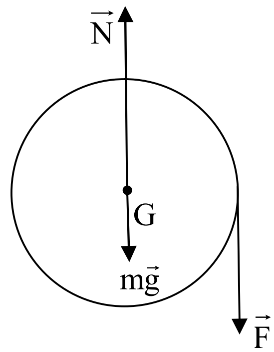
$1u = 931{,}5\ MeV/c^2 = 1{,}66 \times 10^{-27}$ kg ;

Planck's constant: $h = 6{,}63 \times 10^{-34}$ J.s ;

$1eV = 1{,}6\ 10^{-19}$ J ;

$c = 3 \times 10^8$ m/s .

First exercise. (7pts)



A- **1)** **a** – The weight $m\vec{g}$, the reaction $\vec{N}$ and the force $\vec{F}$ ½

b- $\mathcal{M}(m\vec{g}) = \mathcal{M}(\vec{N}) = 0$ (on the axis)

$\mathcal{M}(\vec{F}) = M \Rightarrow \sum \mathcal{M} = M$ ½

c- $\dfrac{d\sigma}{dt} = I_0\ddot{\theta} = M \Rightarrow \ddot{\theta} = \dfrac{M}{I_0}$ = cte and $\dot{\theta}_0 = 0 \Rightarrow$ Motion is uniformly accelerated. ¾

2) **a-** $\dfrac{d\sigma}{dt} = M \Rightarrow \sigma = Mt + \sigma_0 \quad \sigma_0 = I_0\,\theta_0' = 0 \Rightarrow \sigma = Mt$ ¾

b- $I_0\theta' = Mt \Rightarrow I_0 = \dfrac{Mt}{\theta'} = \dfrac{0{,}2\times 5}{2\times\pi\times 80} = 2\times 10^{-3}\ Kgm^2$ ½

B-1) M.E= $\dfrac{1}{2}I\theta'^2$ - mgR cosθ 1

2) $\dfrac{dME}{dt} = 0 \Rightarrow I\,\theta'\theta'' + mg\,R\theta'\sin\theta = 0$ or $\sin\theta = \theta \Rightarrow \theta'' + mg\dfrac{R}{I}\theta = 0$ 1

3) $\omega^2 = \dfrac{mgR}{I} \Rightarrow T = 2\pi\sqrt{\dfrac{I}{mgR}}$ ½

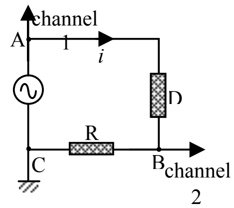
4) $T = \dfrac{7.7}{10} = 0.77$ s thus :

$$I = \frac{T^2 mgR}{4\pi^2} = \frac{(0.77)^2\times 0.4\times 10\times 0.1\times(0.32)^2}{4} = 6.07\times 10^{3}\ kgm^2$$ 1

5) The relation $I = I_0 + mR^2$ gives $I_0 = 6\times 10^{-3} - 0.4\,(0.1)^2 = 2\times 10^{-3}$ kgm². ½

Second exercises (7 pts)

1) connections ½



2) a- $\omega = 100\pi = \dfrac{2\pi}{T} \Rightarrow T = 2\times10^{-2}\,s = 20ms$ ½

b- T corresponds to 4 div ; thus 4 div $\Rightarrow 2\times10^{-2}s \Rightarrow$
1 div. Corresponds to 5 ms => S_h = 5 ms/div ¾

3) a- $i = \dfrac{u_{BC}}{R}$. Then i is the image of u_{BC} ½

b- (D) is a capacitor since the current i leads the voltage u_{AC} ½

4) a- $|\varphi| = \dfrac{2\pi\times 0.5}{4} = \dfrac{\pi}{4}\text{rad}$; u_{BC} leads u_{AC} by $\dfrac{\pi}{4}\text{rad}$ ¾

b- U_{mR} = 2 div × 2 V/div = 4 V $\Rightarrow I_m = \dfrac{U_{mR}}{R} = \dfrac{4}{40} = 0.1\text{A}$ ¾

c- $i = 0{,}1\cos(100\pi t + \dfrac{\pi}{4})$ ½

5) $i = C\dfrac{du_{AB}}{dt} \Rightarrow u_{AB} = \dfrac{1}{C}\int i\,dt = \dfrac{0{,}1}{100\pi C}\sin(100\pi t + \dfrac{\pi}{4})$ 1

6) $u_{AC} = u_{AB} + u_{BC} \Rightarrow$

$4\sqrt{2}\cos(100\pi t) = \dfrac{0.1}{100\pi C}\sin(100\pi t + \dfrac{\pi}{4}) + 4\cos(100\pi t + \pi/4)$ ¼

For t = 0 : $4\sqrt{2} = \dfrac{0.1}{100\pi C}\dfrac{\sqrt{2}}{2} + 4\dfrac{\sqrt{2}}{2} \Rightarrow C = 80\mu F$ 1

Third exercies (6 ½ pts)

A- 1) The two sources are synchronous ¼

2) The coherence ¼

3) since the sources are synchronous and coherent (or coherent) ¼

B-I – 1- a) Table ¾

λ (innm)	470	496	520	580	610
5 i (in mm)	11.75	12.40	13.00	14.50	15.25
i (in mm)	2,35	2,48	2,60	2.90	3.05

b) i- $\frac{i}{\lambda} = \frac{2.35\times10^{6}}{470} = \frac{3.05\times10^{6}}{610}$ = …………..= 5000 = positive constant ½

ii- $\frac{i}{\lambda}$ α = 5000 ¼

iii- $i = \frac{\lambda D}{a} \Rightarrow \frac{i}{\lambda} = \alpha = 5000$ ¾

2) The relation $i = \frac{\lambda D}{a}$ allows aus to write : $\frac{i_1}{i_2} = \frac{D_1}{D_2}$. Thus $\frac{2{,}48}{3.72} = \frac{D}{D+0.5}$ $\Rightarrow$ D = 1 m 1

3) $b = 5000 = \frac{D}{a} = \frac{1}{a}$ => a = 0.2 mm ½

II- 1) $\lambda_{air} = \frac{c}{f}$; $\lambda_{water} = \frac{V}{f}$ => $\frac{\lambda_{water}}{\lambda_{air}} = \frac{V}{c} = \frac{1}{n} \Rightarrow \lambda_{water} < \lambda_{air}$. ½

½

2) i is proprtional to λ ; upon passing from air to water, the wavelength decreases,this leads to a decrease in the interfringe distance i and the system of fringes seems closer

3) i_{water} = 1.95 mm ; $\frac{i_{water}}{i_{air}} = \frac{\lambda_{water}}{\lambda_{air}} = \frac{1}{n}$; thus $\frac{1.95}{2.6} = \frac{1}{n}$,

We get: n = 1.33 1

Fourth exercise (7 pts)

A- Conservation of mass number: $98 + A = 99 + 1 \Rightarrow A = 2$
Conservation of charge number: $42 + Z = 43 \Rightarrow Z = 1$. ½

B- 1) ${}^{98}_{42}Mo \longrightarrow {}^{99}_{43}Tc + {}^{0}_{1}e + {}^{0}_{0}\upsilon$ ½

2) $\Delta m = m_{before} - m_{after} = 98.88437 - 98.88235 - 55\times10^{-5} = 1.47\times10^{-3}$ u ½

$E = \Delta m\, c^2 = 1{,}47\times10^{-3}\times 931.5\,MeV/c^2 \times c^2 = 1.37$ MeV ¾

3) a- i) ${}^{99}_{43}Tc^{*} \longrightarrow {}^{99}_{43}Tc +$ ½

ii) Electromagnetic ¼

b- i) The conservation of total energy gives :

$m({}^{99}_{43}Tc^{*})c^2 + E^{*}c = m({}^{99}_{43}Tc)\,c^2 + Ec + E(\gamma) \Rightarrow m({}^{99}_{43}Tc^{*})c^2 = m({}^{99}_{43}Tc)\,c^2 + E(\gamma)$

$\Rightarrow m({}^{99}_{43}Tc^{*}) = m({}^{99}_{43}Tc) + \dfrac{E(\gamma)}{c^2} = 98.88235\ u + \dfrac{0.14MeV/c^2}{931.5}\ u = 98.88250\ u$ 1½

ii) $E_1 = \dfrac{hc}{\lambda} \Rightarrow \lambda = \dfrac{hc}{E_1} = \dfrac{6.63\times10^{-34}\times3\times10^{8}}{0.14\times1.60\times10^{\ 13}} = 8.88\times10^{-12}\,m$ ½

C- 1) The molybdenum 99 has a half-life 10 times longer than that of technetium99, it thus lasts stored for a longer time ½

2) The number of nuclei of ${}^{99}_{42}Mo$ at the instant $t_0 = 0$ is :

$N_o = \dfrac{10^{24}}{1.66\times98.88437} = 6.09\times10^{21}$ nuclei 1/2 the number of ${}^{99}_{42}Mo$ nuclei at the instant t = 24 h is

$N = N_o e^{-\lambda t} = 6.09\times10^{21}\, e^{-\frac{0.693\times24}{67}} = 4.75\times10^{21}$ nuclei 1/2

The number of technetium nuclei obtained at the end of 24 hours is : $N_0 - N = 1.34\times10^{21}$ nuclei
The mass of Tc is : $1.34\times10^{21}\times98.88235\times1.66\ 10^{-27} = 0.22$ g
1/2

مسابقة في مادة الفيزياء
المدة: ثلاث ساعات

الاسم:
الرقم:

This exam is formed of four exercises in 4 pages numbered from 1 to 4.

<u>The use of a non-programmable calculator is recommended</u>

<u>First exercise</u> (7 pts.) Determination of the characteristics of a coil

In order to determine the inductance L and the resistance r of a coil, we connect it in series with a capacitor of capacitance C = 160 µF across the terminals of a low frequency generator (LFG) delivering an alternating sinusoidal voltage

$u_g = u_{AD} = 20\sin(100\pi t)$ (u in V , t in s) (figure 1).

The circuit thus carries an alternating sinusoidal current i.

An oscilloscope is connected so as to display the voltage $u_g = u_{AD}$ on the channel Y_A, and the voltage $u_{coil} = u_{BD}$ on the channel Y_B.

We see on the screen of the oscilloscope a display of the waveforms represented in figure 2.

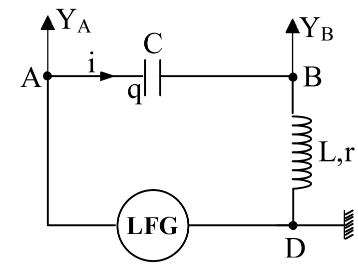


Figure 1

1) Knowing that the vertical sensitivity S_V is the same on both channels, calculate its value.

2) Calculate the phase difference between u_{AD} and u_{BD}. Which of them lags behind the other?

3) Deduce the expression of the voltage u_{BD} across the terminals of the coil as a function of time.

4) Applying the law of addition of voltages, and giving the time t two particular values ,verify that the voltage u_{AB} may be written as

$u_C = u_{AB} = 20\sin(100\pi t - \frac{\pi}{3})$ (u_C in V , t in s).

5) Using the relation between the current i and the voltage u_C, determine the expression of i as a function of time.

6)a) Give the expression of the voltage u_{BD} across the terminals of the coil as a function of i.

b) Calculate r and L by giving t two particular values.

7) In order to verify the preceding calculated values of L and r, we proceed in the following way:

- we measure the average power consumed in the circuit, for ω =100π rad/s and we obtain 8.66 W
- we keep the maximum value of u_g constant but we vary its frequency f ; for f = 71 Hz, the effective value of the current in the circuit is maximum .

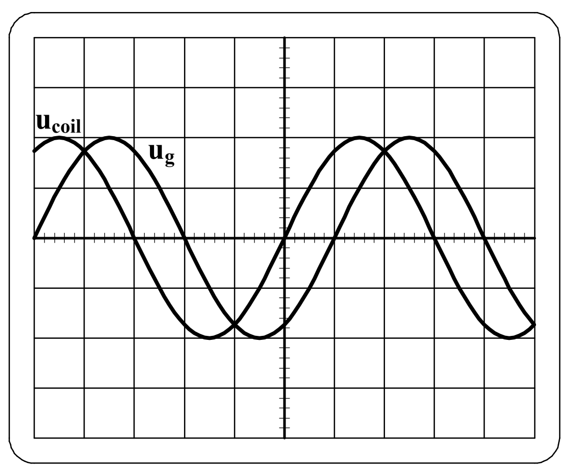


Figure 2

Determine the values of r and L.

<u>Second exercise</u> : (6 ½ pts) Atomic nucleus

The object of this exercise is to compare the values of physical quantities characterizing the stability of different nuclei and to verify that, during nuclear reactions, certain nuclei are transformed into more stable nuclei with the liberation of energy.

Numerical data:

Mass of a neutron: $m_n = 1.0087$ u ; mass of a proton : $m_p = 1.0073$ u ;
mass of an electron : $m_e = 0.00055$ u ; 1 u = 931.5 MeV /c^2.

I – Stability of atomic nuclei

Consider the table below that shows some physical quantities associated with certain nuclei.

Nucleus	${}^{2}_{1}H$	${}^{3}_{1}H$	${}^{4}_{2}He$	${}^{14}_{6}C$	${}^{14}_{7}N$	${}^{94}_{38}Sr$	${}^{140}_{54}Xe$	${}^{235}_{92}U$
Mass (u)	2.0136	3.0155	4.0015	14.0065	14.0031	93.8945	139.892	234.9935
Binding energy E_b (MeV)	2.23	8.57	28.41	99.54	101.44	810.50	1164.75	
Binding energy per nucleon $\frac{E_b}{A}$ (MeV/nucleon)	1.11		7.10		7.25	8.62		

1) ***a)*** Define the binding energy of a nucleus.
   b) Write the expression of the binding energy E_b of a nucleus ${}^{A}_{Z}X$ as a function of Z, A, m_p, m_n, m_X (the mass of the nucleus ${}^{A}_{Z}X$) and the speed of light in vacuum c.
   c) Calculate , in MeV, the binding energy of the uranium 235 nucleus.
   d) Complete the table by calculating the missing values of $\frac{E_b}{A}$.
   e) Give the name of the most stable nucleus in the above table. Justify your answer.
2) Each of the considered nuclei in the table belongs to one of the three groups given by:
   A < 20 ; 20 < A < 190 ; A > 190.

Referring to the completed table, trace the shape of the curve representing the variation of $\frac{E_b}{A}$ as a function of A . Specify on the figure the three mentioned groups.

II – Nuclear reactions and stability of the nuclei

Consider the following three nuclear reactions:

${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$ (reaction 1) ;

${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}H_e + {}^{1}_{0}n$ (reaction 2) ;

${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{140}_{54}X_e + {}^{94}_{38}Sr + 2\,{}^{1}_{0}n$ (reaction 3).

1) Indicate the type of each nuclear reaction (fission, radioactivity or fusion).
2) **a)** Show that each of the above nuclear reactions liberates energy.
b) Referring to the above table, verify that in each of these nuclear reactions, each of the produced nuclei is more stable than the initial nuclei.

Third exercise (6 ½ pts.) Index of refraction of atmospheric air

The index of refraction of pure air is supposed to be equal to 1.
Atmospheric air is not pure, it is polluted; it contains carbon dioxide.
The index of refraction n of polluted air is given by the relation:
$n = 1 + 1.55\times10^{-6}\,y$ where y % represents the percentage of carbon dioxide in air.
In order to determine the value of y, we use Young's double-slit apparatus of interference.
The two slits F_1 and F_2, separated by a distance a, are illuminated with a laser beam of wavelength $\lambda = 0.633$ µm in pure air.
The beam falls normally on the plane (P) that contains the slits.
We observe interference fringes on a screen (E) parallel to (P) found at a distance D from this plane.
Point O is the foot of the orthogonal projection of I, the mid point of F_1F_2 on the plane (E) (figure 1).

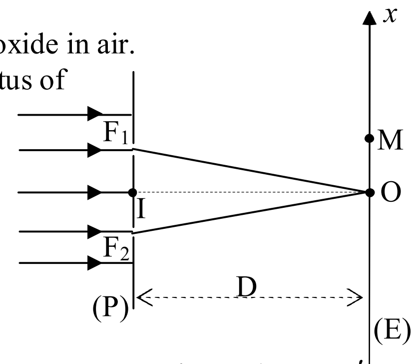


Figure 1

I – Interference in pure air

Recall that for a point M of the screen where OM = x, the optical path difference $\delta = MF_2 - MF_1$ is given by the relation $\delta = \frac{ax}{D}$.

1) O is the center of the central bright fringe. Why?

2) M is the center of the bright fringe of order k.

a) Give the expression of δ in terms of k and λ.

b) Deduce the expression of the interfringe distance i in terms of λ, D and a.

3) M is the point of (E) so that $MF_2 - MF_1 = 1.266\ \mu m$. .

a) Specify the nature and the order of the fringe whose center is at M. Justify your answer.

b) Express x in terms of i.

II- Interference in polluted air

We intend to measure the index of refraction n of air polluted with carbon dioxide. In Young's double- slit apparatus used, we consider that the beam issued from F_2 propagates in pure air whereas the beam issued from F_1 propagates a distance ℓ = 50 cm in polluted air and the rest of its path in pure air (figure 2).
We observe, in this case, that the system of interference fringes is displaced upwards.

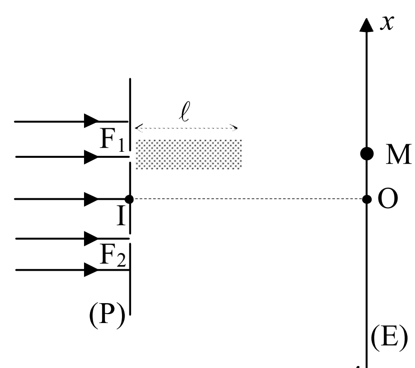


Figure 2

1- Knowing that v is the speed of light issued from F_1 in polluted air , give the expression of the time t that light needs to cover the distance ℓ in polluted air in terms of v and ℓ .

2- Knowing that c is the speed of light in pure air, determine the expression of the distance d that light issued from F_2 would cover in pure air during the same time t in terms of ℓ and n.

3- Give the expression of the increase in the optical path due to the passage in polluted air in terms of ℓ and n.

4- The new expression of the optical path difference is then: $\delta' = MF_2 - MF_1 = \frac{ax}{D} - \ell(n-1)$

a) Knowing that the center of the central bright fringe is displaced up to occupy the position that was occupied by the center of the bright fringe of order 2, the interfringe distance being the same, determine the expression that gives n in terms of ℓ and λ .

b) Show that the value of n is 1.0000025.

5- **a)** The index n being given by : $n = 1 + 1.55\times10^{-6}\,y$, calculate the value of y .

b) Air polluted with carbon dioxide becomes harmful when $y \geq 0.5$.
Is this polluted air harmful? Why ?

<u>Fourth exercise</u> (7 ½ pts) <u>Free mechanical oscillations</u>

A horizontal elastic pendulum is formed of a homogeneous metallic rod MN of mass m = 0.5 kg and of length ℓ , and a spring of un-jointed turns of negligible mass having a stiffness k = 50 N/m.
The length of the spring, when free, is L_0. One of the ends of this spring is connected at I to a fixed support while the other end is connected to the midpoint G of the rod. This rod may slide without friction along the metallic rails AA′ and CC′, that are horizontal and parallel to the axis x′x of the spring ; during sliding, the rod remains perpendicular to the rails , and G moves on the axis x′ x.
We move the rod , from its equilibrium position , kept parallel to itself, by 5cm in the positive direction and then we release it without initial velocity at the instant $t_o = 0$.

At the instant t , the abscissa of G is $x = \overline{OG}$ and $v = \frac{dx}{dt}$ is the algebraic measure of its velocity; the origin of abscissa, O, corresponds to the position of G at equilibrium when the length of the spring is L_0 (figure 1).

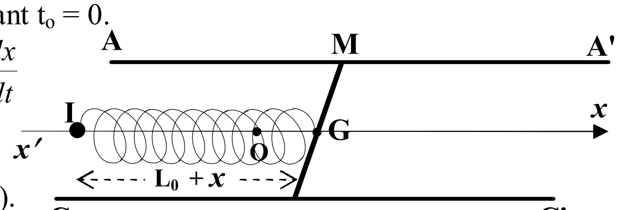


Fig.1

I – Free un-damped oscillations

1) Write, at the instant t, the expression of the mechanical energy M.E of the system (pendulum, Earth) in terms of m, x, k and v taking the horizontal plane through G as a gravitational potential energy reference.

2) Derive the second order differential equation in x that describes the motion of G.

3) The solution of this differential equation is given by the expression: $x = X_m \cos(\omega t + \varphi)$ where X_m is the amplitude of oscillations. Determine the values of ω , X_m and φ .

II –Free damped oscillations

The system formed of the pendulum and the rails is placed within a uniform magnetic field $\vec{B}$, perpendicular to the plane of the rails (figure 2).
We connect between A and C a resistor of convenient resistance ; the resistance of the whole circuit is then R .

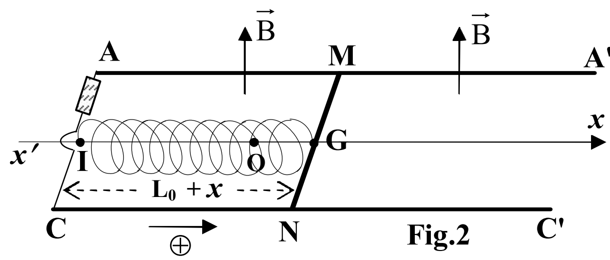


Fig.2

After shifting the rod by 5 cm in the positive direction, we release it from rest at the instant $t_0 = 0$.
An induced current i passes in the circuit .
The horizontal pendulum performs few oscillations then comes to rest within an interval of time t_1.

1) During motion ,an induced electromotive force e appears across the ends M and N of the rod. Explain why.

2) a) Determine, at the instant t , the expression of the magnetic flux through the surface limited by the circuit AMNC in terms of B, L_0, x and ℓ ,taking into account the arbitrary positive direction chosen in figure 2.

b) Deduce the expression of the induced emf e in terms of B, ℓ and v.

c) Determine the expression of i in terms of B, R , ℓ and v.

d) Specify the direction of the current induced when the rod is moving in the positive direction .

3) **a)** Interpret the damping of the oscillations and the stopping of the rod.

b) Calculate the mechanical energy of the oscillator at the instant $t_0 = 0$.

c) Deduce the value of the energy dissipated in the circuit between the instants $t_0 = 0$ and t_1.

d) In what form is this energy dissipated?

Solution

First exercise : (7 pts)

1) The maximum voltage across the terminals of the generator corresponds to 2 div

$\Rightarrow S_V = \dfrac{20\text{ V}}{2\text{div}} = 10\text{V/div}$ **($\frac{1}{2}$ pt)**

2) The phase difference extends over 1 div and the period over 6 div

$\varphi = \dfrac{(1)(2\pi)}{6} = \dfrac{\pi}{3}$ rad. u_g lags u_{coil} **($\frac{3}{4}$ pt)**

3) $(U_m)_{coil} = 20V$, $\omega = 100\pi$ and u_{coil} leads u_g by $\dfrac{\pi}{3}$ rad $\Rightarrow u_{coil} = 20\sin(100\pi t + \dfrac{\pi}{3})$

(1 pt)

4) $u_{AD} = u_{AB} + u_{BD}$. Let $u_{AB} = A\sin(100\pi t + \varphi)$.

$20\sin(100\pi t) = A\sin(100\pi t + \varphi) + 20\sin(100\pi t + \dfrac{\pi}{3})$

For t = 0 , we get : $0 = A\sin\varphi + 20\dfrac{\sqrt{3}}{2}$; $A\sin\varphi = -10\sqrt{3}$

For $100\pi t = \dfrac{\pi}{2}$, we get : $20 = A\cos\varphi + 10$; $A\cos\varphi = 10$

$\Rightarrow \varphi = -\dfrac{\pi}{3}$ and $A = 20$. $\Rightarrow u_{AB} = 20\sin(100\pi t - \dfrac{\pi}{3})$ **($1\frac{3}{4}$ pt)**

5) $i = C\dfrac{du_C}{dt}$; $i = 160\times10^{-6}[20\times100\pi\cos(100\pi t - \dfrac{\pi}{3})] = 1\cos(100\pi t - \dfrac{\pi}{3})$

$= \sin(100\pi t + \dfrac{\pi}{6})$ **($\frac{1}{2}$ pt)**

6) $u_{coil} = ri + L\dfrac{di}{dt}$; $20\sin(100\pi t + \dfrac{\pi}{3}) = r\sin(100\pi t + \dfrac{\pi}{6}) + L(100\pi)[\cos(100\pi t + \dfrac{\pi}{6})]$

For t = 0, we obtain : $20\dfrac{\sqrt{3}}{2} = r(0.5) + 100\pi L\dfrac{\sqrt{3}}{2}$

For $100\pi t = \pi/2$, we obtain : $10 = r\dfrac{\sqrt{3}}{2} - 50\pi L$

$\Rightarrow L = \dfrac{1}{10\pi} = 0.032$ H and $r = 10\sqrt{3}\ \Omega$. **($1\frac{1}{2}$ pt)**

7) The electric power is consumed only in the resistor of the coil :

$P = r(I_{eff})^2 = 8.66 = (\dfrac{1}{\sqrt{2}})^2 r \Rightarrow r = 17.3\Omega = 10\sqrt{3}\Omega$. **($\frac{1}{2}$ pt)**

The observed phenomena is the current resonance. In this case we have :

$LC\omega^2 = 1$; or $L = \dfrac{1}{C\omega^2} = \dfrac{10^6}{160(142\pi)^2} = 0.032$ H. **($\frac{1}{2}$ pt)**

Second exercise : (6 ½ pts)

I - 1- a) The binding energy of a nucleus is the minimum energy needed in order to break the nucleus into its nucleons ($\frac{1}{2}$ pt)

b) $E_b = [Zm_p + (A-Z)m_n - m_X]\,c^2$ ($\frac{1}{2}$ pt)

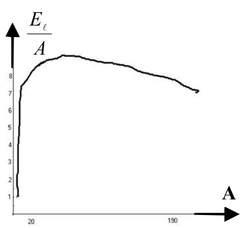
c) $\Delta m = Zm_p + (A-Z)m_n - m_X = 92\times 1.0073 + 143\times 1.0087 - 234.9935 = 1.9222$ u
$E_b = 1.9222\times 931.5$ Mev $= 1790.53$ Mev. (1 pt)

2- a) Table ($\frac{1}{2}$ pt)

${}^{2}_{1}H$	${}^{3}_{1}H$	${}^{4}_{2}He$	${}^{14}_{6}C$	${}^{14}_{7}N$	${}^{94}_{38}Sr$	${}^{140}_{54}Xe$	${}^{235}_{92}U$
1.11	2.86	7.10	7.11	7.25	8.62	8.32	7.62

b) The nucleus that has greater binding energy per nucleon is more stable $\Rightarrow$ strontium is the most stable nucleus ($\frac{1}{2}$ pt)

c) Shape of the curve ($\frac{1}{2}$ pt)



II- 1) Reaction (1) : radioactivity ; reaction (2) : fusion ; reaction (3) : fission. ($\frac{3}{4}$ pt)

2) a) For the radioactivity reaction $\Delta M = M_{before} - M_{after} = 14.0065 - (14.0031 + 0.00055) = 0.00285$ u
For the fusion reaction $\Delta M = M_{before} - M_{after} = 2.0136 + 3.0155 - 4.0015 - 1.0087 = 0.0189$ u
For the fission reaction $\Delta M = M_{before} - M_{after} = 0.1983$ u.
In the 3 reactions there is a mass defect $\Rightarrow$ The 3 reactions liberates energy. ($1\frac{1}{2}$ pt)

b) - The ${}^{14}_{7}N$ nucleus is more stable than the ${}^{14}_{6}C$ nucleus.
- The ${}^{4}_{2}H_e$ nucleus is more stable than the nuclei ${}^{2}_{1}H$ and ${}^{3}_{1}H$.
- The ${}^{140}_{54}X_e$ nucleus and the nucleus ${}^{94}_{38}Sr$ are more stable than the ${}^{235}_{92}U$ nucleus. ($\frac{3}{4}$ pt)

Third exercise (6 ½ pts)

I – **1)** The point O is characterized by $\delta = 0$, So a bright fringe is formed at O. **($\frac{1}{2}$ pt)**

2) a) $\delta = k\lambda$ **($\frac{1}{4}$ pt)**

b) $\delta = \frac{ax}{D} = k\lambda \Rightarrow x_k = \frac{k\lambda D}{a}$ and $x_{k+1} = \frac{(k+1)\lambda D}{a} \Rightarrow i = x_{k+1} - x_k = \frac{\lambda D}{a}$ **(1 pt)**

3) a) $\frac{MF_2 - MF_1}{\lambda} = 2$ is of the form $\delta = k\lambda$ such that $k = 2$; therefore a bright fringe of order 2 is formed at M. **(1pt)**

b) $\frac{ax}{D} = 2\lambda \Rightarrow x = \frac{2\lambda D}{a} = 2i$ **($\frac{1}{2}$ pt)**

II – 1) $t = \frac{\ell}{v}$ **($\frac{1}{2}$ pt)**

2) $d = ct = \frac{c\ell}{v} = n\ell$ **($\frac{1}{2}$ pt)**

3) $n\ell - \ell = \ell(n-1)$ **($\frac{1}{2}$ pt)**

4) a) $\delta' = 0 \Rightarrow \frac{ax}{D} = (n-1)$ et $x = 2i \Rightarrow n = \frac{2\lambda}{\ell} + 1$ **($\frac{1}{2}$ pt)**

b) $n = 1.0000025$ **($\frac{1}{2}$ pt)**

5) a) $1.0000025 = 1 + 1.55\times10^{-6}y \Rightarrow y = 1.61$. **($\frac{1}{2}$ pt)**

b) $y = 1.61 > 0.5$, therefore the air of the room is harmful. **($\frac{1}{4}$ pt)**

Fourth exercise : (7 ½ pts)

I - 1) $M.E = K.E + P.E_e + P.E_g = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 + 0$ **($\frac{1}{2}$ pt)**

2) M.E= cte $\Rightarrow \frac{dM.E}{dt} = 0 = mvv' + kxv \Rightarrow x'' + \frac{k}{m}x = 0$ **($\frac{1}{2}$ pt)**

3) $\omega = \sqrt{\frac{k}{m}} = 10$ rad/s ; $v = -X_m\omega\sin(\omega t + \varphi)$, for $t = 0$, $v = -X_m\omega\sin\varphi = 0$ and $x_0 = X_m\cos\varphi = d > 0 \Rightarrow \sin\varphi = 0 \Rightarrow \varphi = 0$ and $X_m = 5$ cm **(1 $\frac{1}{4}$ pt)**

II - 1) During motion the magnetic flux that traverses the circuit AMNC is:
$\phi = BS\cos0$; S varies $\Rightarrow$ flux varies $\Rightarrow$ the induced e.m.f $e = -\frac{d\varphi}{dt}$ exists **(1 pt)**

2) a) $\phi = BS\cos0 = B(L_0 + x)\,\ell$ **($\frac{1}{2}$ pt)**

b) $e = -\frac{d\varphi}{dt} = -B\ell\frac{dx}{dt} = -B\ell v$ **($\frac{1}{2}$ pt)**

c) The induced current is given by $i = \frac{e}{R} = \frac{-B\ell v}{R}$. **($\frac{1}{2}$ pt)**

d) $v > 0 \Rightarrow i < 0 \Rightarrow$ The induced current circulates in the negatives direction of the circuit (from M to N in the rod). **($\frac{1}{2}$ pt)**

3) a) During motion ,the rod that is within the magnetic field is submitted to Laplace force $\vec{F}$, according to Lenz law it should opposes the causes that producing it, therefore $\vec{F}$ opposes the displacement of the rod and plays the role of the force of friction that causes the damping of the oscillation and finally stops the rod . Therefore the motion is damped. **(1 pt)**

b) At $t_0 = 0$, $M.E = \frac{1}{2}kx_m^2 = 0.0625$ J. **($\frac{1}{2}$ pt)**

c) $|\Delta M.E| = |0 - 0.0625| = 0.0625$ J. **($\frac{1}{2}$ pt)**

d) In the form of electrical energy (or thermal in R). **($\frac{1}{4}$ pt)**

مسابقة في مادة الفيزياء
المدة: ثلاث ساعات

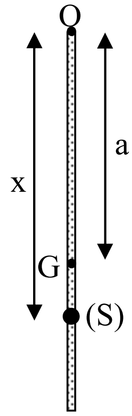
الاسم:
الرقم:

This exam is formed of 4 exercises in 4 pages

The use of a non-programmable calculator is recommended

First exercise : (7 pts)

Mechanical oscillations



The object of this exercise is to study the response of a simple pendulum to the excitations produced by a compound pendulum of adjustable period.

In order to do that, we consider a simple pendulum (R) and a compound pendulum (E). (R) is equiped with a plate of negligible mass, allowing to control the damping due to air. (E) is formed of a homogeneous rod of mass M, of length $\ell = 1$ m and of negligible cross-section, along which a solid (S), taken as a particle of mass M'=M, may slide (E) may oscillate around a horizontal axis (Δ) perpendicular to the rod through its upper extremity O (Figure).

G is the center of gravity of the compound pendulum thus formed and I the moment of inertia of this pendulum about (Δ). Take OG = a and denote by x the distance between the position of (S) and O.

Take : $g = 10$ m/s^2 ; $\pi^2 = 10$; $\sin\theta \approx \theta$ rad pour $\theta \leq 10^0$.

A- Theoretical study

The pendulum (E) is shifted from its equilibrium position by a small angle and then released from resta t the instant $t_0 = 0$. (E) starts to oscillate around its position of stable equilibrum. We neglect all the forces of friction.

At any instant t, OG makes with the vertical through O an angle θ and (E) acquires an angular velocity θ'. The horizontal plane through O is taken as a gravitational potential energy reference for the system [(E), earth]

1- Show that the expression of the mechanical energy of the system [(E)-earth] may be written as :

$$M.E = \frac{1}{2} I\theta'^2 - 2Mga\cos\theta .$$

2- Etermine the second order differential equation in θ that governs the motion of (E) for small oscillations ($\theta \leq 10^o$).

3- **a**) Show that the expression of a may be written as : $a = \frac{\ell + 2x}{4}$.

b) The moment of inertia of the rod alone about the axis (Δ) is : $I_1 = M\frac{\ell^2}{3}$.

Show that the expression of the moment of inertia I is given by : $I = \frac{M(\ell^2 + 3x^2)}{3}$.

4- Show that the expression of the proper period T of (E), in terms of x, may be given in the form

$$T = \sqrt{\frac{8(1+3x^2)}{3(1+2x)}} .$$

B- Experimental study

1- Consider the pendulum (R) alone. It is shifted from its equilibrium position by a small angle, and is then released from rest. The duration t_1 of 10 oscillations is measured and found to be t_1= 16,6 s. Calculate the duration T' of one oscillation.

2- (E) and (R), initially at rest, are coupled by means of a spring. For each value of x, the pendulum (E) is shifted from its equilibrium position by a small angle then released from rest; it causes then (R) to oscillate. We assume that (E) oscillates with a period equal to its proper period T.

When x is made to vary, we notice that the amplitude θ_m of the oscilliations of (R) varies.

a) The oscillations of (R) are said to be forced. Compare then, for each value of x, the period of oscilliations of (R) and that of (E).

b) **i)** We give x the value 0.3 m. In steady state, (R) oscillates with a period T_1 and of amplitude θ_{m1}

ii) We give x the value 0.65m. In steady state, (R) performs oscilliations of period $T_2 = 1,62$ s and of amplitude θ_{m2}. Compare, with justification, θ_{m1} and θ_{m2}.

c) For a certain value of x, and in steady state, (R) oscillates with an amplitude $\theta_{m(max)}$.

i) Give the name of the phenomenon that took place.

ii) Determine the value of x.

d) Trace the shape of the graph that shows the variation of the amplitude θ_m of the oscilliations of (R) as a function of the period T of (E).

e) The plate of (R) is put in such a way so as to increase the friction with air. Trace, on the same sustem of axes of question (d), the shape of the curve that shows the variation of the amplitude θ_m of the oscilliations of (R) as a function of the period T of (E).

<u>Second exercise</u> : (7 pts)

Ignition system in a car

The study of the ignition system in certain cars is reduced to the study of a circuit formed of a coil (B) of inductance L and resistance r, a resistor of resistance R, an ammeter (A) and a switch K, all connected in series across a generator (G) that provides across its terminals M and N a voltage $u_{MN} = E = 12$ V (Figure1).

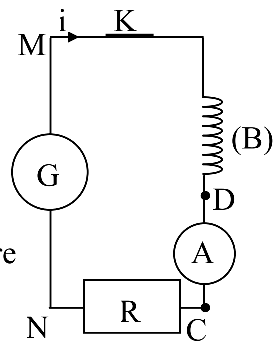
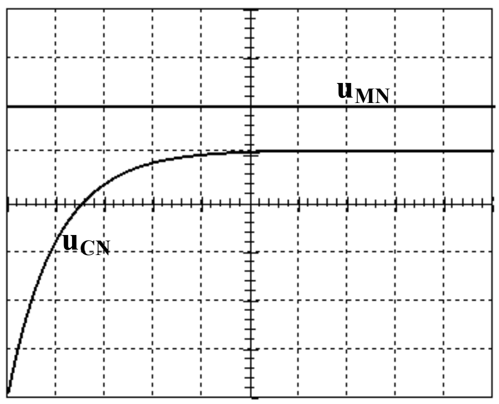


Figure 1

We close the switch K at the instant $t_0 = 0$.
At the instant t, the circuit carries a current i. We display, using an oscilloscope, the voltage u_{MN} on the channel Y_1 and the voltage u_{CN} on the channel Y_2. The waveforms are represented in figure 2.
The vertical sensitivity on both channels is : 2 V / div.
The horizontal sensitivity(time base) is 1 ms /div.
In steady state, the ammeter reads $I_0 = 0,2$ A.

1- Redraw figure 1 showing on it the connections of the oscilloscope.



0 Volt **Figure 2**

2- **a)** Derive the diffenrential equation that governs the variation of the current I as a function of time.

b) i) Show that in steady state: $E = (R + r) I_0$ and that $u_{MD} = rI_0$.

ii) Determine R and r using the waveforms and the preceding results.

3- **a) i)** Show, using the preceding differential equation, that the voltage u_{CN} satisfies the relation $\frac{RE}{L} = \frac{du_{CN}}{dt} + \frac{R+r}{L}u_{CN}$

ii) Deduce the expression of $\frac{du_{CN}}{dt}$, in terms of R, E et L, at the instant $t_0 = 0$.

iii) The time constant τ is the abscissa of the intersection of the tangent at the origin to the curve u_{CN} and the asymptote to that curve. Show that the expression of τ is : $\tau = \frac{L}{R+r}$.

b) Show, using one of the waveforms, that the value of τ is 1 ms.

c) Deduce the value of L.

4- Determine the maximum energy stored in the coil (B).

5- The above circuit (ignition system) helps, through an intermediary switch, to feed the spark plugs of the car at well determined instants, with the energy needed to make the engine function normally.

The expression of the current I, in the circuit, is given by : $i = I_0(1 - e^{\frac{-t}{\tau}})$.

We define the « rate of storage » of the coil as the ratio of the energy stored in the coil at a given instant to the maximum energy it can store. Determine the minimum duration of closure of the switch so that the rate of storage of the coil is not less than 90.3 %.

Third exercise : (7 pts)

Electromagnetic oscillations

An oscillating circuit is formed of a capacitor of capacitance C =1μF and a coil of inductance L and resistance r. In order to determine L and r, we connect up the circuit whose diagram is represented in figure1. The connections of the oscilloscope are as indicated on this figure.

The E.M.F of the generator is : E = 10 V.

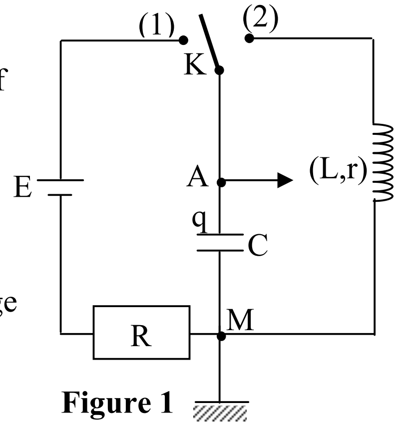


Figure 1

A- Charging the capacitor

The switch K is in position (1). The capacitor is totally charged and the voltage across its terminals is $u_{AM} = U_0$.

1- Determine the value of U_0.

2- Calculate the electric energy stored in the capacitor.

B – Electromagnetic oscillations

The capacitor being totally charged, we move thw switch K to the position (2) at the instant $t_0 = 0$. At the instant t, the circuit carries a current i and the armature (A) carries the charge q.

I – Ideal circuit

In the ideal circuit, we neglect the resistance r of the coil.

1- Redraw figure 1 indicating an arbitrary direction of the current.

2- Derive the differential equation that governs the variation of the voltage $u_{AM} = u_C$ across the terminals of the capacitor as a function of time.

3- Deduce, then, the expression of the proper period T_o of the electric oscilliations in terms of L and C.

4- Give the shape of the curve representing the variation of u_C as a function of time.

5- Specify the mode of electric oscilliations that is taking place in the circuit.

II – Real circuit

The variation of the voltage u_C observed on the screen of the oscilloscope is represented in the waveform of figure2.

1- Specify the mode of electric oscilliations that takes place in the circuit.

2- By referring to the waveform :

a) Give the value of the pseudo-period T of the electric oscillations.

b) Verify that the ratio of two positive extreme values of the voltage u_C is practically equal to a constant a (this is limited to the first four extreme values).

3- We denote by E_n and $E_{(n+1)}$ the electromagnetic energy of the electric oscillator at the instants nT and (n+1)T respectively (n is a positive whole number).

a) The energy stored in the circuit at the instant when the voltage u_C is maximum is electric. Why?

b) Derive the expression of the ratio $\frac{E_{(n+1)}}{E_n}$ in terms of a.

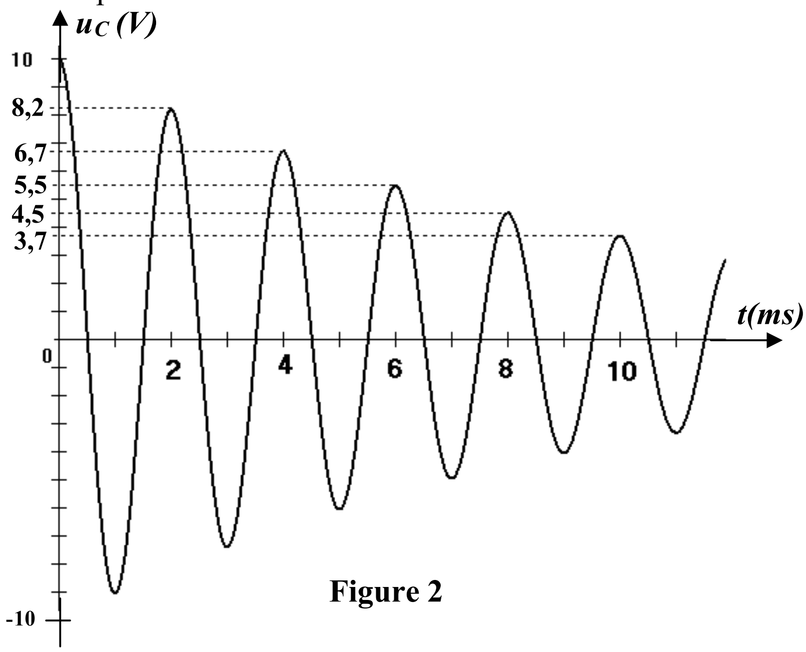


Figure 2

c) Determine L and r knowing that $\frac{E_{(n+1)}}{E_n} = e^{\frac{-r}{L}T}$ and that the expression of the pseudo-period T is:

3

T est : $\frac{4\pi^2}{T^2} = \frac{4\pi^2}{T_o^{\ 2}} - \frac{1}{4}(\frac{r}{L})^2$.

Fourth exercise : (6 ½ pts)

Radioactivity

The object of this exercise is to show evidence of some characteristics of a thorium nucleus 230 and its role in dating.

Given : speed of light in vacuum : $c = 3 \times 10^8$ ms^{-1}; $1eV = 1,6\times 10^{-19}$ J;
Avogadro's number : $N = 6,02\times 10^{23}$ mol^{-1};
Planck's cpnstant :$h = 6,63\times 10^{-34}$ J.s; $1u = 931,5$ MeV/c^2 ;
masses of the nuclei : $m\left({}^{A}_{88}Ra\right) = 225,9770$ u; $m\,({}^{230}_{Z}Th) = 229,9836$ u; $m(\alpha) = 4,0015$u.

A- Decay of a thorium nucleus 230

The thorium nucleus $({}^{230}_{Z}Th)$ is radioactive and is an α emitter . The daughter nucleus is the isotope of the radium$\left({}^{A}_{88}Ra\right)$.

1- **a)** Write the equation of this decay and determine the values of A and Z.
b) Determine the energy liberated by the decay of a thorium nucleus 230.

2- A decay of a thorium nucleus 230 at rest, ttakes place without the emission of γ radiation. The daughter nucleus (${}^{230}_{z}$th) obtained has a speed almost zero. Determine the value of the kinetic energy K.E$_1$ of the emmitted α particle.

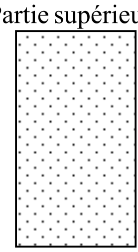
3- Another decay of a thorium nucleus 230 is accompanied with the emission of a γ radiation of wavelength $6\times 1^{0\text{-}12}$ m in vacuum.
a) Calculate the energy of this radiation.
b) Deduce the value of the kinetic energy K.E$_2$ of the emitted α particle.

4- A sample of 1g of thorium nucleus 230of activity $A_0 = 7,2\times 10^8$ decays/s is placed near a sheet of aluminum at the instant $t_0 = 0$. The α particles are stopped by the aluminum sheet whereas the photons are not absorbed.
a) Determine, in J, the energy W transfered to the aluminum sheet during the first second knowing that 50% of the decays are accompanied with γ emission, and that the activity A_o remains practically constant within this second.
b) Calculate the number of nuclei present in 1g of thorium 230. Deduce, in year^{-1}, the value of the radioactive constant λ of thorium 230.

B- Dating of marine sediments

Due to the phenomenon of erosion, a part of the rocks is driven into the oceans.
Some of these rocks contain the radioactive uranium 234 $({}^{234}_{92}U)$ which gives thorium 230.
The uranium 234 is soluble in sea-water, whereas thorium is not, but it is accumulated at the bottom of the oceans with other sediments.
We take a specimen, formed of a cylinder from the bottom of the ocean.
This specimen has an upper layer that is just formed, and a lower layer that is formed a time t ago. We take a sample (a) from the upper part and another sample (b), of the same mass, from the lower part.
It is found that the sample (a) produces 720 decays/s and (b) 86.4 decays/s.
Determine t in years.

Partie supérieure



Partie inférieure

Solution

First exercice : (7 pts)

A- 1- ME = KE + PE_g ; KE $= \frac{1}{2} I\,\theta'^2$; $PE_g = -2Mgh_G$ where $h_G = a\cos\theta$ **(3/4 pt)**

2- $\frac{dME}{dt} = 0 = I\theta'\theta'' + 2\,M\,g\,a\theta'\sin\theta$; for $\theta \le 10^o$ we get : $\theta'' + \frac{2Mga}{I}\theta = 0$ **(3/4pt)**

3- a) $OG = a = \dfrac{\frac{M\ell}{2} + Mx}{2M} = \dfrac{\ell + 2x}{4}$ **(1/2pt)**

b) $I = I(tige) + I(S) = \frac{M\ell^2}{3} + M\,x^2 = \frac{M(\ell^2 + 3x^2)}{3}$ **(1/2pt)**

4- $\omega^2 = \frac{2Mga}{I}$ and $T = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{I}{2Mga}} \Rightarrow T = \sqrt{\frac{8(1+3x^2)}{3(1+2x)}}$ **(1pt)**

B- 1) $T' = \frac{16{,}6}{10} = 1{,}66\,s$ **(1/4pt)**

2) a) T' = T **(1/2pt)**

b) i) $T_1 = T = \sqrt{\frac{8(1+3x^2)}{3(1+2x)}}$. for x = 0,3 m$\Rightarrow T_1 = 1{,}45$ s **(1/2pt)**

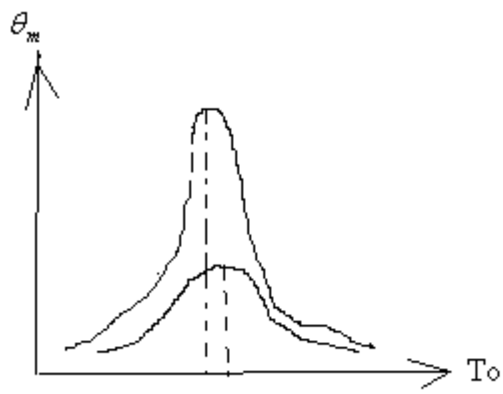
ii) T_2 is closer to T' que T_1, therefore $\theta_{m2} > \theta_{m1}$ **(1/2 pt)**

c) i) Resonance **(1/4pt)**

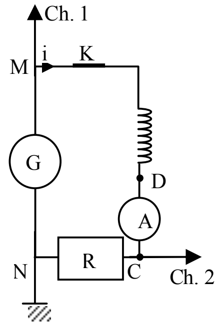
ii) At resonance T = T'$\Rightarrow \sqrt{\frac{8(1+3x^2)}{3(1+2x)}} = 1{,}66$

$\Rightarrow 24x^2 - 16{,}53x - 0{,}27 = 0 \Rightarrow x = 0{,}7$ m **(1pt)**

d) ; e) **(1/2pt)**



<u>Second exercise</u> : (7 pts)



1)Connection of the oscilloscope. **(1/2 pt)**

2) **a)** $u_{MN} = u(B) + u(R)$ **(1/4pt)**

$E = ri + L\frac{di}{dt} + Ri = (R+r)i + L\frac{di}{dt}$

b) i) In steady state, $i = cte = I_0 \Rightarrow \frac{di}{dt} = 0$

$\Rightarrow E = (R+r)\,I_0$ et $u_{MD} = rI_0$ **(1/2pt)**

ii) $R + r = \frac{E}{I_0} \Rightarrow R + r = 60\ \Omega.$

$U_0 = R\,I_0,\quad U_0 = 5\times 2 = 10\ V \Rightarrow R = 50\ \Omega\ ; \Rightarrow r = 10\Omega$ **(1 pt)**

3) **a) i)** $u_{CN} = u_R = Ri \Rightarrow i = \frac{u_{CN}}{R}$ et $\frac{di}{dt} = \frac{1}{R}\times\frac{du_{CN}}{dt}.$

$E = (R+r)\times\frac{u_{CN}}{R} + \frac{L}{R}\frac{du_{CN}}{dt} \Rightarrow \frac{RE}{L} = \frac{du_{CN}}{dt} + \frac{(R+r)}{L}\,u_{CN}$ **(3/4pt)**

ii) at $t = o$, $u_{CN} = 0 \Rightarrow \left(\frac{du_{CN}}{dt}\right)_{t=0} = \frac{RE}{L}$ **(1/2 pt)**

iii) $\left(\frac{du_{CN}}{dt}\right)_{t=0}$ is the slope of the tangent to the curve of u_{CN} :

$\left(\frac{du_{CN}}{dt}\right)_{t=0} = \frac{U_0}{\tau} \Rightarrow \frac{RE}{L} = \frac{U_0}{\tau} \Rightarrow \tau = L\,\frac{U_0}{RE}.$

$\tau = \frac{LI_0R}{[R(R+r)I_0]} = \frac{L}{(R+r)}.$ **(1 pt)**

b) Explanation of the used method. **(1/4pt)**

c) $L = (R+r)\,\tau = 60\times 10^{-3}\ H = 60\ mH.$ **(1/2 pt)**

4) $E_{max} = \frac{1}{2}L\,I_0^2 = \frac{1}{2}\,60\times 10^{-3}\times 0{,}04 = 1{,}2\times 10^{-3}\ J.$ **(1/2 pt)**

5) $i = I_0\,(1 - e^{-t/\tau})\ ;\ E = \frac{1}{2}L\,i^2 = \frac{1}{2}L\,I_0^2\,(1 - e^{-t/\tau})^2$

$\frac{E}{E_{max}} = \frac{0{,}5LI_0^2(1-e^{-t/\tau})^2}{0{,}5LI_0^2} \geq 0{,}903 \Rightarrow (1 - e^{-t/\tau}) \geq \sqrt{0{,}903}$

$\Rightarrow e^{-t/\tau} \leq 1 - \sqrt{0{,}903} = 0{,}05 \Rightarrow \frac{-t}{\tau} \leq Ln\,(0{,}05)$

$\Rightarrow t \geq 3$ ms the minimum duration of closure is 3 ms. **(1 1/4pt)**

<u>Third exercise</u> : (7 pts)

A - 1) At the end of charging $i = 0 \Rightarrow u_C = E - Ri = E = U_0 = 10$ V **(1/2 pt)**

2) $W = ½ C(E)^2 = 5\times10^{-5}$ J **(1/2pt)**

B- I) 1) Figure **(1/4pt)**

2) $u_C = u_{AM} = L\frac{di}{dt}$; $i = -\frac{dq}{dt} = -C\frac{du_C}{dt} = -C\,u'_C$ **;** $\frac{di}{dt} = -C\,u''_C \Rightarrow$

$LC\,u''_C + u_C = 0$ **(3/4pt)**

3) $LC\,u''_C + u_C = 0 \Rightarrow u'_C + \frac{1}{LC}u_C = 0 \Rightarrow$ The proper pulsation ω_0 of the oscillation is $(\omega_0)^2 = \frac{1}{LC} \Rightarrow$ the proper period is $T_0 = \frac{2\pi}{\omega_0} = 2\pi\sqrt{LC}$ **(3/4 pt)**

4) (1/4 pt)

5) The oscillation is free un damped **(1/4 pt)**

II- 1) The oscillation is free damped **(1/4 pt)**

2) a) T = 2 ms **(1/4pt)**

b) $\frac{8,2}{10} = \frac{6,7}{8,2} = \frac{5,5}{6,7} = 0,82$ **= cte =** a **(1/2 pt)**

3) a) Si u_C is max. $\Rightarrow i = -C\frac{du_C}{dt} = 0 \Rightarrow$ the magnetic energy in the coil $E_{magn} = ½ Li^2$ is zero. The energy stored is in the electric form in the capacitor. $[E_{él} = ½ C(u_C)^2]$. **(3/4pt)**

b) $\frac{E_{(n+1)}}{E_n} = \frac{0,5C(u_{Cmax(n+1)})^2}{0,5C(u_{Cmax(n)})^2} = a^2$ **(3/4 pt)**

c) $\frac{E_{(n+1)}}{E_n} = e^{-\frac{r}{L}T} = a^2 \Rightarrow -\frac{rT}{L} = 2\ln a \Rightarrow \frac{r}{L} = \frac{-2\ln a}{T} = -2\frac{\ln 0,82}{0,002} = 198,45$

$\frac{4\pi^2}{T^2} = \frac{4\pi^2}{T_o^2} - \frac{1}{4}(\frac{r}{L})^2$ with $T_0^2 = 4\pi^2 LC = 4\pi^2 \times10^{-6} L$, we get :

L = 0,1 H and r = 20 Ω. **(1 1/4pt)**

Fourth exercise : (6 ½ pts)

A- **1)** a) $({}^{230}_{Z}Th) \longrightarrow \left({}^{A}_{88}Ra\right) + {}^{4}_{2}He$

$230 = A + 4 \Rightarrow A = 226; \quad Z = 88 + 2 = 90.$ **(3/4 pt)**

b) $\Delta m = m({}^{230}_{Z}Th) - m\left({}^{A}_{88}Ra\right) - m({}^{4}_{2}He) = 5{,}1.10^{-3}$ u $= 4{,}75$ MeV/c^2

$E = \Delta m.c^2 = 4{,}75$ MeV. **(1 pt)**

2) The liberated energy appears in the form of kinetic energy of the particle α and electromagnetic energy of the radiation γ : $E = E_C + E(\gamma)$.

In the case where $E(\gamma) = 0$, we obtain $E = E_C = E_{C1} = 4{,}75$ MeV. **(1/2 pt)**

3) a) $E(\gamma) = \frac{hc}{\lambda} = 3{,}315\times10^{-14}$ J $= 0{,}21$ MeV **(1/2 pt)**

b) $E_{C2}({}^{4}_{2}He) = 4{,}75 - 0{,}21 = 4{,}54$ MeV. **(1/2 pt)**

4) a) Let x be the number of decays/s for each type. We get : $xE_{c1} + xE_{c2} = W$; but

$A_0 = 2x = 7{,}2\times10^8$ Bq. $\Rightarrow \frac{A_0}{2}(E_{c1} + E_{c2}) = W \Rightarrow W = 5{,}35\times10^{-4}$ j. **(1 1/4 pt)**

b) $n_0 = \frac{m}{M}N = \frac{6{,}02\times10^{23}}{230} = 2{,}62\times10^{21}$ nuclei ; $\lambda = \frac{A_0}{n_0} = 2{,}75\times10^{-13}$ s^{-1} $= 86724\times10^{-10}$ year^{-1}. **(1 pt)**

B- $A = A_0 e^{-\lambda t} \Rightarrow \ln 0{,}12 = -\lambda t \Rightarrow t = 244484$ years. **(1 pt)**

وزارة التربية والتعليم العالي
المديرية العامة للتربية
دائرة الامتحانات

امتحانات الشهادة الثانوية العامة
فرع العلوم العامة

دورة سنة 2007 العادية

مسابقة في مادة الفيزياء
المدة: ثلاث ساعات

الاسم:
الرقم:

This exam is formed of four exercises in four pages numbered from 1 to 4
<u>The use of a non-programmable calculator is recommended</u>

<u>First exercise</u> *(7 ½ pts)* **Solid in rotation**

Consider a rigid rod AB, of negligible mass and of length AB = L = 80 cm. The rod may rotate around a horizontal axis (Δ), perpendicular to it through its midpoint O. Two identical particles, each of mass m = 10g , may slide along this rod. Take $g = 10\ m/s^2$; $0.32\pi = 1$.

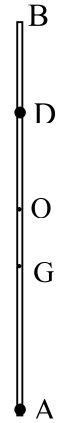


Fig.1

I- Work done by the couple of friction

We fix one of the two particles at the end A of the rod while the other particle is fixed at another point D , at a distance $\frac{L}{4}$ from O .

G being the centre of gravity of the system (S) formed of the rod and the two particles, we suppose OG = a .

Take as a gravitational potential energy reference, the horizontal plane through G when (S) is in the position of stable equilibrium (Fig.1).

1) Show that $a = \frac{L}{8}$.

2) (S) is in its stable equilibrium position .At the instant $t_0 = 0$, we communicate to (S) an initial kinetic energy $E_0 = 1.95 \times 10^{-4}$ J ; (S) oscillates then around (Δ), on both sides of its position of stable equilibrium. At an instant t, OG makes an angle θ with the vertical through O.

a) Neglecting friction, show that:

i. the expression of the gravitational potential energy of the system [(S),Earth] is $P.Eg = 2mga(1-\cos\theta)$;

ii. the value of the mechanical energy of the system [(S), Earth] is E_0 ;

iii. the value of the angular amplitude of the motion of (S) is $\theta_m = 8^o$.

b) In reality, the forces of friction form a couple whose moment about the axis (Δ) is $\mathcal{M}$. We suppose that $\mathcal{M}$ is constant .The measurement of the first maximum elongation of (S) is then $\theta_{1m} = 7°$ at the instant t_1.

i. Determine the expression giving the variation of the mechanical energy of the system [(S), Earth] between t_0 and t_1 in terms of m, g, a, θ_{1m} and E_0 .

ii. Deduce the value W of the work done by $\mathcal{M}$ between t_0 and t_1.

II- Moment of the couple of friction

We fix each particle on an extremity of the rod (figure 2). At the instant $t_0 = 0$, and we give (S), a rotational speed $N_0 = 1$ turn/s and we suppose that $\mathcal{M}$ keeps the same preceding value.

1) Show that the moment of inertia of (S) with respect to (Δ) is $I = 32 \times 10^{-4}\ kg.m^2$.

2) Show that the value of the angular momentum of (S) with respect to (Δ), at t_0, is $\sigma_0 = 2 \times 10^{-2}\ kg.m^2/s$.

3) a) Give the names of the external forces acting on (S).

b) Show that the value of the resultant moment of these forces, with respect to (Δ), is equal to $\mathcal{M}$.

c) Find, applying the theorem of angular momentum, the expression of the angular momentum σ of (S) with respect to (Δ), in terms of $\mathcal{M}$, t and σ_0.

4) Launched with the rotational speed $N_0 = 1$ turn/s, (S) stops at the instant t' = 52.8 s. Determine then the value of $\mathcal{M}$.

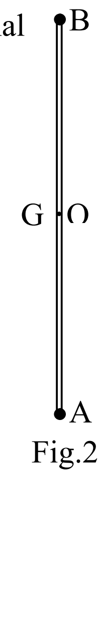


Fig.2

III- Relation between W and $\mathcal{M}$

Referring to the parts **I** and **II**, verify that the work W is $W = \mathcal{M} \times \theta_{1m}$.

Second exercise (6 ½ pts) Energy dissipated during the charging of a capacitor

The object of this exercise is to determine the energy dissipated, by Joule's effect, during the charging of a capacitor.

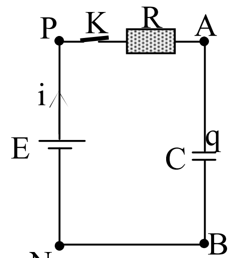


Fig.1

We charge a capacitor of capacitance $C = 5 \times 10^{-3}$F, initially neutral, using an ideal generator of constant voltage of e.m.f E through a resistor of resistance $R = 200\ \Omega$ (fig.1).
At the instant $t_0 = 0$, the switch K is closed. The circuit thus carries a current i at the instant t.

I-Exploiting a waveform

Using an oscilloscope, we display the variations of the voltage $u_R = u_{PA}$ across the resistor and that of $u_C = u_{AB}$ across the capacitor.
We obtain the waveforms of figure 2.

1) The curve (b) represents the variation of u_R as a function of time. Why?

2) Determine, using the waveforms:

a) the value of E ;

b) the maximum value I of i;

c) the time constant τ of the RC circuit.

3) Give the time at the end of which the capacitor will be practically completely charged.

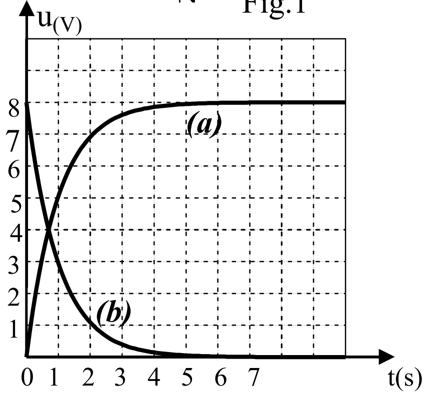


Fig.2

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II- Theoretical study of charging

1) Show that the differential equation in u_C may be written as: $E = RC\dfrac{du_C}{dt} + u_C$

2) The solution of this equation has the form $u_C = A e^{\frac{-t}{\tau}} + B$ where A, B and τ are constants.

a) Determine , starting from the differential equation ,the expression of B in terms of E and that of τ in terms of R and C.

b) Using the initial condition, determine the expression of A in terms E.

3) Show that: $i = \dfrac{E}{R} e^{\frac{-t}{\tau}}$.

III- Energetic study of charging

1) Calculate the value of the electric energy W_C stored in the capacitor at the end of the charging process.

2) The instantaneous electric power delivered by the generator at the instant t is $p = \dfrac{dW}{dt} = Ei$ where W is the electric energy delivered by the generator between the instants t_0 and t.

a) Show that the value of the electric energy delivered by the generator during the whole duration of charging is 0.32 J.

b) Deduce the energy dissipated due to Joule's effect in the resistor.

Third exercise (6 ½ pts) Ionization energy

Given: 1 eV = 1.6×10^{-19}J ; Planck's constant h = 6.62×10^{-34} J.s; speed of light in vacuum c = 3×10^{8} m/s.

The object of this exercise is to compare the ionization energy of the hydrogen atom with that of the helium ion He^{+} and that of the lithium ion Li^{2+} each having only one electron in the outermost shell.

The quantized energy levels of each is given by the expression $E_n = -\dfrac{E_0}{n^2}$ where E_0 is the ionization energy and n is a non-zero positive whole number.

I- Interpretation of the existence of spectral lines

1) Due to what is the presence of emission spectral lines of an atom or an ion?

2) Explain briefly the term "quantized energy levels"**.**

3) Is a transition from an energy level m to another energy level p (p < m) a result of an absorption or an emission of a photon? Why?

II- Atomic spectrum of hydrogen

For the hydrogen atom $E_0 = 13.6$ eV.

1) A hydrogen atom, found in its ground state, interacts with a photon of energy 14 eV.

a) Why?

b) A particle is thus liberated. Give the name of this particle and calculate its kinetic energy.

2) ***a)*** Show that the expression of the wavelengths λ of the radiations emitted by the hydrogen atom is:

$\frac{1}{\lambda} = R_1(\frac{1}{p^2} - \frac{1}{m^2})$ where m and p are two positive whole numbers so that m > p and R_1 is a positive constant to be determined in terms of E_o, h and c. .

b) Verify that $R_1 = 1.096 \times 10^7$ m^{-1}.

III- Atomic spectrum of the helium ion He^+

The spectrum of the ion He^+ is formed, in addition to others, of two lines whose corresponding reciprocal wavelengths $\frac{1}{\lambda}$ are: 3.292×10^7 m^{-1} ; 3.901×10^7 m^{-1} respectively. These lines correspond, respectively, to the transitions: (m = 2 $\rightarrow$ p = 1) and (m = 3 $\rightarrow$ p = 1).

1)a) Show that the values of $\frac{1}{\lambda}$ satisfy the relation $\frac{1}{\lambda} = R_2(\frac{1}{p^2} - \frac{1}{m^2})$ where R_2 is a positive constant.

b) Deduce that $R_2 = 4.389 \times 10^7$ m^{-1}.

2) Find a relation between R_2 and R_1.

IV-Atomic spectrum of the lithium ion Li^{2+}

Also, the ion Li^{2+} may emit radiations whose wavelengths λ are given by : $\frac{1}{\lambda} = R_3(\frac{1}{p^2} - \frac{1}{m^2})$

where m and p are two positive whole numbers so that m > p and $R_3 = 9.860 \times 10^7$ m^{-1} .

Find a relation between R_3 and R_1.

V-Charge number and ionization energy

The charge numbers Z of the elements hydrogen, helium and lithium are respectively 1 , 2 and 3 .

Compare the ionization energy of the hydrogen atom with that of He^+ ion and that of Li^{2+} ion. Conclude.

Fourth exercise (7 pts) An analogy

The object of this exercise is to show evidence of the analogy between a mechanical oscillator and an electric oscillator in the case of free oscillations.

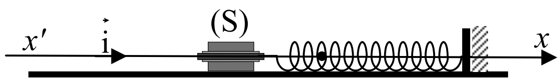


Fig.1

A- Mechanical oscillator

A horizontal mechanical oscillator is formed of a solid (S) of mass m = 0.546 kg and a spring of un-jointed turns of stiffness k = 5.70 N/m and of negligible mass .

The center of mass G of (S) is initially at the equilibrium position O on the axis x'x.

(S), shifted from O by a certain distance, is then released without initial velocity at the instant $t_0 = 0$.

G thus performs a rectilinear motion along the axis x'x (fig.1). At the instant t, its abscissa is x $(\overrightarrow{OG} = x\,\vec{i})$ and its velocity is $\vec{V}$ $(\vec{V} = V\vec{i} = \frac{dx}{dt}\vec{i})$.

The horizontal plane through the axis x’x is taken as a gravitational potential energy reference.

I – General study

1) Write down the expression of the mechanical energy M.E of the system [oscillator, Earth] in terms of m, k, x and V.

2) Determine the expression giving $\frac{d(M.E)}{dt}$, the derivative of M.E with respect to time.

II- Free non-damped oscillations

We neglect all friction.

1) Derive the second order differential equation that governs the variations of x as a function of time.

2) Deduce the expression of the proper frequency f_0 of the oscillator and show that its value is 0.51 Hz.

III- Free damped oscillations

In reality, the force $\vec{F}$ of friction is not negligible and its expression is given by: $\vec{F} = - \lambda\ \vec{V}$ at an instant t , λ being a positive constant.

1) Derive the second order differential equation describing the variations of x as a function of time knowing that $\frac{d(M.E)}{dt} = \vec{F}.\vec{V}$

2) The adjacent figure2 shows the variations of x as a function of time.

a) How does the effect of the force of friction appear?

b) Determine the pseudo-frequency f of the mechanical oscillations.

c) Calculate the value of λ, knowing that f is given by the expression :

$$f^2 = (f_0)^2 - \frac{1}{4\pi^2}\left(\frac{\lambda}{2m}\right)^2.$$

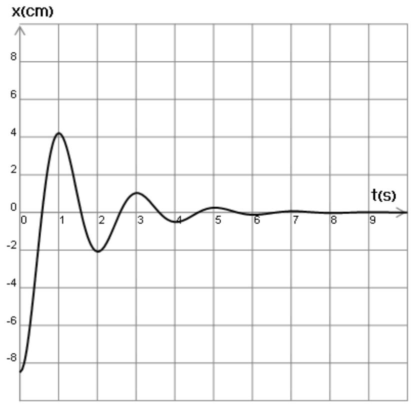


Fig.2

B-Electric oscillator

This oscillator is a series circuit formed of a coil of inductance L= 43 mH and of resistance r =11 Ω, a resistor of adjustable resistance R , a switch K and a capacitor of capacitance C = 4.7 μF initially charged with a charge Q (Fig.3).

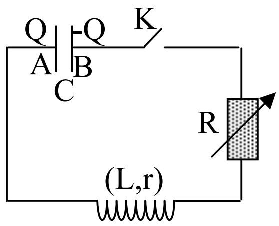


Fig. 3

We close the switch K at the instant t_0 = 0. The circuit is thus the seat of electric oscillations. At the instant t, the armature A carries a charge q and the circuit carries a current i (Fig.4).

1) Write down the expression of the electromagnetic energy E of the circuit at the instant t (total energy of the circuit) as a function of L, i, q and C.

2) Knowing that $\frac{dE}{dt} = -(R+r)i^2$, derive the second order differential equation of the variations of q as a function of time.

3) Give the expression of the proper frequency f_0' of the electric oscillations and show that its value is 354.2 Hz.

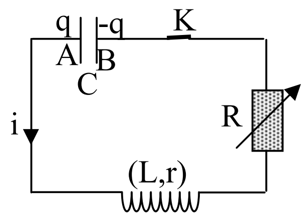


Fig. 4

4) The figure 5 gives the variations of q as a function of time.

a) Due to what is the decrease with time in the amplitude of oscillations?

b) Determine the pseudo-frequency f' of the electric oscillations.

C-An analogy

1) Match each of the physical mechanical quantities x, V, m, λ and k with its corresponding convenient electric quantity.

2) a) Deduce the relation between f', f_0', L and (R + r).

b) Calculate the value of R.

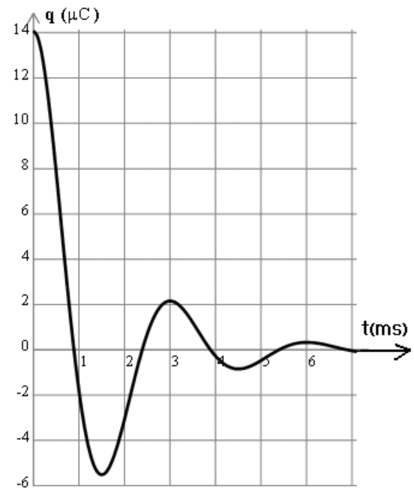


Fig.5

Solution

First exercise (7 ½ pts)

I- 1) a = OG = $\frac{m\frac{L}{2}-m\frac{L}{4}}{2m}=\frac{L}{8}$ **. (1/2 pt)**

2) a- i) $PE_g = M_t\, gh_G = 2mg\,(a - a\cos\theta) = 2mga(1-\cos\theta)$. **(1/2pt)**

ii) The mechanical energy is conserved because friction is neglected
$\Rightarrow ME_i = ME_f \Rightarrow ME = KE_0 + PE_{g0} = KE_0 + 0$ (For $\theta = 0$).**(1/2pt)**

iii) $ME_i = ME_f \Rightarrow 1.95\times 10^{-4} = 2mg.a\,(1 - \cos\theta_m) \Rightarrow \theta_m = 8^0$ **(1/2pt)**

b- i) $\Delta ME = 2mga(1 - \cos\theta_{1m}) - KE_0$ **(1/2pt)**

ii) $W = \Delta ME = 2 \times 0.01 \times 10 \times 0.1(1- 0.99255) - 1.95 \times 10^{-4}$
$= 1.49 \times 10^{-4} - 1.95 \times 10^{-4} = -4.6 \times 10^{-5}$ J. **(1/2 pt)**

II- 1) $I = 2m\frac{L^2}{4} = 32 \times 10^{-4}$ kg.m^2. **(1/2 pt)**

2) $\sigma_0 = I\,\theta_0' = I\times 2\pi N_0 = 2 \times 10^{-2}$ kg.m^2/s. **(3/4pt)**

3) a) The forces applied on (S) are : weight $\mathbf{2}\,m\vec{g}$
the reaction $\vec{R}$ of axis (Δ) and the couple of friction. **(1/2pt)**

b) $\Sigma\, \mathcal{M}/\Delta = \mathcal{M}(\vec{R})/\Delta + M(\mathbf{2}\,m\vec{g})/\Delta + \mathcal{M}$ (couple) $/\Delta$;
or $\mathcal{M}(\vec{R}) = \mathcal{M}$ (weight) = 0 (because the 2 forces passes through the axis) ;
$\Rightarrow \Sigma\,\mathcal{M} = \mathcal{M}$ **(1/2pt)**

c) $\frac{d\sigma}{dt} = \Sigma\,\mathcal{M} = \mathcal{M} \Rightarrow \sigma = \mathcal{M}\,t + \sigma_0$. **(1 pt)**

4) $\theta' = 0 \Rightarrow \sigma = 0 = \mathcal{M}\,t' + \sigma_0 \Rightarrow \mathcal{M} = -\frac{\sigma_0}{t'} = -3.78 \times 10^{-4}$ m.N. **(3/4 pt)**

III- $\mathcal{M}\,\theta = -3.78 \times 10^{-4} \times \frac{7\times\pi}{180} = -4.6 \times 10^{-5}$ J and $W = -4.6 \times 10^{-5}$ J
$\Rightarrow W = \mathcal{M}\,\theta$ (θ in rad). **(1/2pt)**

Second exercise (6 ½ pts)

I- 1) The current i decreases with time, [at the end of charging i = 0] $\Rightarrow$ the voltage $u_R = Ri$ is represented by the curve (b). **(1/2 pt)**

2) a) Explantion : at the end of charging $u_C = E$; $E = 8$ V. **(1/2 pt)**

b) $RI = 8 \Rightarrow I = \frac{8}{200} = 0.04$ A. **(1/2 pt)**

c) Method **(1/2 pt)** $\tau = 1$s. **(1/4 pt)**

3) $5\tau = 5$ s **(1/4 pt)**

II- 1) $u_R = Ri = R\frac{dq}{dt} = RC\frac{du_C}{dt}$; thus $E = u_R + u_C = RC\frac{du_C}{dt} + u_C$ **(1/2 pt)**

2) a) $u_C = Ae^{-\frac{t}{\tau}} + B \Rightarrow (-\frac{RCA}{\tau})e^{-\frac{t}{\tau}} + Ae^{-\frac{t}{\tau}} + B = E \Rightarrow B = E$ and $\tau = RC$ **(1 pt)**

b) For t = 0 $u_C = 0 = A + B \Rightarrow A = -B = -E$. **(1/2 pt)**

3) $u_C = E(1 - e^{-\frac{t}{\tau}})$ thus $i = C\frac{du_C}{dt} = C\frac{E}{RC}e^{-\frac{t}{\tau}} = \frac{E}{R}e^{-\frac{t}{\tau}}$. **(1/2 pt)**

III- 1) $W_C = \frac{1}{2}CE^2 = 0.16$ J **(1/2 pt)**

2) a) $\frac{dW}{dt} = Ei \Rightarrow W$ = primitive of Ei = primitive of $E\frac{E}{R}e^{-\frac{t}{\tau}} \Rightarrow$

$W = -CE^2 e^{\frac{-t}{\tau}} + cte.$

For t = 0, the electric energy delivered by the generator is zero $\Rightarrow$

$cte = CE^2 \Rightarrow$ the expression of the dissipated energy as a function of time is :

$W = CE^2(1 - e^{\frac{-t}{\tau}})$.

For t = 5RC (as $t \to \infty$), $1 - e^{\frac{-t}{\tau}} \to 1$ and $W = CE^2 = 0.32$ J **(3/4 pt)**

b) $W_R = W_e - W_C = CE^2 - \frac{1}{2}CE^2 = \frac{1}{2}CE^2 = 0.16$ J **(1/4 pt)**

Third exercise (6 ½ pts)

I -

1) The presence of the lines in this emission spectrum is due to photon, the wavelength is a well determined value that the atom emits it when it undergoes a down ward transition from a higher energy level to a lower energy level. **(1/2 pt)**

2) The atom absorbed a well determined value. **(1/2 pt)**

3) $E_P < E_m \Rightarrow$ the atom loses energy by emitting one photon. **(1/2 pt)**

II – 1) a) The energy of the photon (14 eV) greater than the ionization energy (13.6 eV) **(1/4pt)**

b) Electron ; KE = 14 – 13.6 = 0.4 eV. **(1/2 pt)**

2) a) When an atom of the hydrogenoied pass from a level m to a lower level p, it emits a photon of energy $h\nu = \frac{hc}{\lambda} = E_m - E_p = -\frac{E_0}{m^2} + \frac{E_0}{p^2} \Rightarrow$

$\frac{1}{\lambda} = \frac{E_0}{hc}(\frac{1}{p^2} - \frac{1}{m^2})$ it has the form of $\frac{1}{\lambda} = R_1(\frac{1}{p^2} - \frac{1}{m^2})$ with $R_1 = \frac{E_0}{hc}$ **(1 1/4 pt)**

b) $R_1 = \frac{E_0}{hc} = \frac{13.6 \times 1.6 \times 10^{-19}}{6.62 \times 10^{-34} \times 3 \times 10^8} = 1.096 \times 10^7 \text{ m}^{-1}$. **(1/2 pt)**

III - 1) a) We get : $R_2 = \frac{1}{\lambda(\frac{1}{p^2} - \frac{1}{m^2})}$

For p = 1 and m = 2 gives $\frac{3.292 \times 10^7}{(\frac{1}{1^2} - \frac{1}{2^2})} = 4.389 \times 10^7 \text{ m}^{-1}$

For p = 1 and m = 3 gives $\frac{3.901 \times 10^7}{(\frac{1}{1^2} - \frac{1}{3^2})} = 4.389 \times 10^7 \text{ m}^{-1}$

The value of $\frac{1}{\lambda(\frac{1}{p^2} - \frac{1}{m^2})}$ is the same for the two transitions. **(1pt)**

b) The calculation gives $R_2 = 4.389 \times 10^7 \text{ m}^{-1}$. **(1/4 pt)**

2) $\frac{R_2}{R_1} = 4$ **(1/4 pt)**

IV - $\frac{R_3}{R_1} = 9$. **(1/4 pt)**

V - As Z increases, R increases because $R = \frac{E_0}{hc} \Rightarrow$ the ionization energy E_0 increases as Z increases. **(3/4pt)**

Fourth exercise (7pts)

A- I- 1) $ME = \frac{1}{2} mV^2 + \frac{1}{2} kx^2$ **(1/4 pt)**

2) $\frac{dME}{dt} = mx'x'' + kxx'$ **(1/4 pt)**

II- 1) in this case $\frac{dME}{dt} = 0 \Rightarrow x'' + \frac{k}{m} x = 0$ **(1/4 pt)**

2) The proper angular frequency of oscillations is $\boldsymbol{\omega_0} = \sqrt{\frac{k}{m}} \Rightarrow$ the proper frequency is

$\mathbf{f_0} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$. **(1/2 pt)**

$f_0 = 0.51$ Hz. **(1/4 pt)**

III- 1) $\frac{dME}{dt} = \vec{F} \cdot \vec{v} \Rightarrow mx'x'' + kxx' = -\lambda x' x' \Rightarrow x'' + \frac{\lambda}{m} x' + \frac{k}{m} x = 0$. **(1/2 pt)**

2) a) The effect of the force of friction is to decrease the amplitude **(1/4 pt)**

b) The pseudo-period is $T = 2$ s $\Rightarrow f = 0.5$ Hz. **(1/2 pt)**

c) $\lambda = 0.685$ kg/s. **(1/2 pt)**

B- 1) $E = \frac{1}{2} Li^2 + \frac{1}{2} \frac{q^2}{C}$. **(1/4 pt)**

2) $\frac{dE}{dt} = -(R+r)i^2 \Rightarrow Lii' + \frac{1}{C} qq'$; with $i = -q'$ and $i' = -q''$

$\Rightarrow Lq'q'' + \frac{1}{C} qq' = -(R + r)(q')^2 \Rightarrow q'' + \frac{(R+r)}{L} q' + \frac{1}{LC} q = 0$. **(1/2 pt)**

3) $\mathbf{f'_0} = \frac{1}{2\pi\sqrt{LC}}$. $f'_0 = 354.2$ Hz. **(1/2 pt)**

4) a) the energy lost in the circuit is due to Joule's effect. **(1/4 pt)**

b) $T = 3$ ms $\Rightarrow f' = 333.3$ Hz. **(1/2 pt)**

C –

1) x ---------> q **(1/4 pt)**

V----------> i **(1/4 pt)**

m ---------> L **(1/4 pt)**

λ ---------> (R+r) **(1/4 pt)**

k ---------> $\frac{1}{C}$ **(1/4 pt)**

2) a) $\mathbf{f'^2 = (f'_0)^2} - \frac{1}{4\pi^2}\left(\frac{R+r}{2L}\right)^2$ **(1/4 pt)**

b) $R = 54\ \Omega$. **(1/4 pt)**

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

This exam is formed of four exercises in 4 pages

<u>The use of non-programmable calculators is recommended</u>

<u>First exercise</u> (7 pts) Mechanical oscillations

Consider a pierced disk (D) , of mass M = 59 g , that may rotate , without friction ,about a horizontal axis (Δ) perpendicular to its plane through O , O being the center of the homogeneous disk before being pierced. The center of mass G of the pierced disk (D) is at a distance a from O (a = OG)

The object of this exercise is to determine the value of a and that of the moment of inertia I of the disk (D) with respect to the axis (Δ).

The horizontal plane through O is taken as a gravitational potential energy reference.

Take : $\sin\theta = \theta$ and $\cos\theta = 1 - \frac{\theta^2}{2}$ for small angles ,θ being in radian ; $g = 10\ m/s^2$; $\pi^2 = 10$

I – Compound pendulum

The disk (D) is at rest in its position of stable equilibrium. We shift it by a small angle θ_m and then we release it without velocity at the instant $t_0 = 0$.

The compound pendulum thus formed oscillates without friction on both sides of its equilibrium position with a proper period T_1 (Fig.1).

At an instant t, the position of (D) is defined by its angular abscissa θ that OG makes with the vertical OY, and its angular velocity is $\theta' = \frac{d\theta}{dt}$.

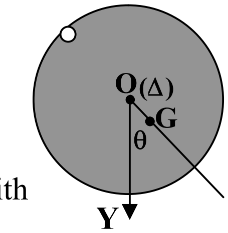


Fig.1

1) Write down, at the instant t, the expression of the kinetic energy of the pendulum in terms of I and θ' .

2) Show that the expression of the gravitational potential energy of the system (pendulum, Earth) is $P.E_g = -\,M\,g\,a\cos\theta$.

3) Write down the expression of the mechanical energy of the system (pendulum, Earth) in terms of M, g, a, θ , θ' and I.

4) Derive the second order differential equation that governs the motion of (D).

5) Deduce that the expression of the proper period T_1, for small oscillations, can be written as :

$$T_1 = 2\pi\sqrt{\frac{I}{Mga}}$$

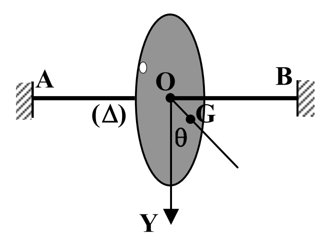


Fig.2

II- Oscillating system

The disk (D) is now welded from its center to two identical and horizontal torsion wires OA and OB (OA = OB) (Fig.2). The extremities A and B are fixed.

The torsion constant of each of the wires is $C = 2.8\times10^{-3}$ m.N.

Starting from its stable equilibrium position, we turn (D) by a small angle θ_m around AB, confounded with (Δ) ; the two wires are twisted , in the same direction, by the same angle θ_m .

Released without velocity at the instant $t_0 = 0$, (D) starts to oscillate around the horizontal axis AB. At an instant t, the position of (D) is defined by its angular abscissa θ that OG makes with the vertical OY, (each wire is then twisted by θ) and its angular velocity is θ'. The oscillating system performs then a periodic motion of proper period T_2 .

1) ***a)*** Write down, at an instant t, the expression of the torsion potential energy of the wires in terms of C and θ.

b) Give then the expression of the potential energy of the system (oscillating system, Earth) in terms of C, θ, M, g and a.

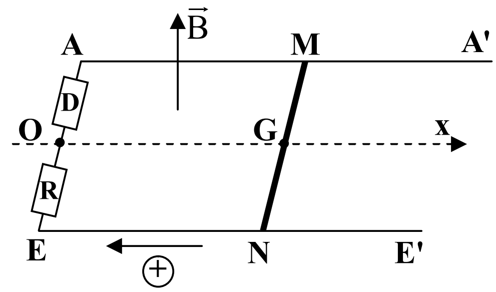
c) Deduce the expression of the mechanical energy of the system (oscillating system, Earth).

2) Determine the expression of the proper period T_2 in terms of I, M, a, g and C.

III- Values of I and a

Knowing that the measured values of T_1 and T_2 are $T_1 = 4.77$s and $T_2 = 2.45$s, use the results of parts **I** and **II**, deduce the values of I and a.

Second exercise (7pts) Mode of charging a capacitor



A metallic rod MN, of length ℓ =1m and of negligible resistance, may slide without friction along two long parallel and horizontal rectilinear rails AA' and EE' of negligible resistance. During its displacement, the rod remains perpendicular to the rails. An electric component (D) and a resistor of resistance R = 100 Ω are connected to the rails with connecting wires. The whole set-up thus described is placed in a uniform vertically upwards magnetic field $\vec{B}$ of magnitude B = 0.8 T (adjacent figure).

At the instant $t_0 = 0$, the center of mass G of the rod is at O. A convenient apparatus causes the rod to move in a uniform translational motion from left to right with a speed v = 0.5 m/s.

At an instant t , the position of G is defined by its abscissa $x = \overline{OG}$ on the axis x'x.

1) Find, at the instant t, the expression of the magnetic flux that crosses the surface AMNE in terms of B, ℓ and x taking into consideration the positive direction indicated on the figure.

2) ***a)*** Explain the existence of an induced e.m.f e across the ends M and N of the rod and show that its value is 0.4 V .

b) At the instant t, an induced current i passes in the circuit. Determine its direction.

c) Draw a diagram showing the equivalent generator between M and N and specify its positive terminal.

3) The component (D) is a capacitor of capacitance $C = 10^{-2}$ F. During the displacement of the rod, (D) undergoes the phenomenon of electric charging.

a) Derive the differential equation that describes the variations of $u_C = u_{OA}$ as a function of time.

b) ***i)*** Calculate the value of the time constant of the circuit thus formed.

ii) After how long would the capacitor be practically charged completely?

c) At the end of charging, the voltage across the capacitor is U and its charge is Q. Calculate U and Q.

d) Determine the values of i at the instants $t_0 = 0$ and $t_1 = 6$ s.

e) At the instant $t_1 = 6$ s, the rod is stopped. The circuit carries again a current.

i) Due to what is this current?

ii) Specify the duration of the passage of this current.

Third exercise (7 pts) The two aspects of light

A – Diffraction

A source of monochromatic radiation of wavelength λ in air illuminates under normal incidence a horizontal slit F of adjustable width a cut in an opaque screen (P). A screen of observation (E) is placed parallel to (P) at a distance D = 5 m (Fig.1).

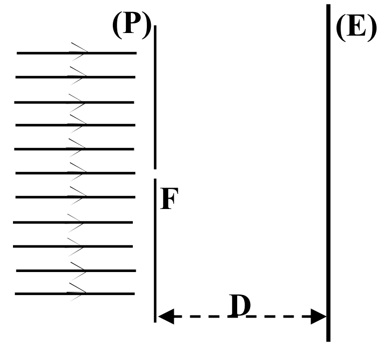


Fig. 1

1) For $\lambda = 0.5\ \mu m$, show on a diagram the shape of the luminous beam emerging from the slit in each of the two following cases :
- width of the slit a = 2 cm.
- width of the slit a = 0.4 mm.

2) The width of the slit is now kept at 0.4 mm and the radiation used belongs to the visible spectrum. (wavelength of the visible spectrum : $0.4\ \mu m \le \lambda \le 0.8\ \mu m$)

a) Write , in this case, the expression giving the angular width of the central bright fringe in terms of λ and a.

b) Show that the linear width of this central fringe is given by : $L = \frac{2D\lambda}{a}$.

c) Calculate the linear widths L_{red} and L_{violet}, when using successively a red radiation ($\lambda_{red} = 0.8\ \mu m$) and a violet radiation ($\lambda_{violet} = 0.4\ \mu m$).

d) We illuminate the slit with white light. We observe over the linear width L_{violet} white light. Justify.

B – Photoelectric effect

A source of wavelength $\lambda = 0.5\ \mu m$ in air illuminates separately two metallic plates, one made of cesium and the other of zinc.
The table below gives, in eV, the values of the extraction energy W_0 (work function) for some metals.

Metal	Cesium	Rubidium	Potassium	Sodium	Zinc
W_0 (eV)	1.89	2.13	2.15	2.27	4.31

Given : $h = 6.63 \times 10^{-34}$ J.s ; 1 eV = 1.6×10^{-19}J ; $c = 3 \times 10^{8}$ m/s.

1) Calculate, in J and in eV, the energy of an incident photon.

2) For what metal would photoelectric emission take place? Justify.

3) Calculate in eV the maximum kinetic energy of an emitted electron.

4) The cesium plate receives a monochromatic luminous beam of wavelength in air $\lambda = 0.5\ \mu m$, of power $P = 3978\times10^{-4}$ W. The number of electrons emitted per second is then $n = 10^{16}$.

a) Calculate the number N of photons received by the plate in one second.

b) The quantum efficiency r of the plate is the ratio of the number of the electrons emitted per second to the number of photons received by the plate during the same time.
Calculate r.

C - Duality wave-particle

The wave theory of light is used to interpret the phenomenon of diffraction. This theory is not able to interpret the photoelectric effect. Why?

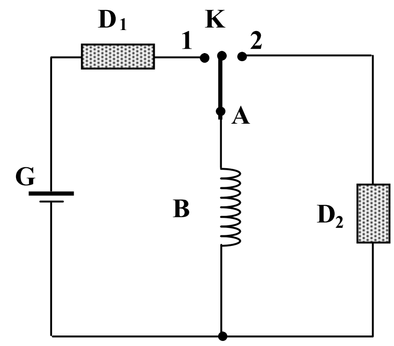


Fig. 1

Fourth exercise (6 ½ pts) Role of a coil in a circuit

Consider the circuit represented in figure 1 where:
(G) is a DC generator of e.m.f $E = 9$ V and of negligible internal resistance ;
(D_1) is a resistor of resistance $R_1 = 90\ \Omega$;
(D_2) is a resistor of resistance R_2 ;
(B) is a coil of inductance $L = 1$ H and of negligible resistance ;
(K) is a double switch.

I - Growth of the current in the component (R_1, L)

We place the switch in position 1 at an instant taken as an origin of time ($t_0 = 0$).
At an instant t, the circuit carries a current i_1.

1) Derive the differential equation in i_1.

2) Verify that $i_1 = \frac{E}{R_1}(1 - e^{\frac{-R_1}{L}t})$ is a solution of the preceding differential equation.

3) ***a)*** Find, in the steady state, the expression of the current I_0 in terms of E and R_1.
b) Calculate I_0.

II – Decay of the current in the component (R_2, L) and illumination of a lamp

A - Decay of the current in the component (R_2, L)

At an instant chosen as a new origin of time ($t_0 = 0$), we turn the switch K to position 2.
At an instant t, the circuit carries thus a current i_2 .

1) Determine the direction of this current .

2) Derive the differential equation in i_2 .

3) The solution of this differential equation is of the form $i_2 = \alpha\, e^{-\beta t}$.
Show that $\alpha = I_0$ and $\beta = \frac{R_2}{L}$.

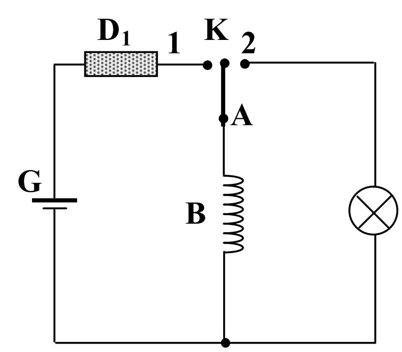


Fig. 2

B – Duration of illumination of a lamp

The resistor D_2 is a lamp of resistance $R_2 = 400\ \Omega$ (fig. 2).
This lamp gives light as long as the current it carries is not less than 20 mA.

1) Show that the lamp gives light at the instant when the circuit is closed.

2) Determine the duration of the illumination of the lamp.

Solution

First exercise : **(7 pts)**

I-

1) K.E = ½ $I(\theta')^2$. **(¼ pt)**

2) P.E = - Mgh; h = $a\cos\theta$ (Figure) $\Rightarrow$ P.E = - $Mga\cos\theta$. **(¾ pt)**

3) M.E = K.E + P.E = ½ $I(\theta')^2 - Mga\cos\theta$. **(¼ pt)**

4) Friction is neglected $\Rightarrow \frac{dE_m}{dt} = 0 = I\theta''\theta' + Mga\theta'\sin\theta$.

   For small angles, $\sin\theta = \theta$ (rad) $\Rightarrow I\theta''\theta' + Mga\theta'\,\theta = 0$

   $\Rightarrow I\theta'' + Mga\theta = 0 \Rightarrow \theta'' + \frac{Mga}{I}\theta = 0$. **(¾ pt)**

5) The motion is angular sinusoidal of angular frequency $\omega_1 = \sqrt{\frac{Mga}{I}}$;

   The period of the motion is $T_1 = \frac{2\pi}{\omega_1} = 2\pi\sqrt{\frac{I}{Mga}}$. **(½pt)**

II-

1) **a)** $P.E_{torsion} = \frac{1}{2} C\theta^2 + \frac{1}{2} C\theta^2 = C\theta^2$ **(½pt)**

   b) $P.E = P.E_g + P.E_{torsion} = - Mga\cos\theta + C\theta^2$. **(½pt)**

   c) M.E = ½ $I(\theta')^2 - Mga\cos\theta + C\theta^2$. **(½pt)**

2) $\frac{dM.E}{dt} = 0 = I\theta''\theta' + Mga\theta'\sin\theta + 2C\theta\theta' \Rightarrow$

   $I\theta'' + Mga\theta + 2C\theta = 0 \Rightarrow \theta'' + [\frac{Mga + 2C}{I}]\theta = 0$. **(1 pt)**

   $T_2 = \frac{2\pi}{\omega_2} = 2\pi\sqrt{\frac{I}{Mga + 2C}}$. **(½ pt)**

III- a = 3.4 mm ; $I = 1.14\times 10^{-3}$ kgm^2. **(1 ½ pt)**

Second exercise : **(7pts)**

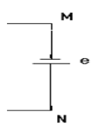
1) $\Phi = B\,S\cos180 = -BS = -B\ell x$ **(½ pt)**

2) **a)** Φ varies because S varies $\Rightarrow e = -\frac{d\varphi}{dt}$ exists. **(½ pt)**

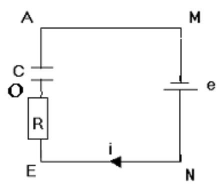
$e = B\ell\frac{dx}{dt} = B\ell v = 0.8\times1\times0.5 = 0.4$ V. **(¾ pt)**

b) The induced current opposes, by its electromagnetic effect, the cause that produces it. The Laplace force then opposes the direction of displacement of the rod ; The induced current then passes through the rod from point M to point N. **(½ pt)**

c) (½ pt)



3) **a)** $e = Ri + u_C = RC\frac{du_C}{dt} + u_C$
(½ pt)



b) i) $\tau = RC = 100\times10^{-2} = 1$ s. **(½ pt)**

ii) The complete charge is practically attained at $5\tau = 5$ s. **(½ pt)**

c) $U = e = 0.4$ V. $Q = CU = 10^{-2}\times0.4 = 0.004$ C. **(1 pt)**

d) $e = Ri + u_C$. For $t_0 = 0$, $u_C = 0 \Rightarrow e = RI_0 \Rightarrow I_0 = \frac{0.4}{100} = 4$ mA

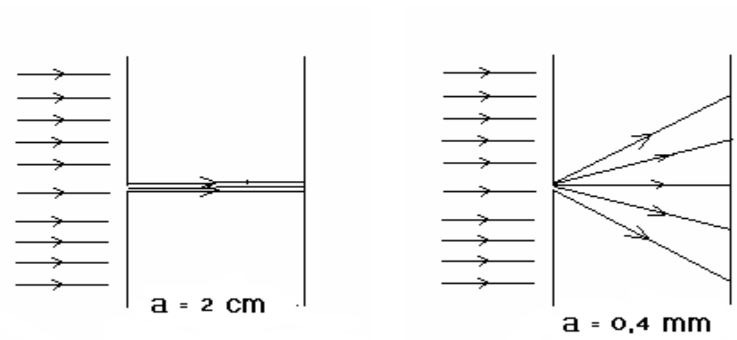
For t = 6 s, the capacitor is charged completely $\Rightarrow u_C = e \Rightarrow i = 0$. **(1 pt)**

e) i) Is a result of discharging of the capacitor through the resistor **(¼ pt)**

ii) The duration of the passage of the current of discharging is
$5\tau = 5RC = 5$ s **(½ pt)**

Third exercise : (7 pts)

A- 1) (½ pt)



2) a) $\alpha = \frac{2\lambda}{a}$. **(½ pt)**

b) $\alpha = \frac{2\lambda}{a} = \frac{L}{D}$ (Figure) $\Rightarrow$ $L = \frac{2D\lambda}{a}$. **(¾ pt)**

c) $L_{Red} = \frac{2D\lambda_{Red}}{a} = 2$ cm ; $\lambda_{Red} = 2\ \lambda_{Violet}$

$\Rightarrow L_{Red} = 2\ L_{Violet}$ $\Rightarrow L_{Violett} = 1$ cm **(½ pt)**

d) The linear width L of the central fringe is: $1\text{cm} \leq L \leq 2$ cm.

All the central bright fringes superposed within 1 cm:

We obtain white fringe. **(¾ pt)**

B-1) $E = h\nu = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{0.5 \times 10^{-6}} = 39.78 \times 10^{-20}$ J

$E = \frac{39.78 \times 10^{-20}}{1.6 \times 10^{-19}}$ eV = 2.49 eV. **(1¼ pt)**

2) There is photoelectric emission from cesium because : 2.49 > 1.89

2.49 < 4.31 $\Rightarrow$ there is no photoelectric emission from zinc. **(½ pt)**

3) $E = W_0 + K.E_{max} \Rightarrow K.E_{max} = 2.49 - 1.89 = 0.6$ eV. **(¾ pt)**

4) **a)** $P = NE \Rightarrow N = \frac{3978 \times 10^{-4}}{39.78 \times 10^{-20}} = 10^{18}$ photons received /s. **(½ pt)**

b) Quantum efficiency = $\frac{n}{N} = \frac{10^{16}}{10^{18}} = 0.01 = 1\%$.**(½ pt)**

C – According to the wave theory, the wave gives energy to the illuminated surface progressively and continuously. This means that whatever the frequency of the incident radiation, a continuous illumination of the metal should produce photoelectric effect. **(1 pt)**

Fourth exercise : (6 ½ pts)

I- 1) $E = R_1 i_1 + L\frac{di_1}{dt}$ **(½ pt)**

2) $\frac{di_1}{dt} = \frac{E}{L}e^{-\frac{R_1}{L}t} \Rightarrow R_1\,[\frac{E}{R_1}(1 - e^{-\frac{R_1}{L}t})] + L(\frac{E}{L}e^{-\frac{R_1}{L}t}) = E$ **[verified] (½ pt)**

3) a) At steady state, i_1= cte $\Rightarrow \frac{di_1}{dt} = 0$; The differential equation in this case:

$E = R_1 I_0 + 0 \Rightarrow I_0 = \frac{E}{R_1}$. **(¾ pt)**

b) $I_0 = \frac{9}{90} = 0.1$ A. **(¼ pt)**

II-

A- 1) During the current decay , the coil, according to Lenz law, produces a current

B- in the same direction as before, from A to D in the coil **(¾ pt)**

2) $u_{coil} = u_{(D2)} \Rightarrow u_{AD} = u_{AD} \Rightarrow L\frac{di_2}{dt} = -R_2 i_2 \Rightarrow L\frac{di_2}{dt} + R_2 i_2 = 0$ **(½ pt)**

3) $\frac{di_2}{dt} = -\alpha\beta e^{-\beta t} \Rightarrow -L\alpha\beta e^{-\beta t} + R_2\alpha e^{-\beta t} = 0 \Rightarrow \alpha e^{-\beta t}(R_2 - L\beta) = 0$.

$R_2 - L\beta = 0 \Rightarrow \beta = \frac{R_2}{L}$. **(¾ pt)**

For t = 0 , $i_2 = I_0 = \alpha = \frac{E}{R_1}$.**(½ pt)**

B – 1) Just after closing the circuit, a current I_0 passes through the lamp
I_0 = 0.1 A > 0.02 A. Therefore the lamp illuminates. **(½ pt)**

2) $\alpha = 0.1$ A and $\beta = \frac{400}{1} = 400\ s^{-1} \Rightarrow i_2 = 0.1\,e^{-400t}$ **(½ pt)**

$0.02 = 0.1\,e^{-400t} \Rightarrow \frac{0.02}{0.1} = e^{-400t} \Rightarrow -400\,t = \ln 0.2 \Rightarrow t = 4$ ms **(1pt)**

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الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	

This exam is formed of four exercises in four pages numbered from 1 to 4.
The use of non-programmable calculator is recommended

First exercise (7.5 points) Compound pendulum

A compound pendulum is formed of a rod AB of negligible mass, which can rotate without friction in a vertical plane around a horizontal axis (Δ) passing through a point O of the rod so that OB = d. A particle of mass M is fixed at point B and another particle C of mass m < M, which can slide on the part OA of the rod is placed at a distance OC = x of adjustable value. Let a = OG be the distance between O and the center of gravity G of the pendulum (Fig.1). The gravitational potential energy reference is the horizontal plane containing O.

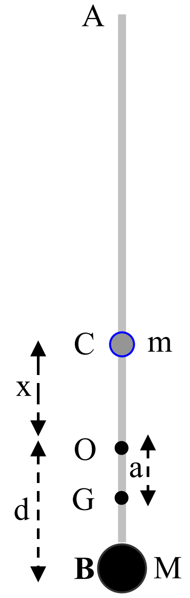


Fig.1

$g = 10 m/s^2$; $\pi^2 = 10$; $\sin\theta = \theta$ and $\cos\theta = 1 - \frac{\theta^2}{2}$,(θ in rad) for $\theta < 10^0$.

***A*- Theoretical study**

1- Show that the position of G is given by: $a = \frac{Md - mx}{(M + m)}$.

2- Find the expression of the moment of inertia I of the pendulum about the axis (Δ) in terms of m, x, M and d.

3- The pendulum thus formed is deviated by an angle θ_0 from its equilibrium position and then released from rest at the instant $t_0 = 0$. The pendulum then oscillates around the stable equilibrium position. At an instant t, the position of the pendulum is defined by the angular abscissa θ, the angle that the vertical through O makes with OG, and its angular velocity is $\theta' = \frac{d\theta}{dt}$.

a) Write, at the instant t, the expression of the kinetic energy of the pendulum in terms of I and θ'.

b) Show that the expression of the gravitational potential energy of the system (pendulum, Earth) is P.E = - (M + m) g a cosθ.

c) Write the expression of the mechanical energy of the system (pendulum, Earth) in terms of M, m, g, a, θ , I and θ'.

d) Derive the second order differential equation in θ that governs the motion of the pendulum.

e) Deduce that the expression of the proper period, for oscillations of small amplitude, has the form: $T = 2\pi\sqrt{\frac{I}{(M + m)ga}}$.

f) Find the expression of the period T, in terms of M, m, d, g and x.

***B*- Application: metronome**

A metronome is an instrument that allows adjusting the speed at which music is played.
The compound pendulum studied in part **A** represents a metronome where M = 50 g, m = 5 g, and d = 2 cm. The graph of figure 2 represents the variations of the period T of this metronome as a function of the distance x.

1) Find, in this case, the expression of the period T of the metronome as a function of x.

2) The leader of the orchestra (conductor), using a metronome to play a distribution, changes the position of C along OA, to follow the rhythm of the musical piece.
The rhythm is indicated by terms inherited from Italian for the classical distribution:

Name	Indication	Period (in s)
Grave	very slow	T = 1.5
Lento	Slow	$1 \le T \le 1.1$
Moderato	Moderate	$0.6 \le T \le 0.75$
Prestissimo	very fast	$0.28 \le T \le 0.42$

Determine, using a method of your choice, the positions between which the leader of the orchestra may move C to adjust the speed to the rhythm **Lento**.

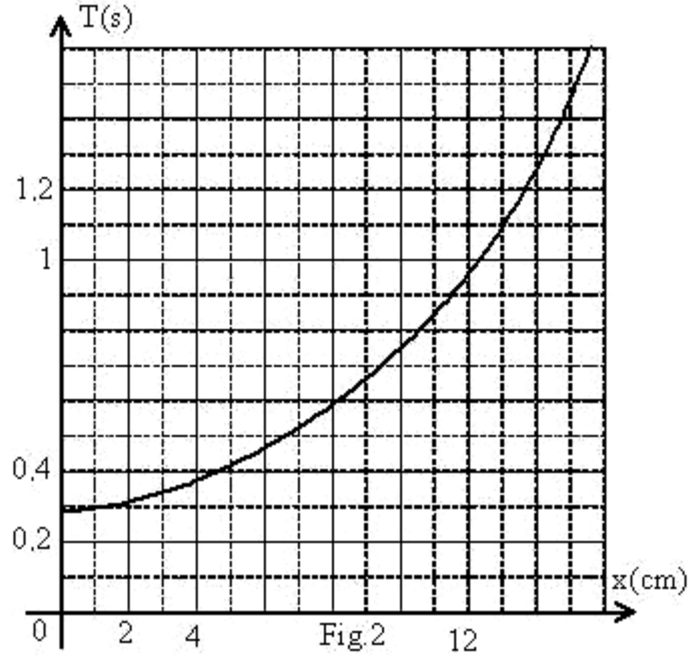


Fig.2

Second exercise (7.5 points) Determination of the capacitance of a capacitor

In order to determine the capacitance C of a capacitor, we consider two experiments.

***A*- First experiment**

We place the capacitor in series, with a coil of inductance L = 0.32 H, a resistor of resistance R = 100 Ω and a low frequency generator G (LFG) that delivers across its terminals an alternating sinusoidal voltage: $u_g = u_{DB} = 8\sin(100\pi t - \pi/3)$ (u_g in V ; t in s) (Fig.1).
As a result, the circuit carries an alternating sinusoidal current of value: $i = I_m \sin(100\pi t)$ (i in A; t in s).
An oscilloscope is connected so as to display, on channel Y_1, the voltage $u_{coil} = u_{AM}$ across the coil and, on channel Y_2, the voltage $u_R = u_{MB}$ across the resistor.
The knob «Inv» (inverse) on channel Y_2 is pushed.
On the screen of the oscilloscope, we observe the waveforms (1) and (2) represented in figure 2.
The vertical sensitivity S_v is the same on the two channels: S_v= 1 V/div. Take $0.32\pi = 1$.

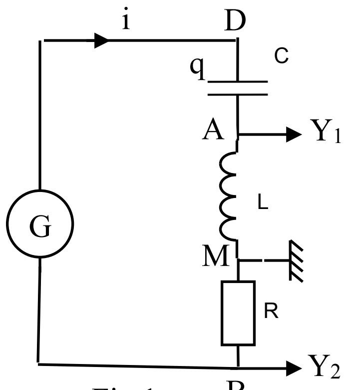


Fig.1

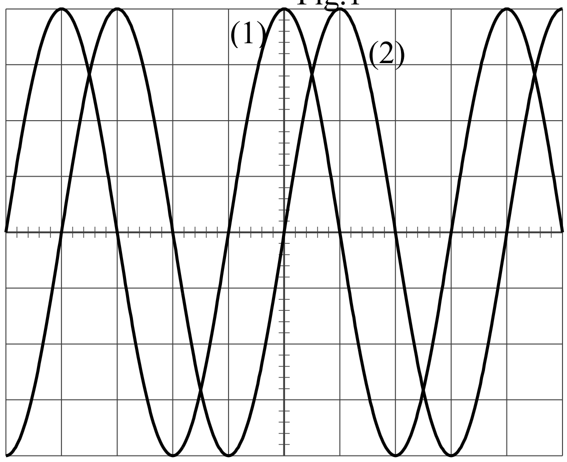


Fig.2

1) Why did we push in the knob «Inv»?
2) Referring to figure 2:
 a) Determine the horizontal sensitivity S_h that is selected on the oscilloscope.
 b) Determine the phase difference between u_b and u_R.
 c) Which of the two voltages leads the other?
 d) Deduce that the coil has a negligible resistance.
 e) Determine the value of I_m.
3) Determine the expression of u_{coil} as a function of time t.
4) Show that expression of the voltage $u_C = u_{DA}$ across the capacitor is given by $u_C = -\dfrac{I_m}{100\pi C}\cos 100\pi t$
5) Applying the law of addition of voltages, determine the value of C by giving t a particular value,

***B*- Second experiment**

The capacitor, initially charged, is now connected across the coil of inductance L = 0.32 H (Fig.3). The oscilloscope, adjusted on the horizontal sensitivity S_h = 2 ms/div, allows to display the voltage u_C across the capacitor (Fig.4).

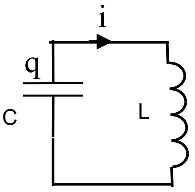


Fig.3

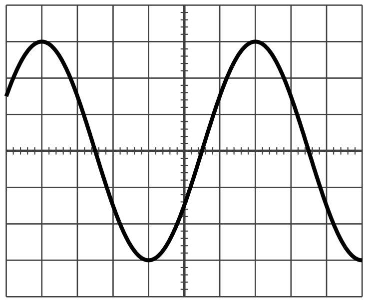


Fig.4

1) a) Show that the voltage u_C is sinusoidal of period T.

b) Determine T in terms of L and C.

2) Calculate the value of C.

Third exercise (7.5 points) Index of refraction of a piece of glass

Consider a glass sheet of thickness e = 5 μm and of index of refraction n, and a source S of white light having a filter so that Young's apparatus receives monochromatic light of wavelength λ in air of adjustable value. The object of this exercise is to study how the index n varies with λ.

***A*- Light interference – Interfringe distance.**

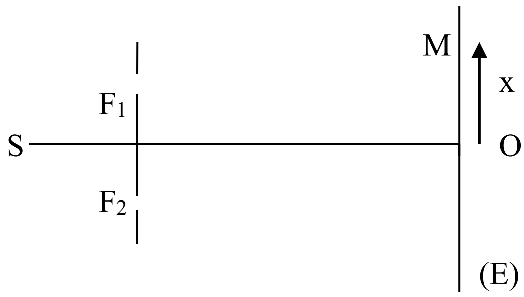
Young's slits apparatus is formed of two very thin slits F_1 and F_2, parallel and separated by a distance a = 0.1 mm, and a screen of observation (E) placed parallel to the plane of the slits at a distance D = 1 m from this plane.

1) F_1 and F_2 are illuminated with a monochromatic radiation of wavelength λ issued from S that is placed at equal distances from F_1 and F_2.

a) F_1 and F_2 must have two basic properties for the phenomenon of interference to be observed. What are they?

b) Describe the system of fringes observed on (E).

c) At the point O of the screen ,equidistant from F_1 and F_2, we observe a bright fringe. Why?



2) We admit that for a point M of (E), such that OM = x, the optical path difference in air or in vacuum is given by $\delta = F_2M - F_1M = \frac{ax}{D}$.

a) Determine the expression of x_k corresponding to the center of the k^{th} bright fringe.

b) Deduce the expression of the interfringe distance i in terms of λ, D and a.

***B*- Introducing the sheet.**

The glass sheet is put now just behind the slit F_1. c and v are the speeds of light in vacuum (and practically in air) and in the glass sheet respectively.

1) Light crosses the glass sheet of thickness e during a time interval τ. Give the expression of τ in terms of e and v.

2) Give the expression of the distance d, covered by light in air during the time interval τ, in terms of n and e.

3) Deduce that the new optical path difference at point M is given by:

$$\delta' = F_2M - F_1M = \frac{ax}{D} - e(n-1).$$

***C*- Measurement of n**

N.**B** : *Introducing the sheet does not affect the expression of the interfringe distance i*
In this question the calculation of n must include 3 decimal places.

1) F_1 and F_2 are illuminated with a red radiation, of wavelength λ_1 = 768 nm, issued from S.

The center of the central fringe is formed at O′, position that was occupied by the center of the 4^{th} bright fringe in the absence of the sheet. Determine the value of n_1, the index of the sheet.

2) $F_1$and F_2 are illuminated with a violet radiation of wavelength λ_2 = 434 nm, issued from S. The center of the central fringe is now formed at O″, position that was occupied by the center of the 8^{th} dark fringe in the absence of the sheet. Determine the value of n_2 , the index of the sheet.

3) Can we consider the value of the index of refraction of a transparent medium without taking into account the radiation used? Why?

Fourth exercise (7.5 points) Nuclear Fission

The object of this exercise is to show evidence of certain properties of nuclear fission.

Given: Masses of nuclei: m (^{235}U) = 234.964 u; m(^{92}Zr) = 91.872 u;

m(^{142}Te) = 141.869 u; m($_{0}^{1}n$) = 1.008u.; 1u = 1.66×10^{-27}Kg ; c = 3×10^{8}ms^{-1};

***A*- Energy of fission.**

One of the fission reactions of the uranium 235, in a nuclear power plant may be written in the form : $_{92}^{235}U + _{0}^{1}n \rightarrow _{40}^{92}Z_r + _{Z}^{142}T_e + x_{0}^{1}n$.

1) Determine Z and x specifying the laws used.

2) Calculate the energy produced by the fission of one nucleus of uranium 235.

3) Determine the mass of uranium 235 used in the power plant during one year, knowing that its useful electric power is 900 MW, and that its efficiency is 30 %.

***B*- Products of fission.**

Among the products of fission, we find, in the core of the reactor, the radioelements: $_{55}^{137}Cs$ and $_{37}^{87}Rb$ of periods 30 years and 5×10^{11} years respectively.

These radioelements are placed in a pool called cooler. The nuclei $_{55}^{137}Cs$ and $_{37}^{87}Rb$ have the masses 137u and 87u respectively.

1) Suppose that 1 g of each of the radioelements is introduced into the pool at the instant t_0 = 0..

a) Calculate the number of nuclei of each of the radioelements at the instant t_0 = 0.

b) Deduce, for each radioelement, the number of nuclei remaining after 3 years stay in the pool.

c) Determine, for each radioelement, the number of decays per day at the moment of taking them out of the pool (3 years later).

2) Assuming that the danger of a radioelement on man depends on the radiations accumulated per day, which, of the two radioelements, is more dangerous? Justify.

***C*- Probability of fission.**

In a physics dictionary, we read that the probability of a nucleus $_{Z}^{A}X$ to become fissionable is proportional to the ratio $\frac{Z^2}{A}$, called the stability factor of a nucleus. This probability is no more zero when this ratio exceeds 35.

1) What do each of Z and A of the nuclide $_{Z}^{A}X$ represent?

2) Show that a nucleus must contain a number of neutrons N such that $N < \frac{Z(Z-35)}{35}$, so that the probability to become fissionable is not zero.

3) Find the maximum number of nucleons that must be contained in a uranium nucleus, of Z = 92, so that the probability to undergo fission is not zero.

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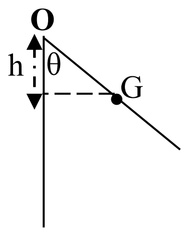
الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	مشروع معيار التصحيح

Part of the Q	Answer	Mark
	First exercise (7.5 points)	
A.1	$(M\text{-}m)\overrightarrow{OG} = M\overrightarrow{OB} + m\overrightarrow{OC} \Rightarrow a = \dfrac{Md - mx}{M + m}$.	**0.75**
A.2	$I = I_M + I_m = Md^2 + mx^2$.	**0.50**
A.3.a	$E_C = ½\, I\dot{\theta}^2$.	**0.50**
A.3.b	$E_{PP} = -(M+m)gh = -(M+m)ga\cos\theta$. 	**1.00**
A.3.c	$E_m = E_C + E_{PP} = ½\, I\dot{\theta}^2 - (M+m)ga\cos\theta$.	**0.25**
A.3.d	$\dfrac{dE_m}{dt} = 0 = I\dot{\theta}\ddot{\theta} + (M+m)ga\dot{\theta}\sin\theta \Rightarrow \ddot{\theta} + \dfrac{(M+m)ga}{I}\sin\theta = 0.$	**1.00**
A.3.e	for small θ , $\sin\theta = \theta \Rightarrow \ddot{\theta} + \dfrac{(M+m)ga}{I}\theta = 0$ $\Rightarrow$ the proper angular frequency is: $\omega = \sqrt{\dfrac{(M+m)ga}{I}}$; the proper period $T = \dfrac{2\pi}{\omega} \Rightarrow T = 2\pi\sqrt{\dfrac{I}{(M+m)ga}}$.	**1.25**
A.3.f	$T = 2\pi\sqrt{\dfrac{Md^2 + mx^2}{g(Md - mx)}}$.	**0.75**
B.1	$T = \sqrt{\dfrac{0.08 + 20x^2}{1 - 5x}}$.	**0.50**
B.2	graphically or by calculus: For T = 1 s , x = 12.3 cm. For T = 1.1 s, x = 13 cm. $\Rightarrow 12.3 < x(cm) < 13$.	**1.00**
	Second exercise (7.5 points)	
A.1	To eliminate the phase opposition obtained from the way with which the coil and the resistor are connected to the oscilloscope. (or: the oscilloscope, as it is connected, displays the voltage u_{BM}, but as we want to display u_{MB}, then we have to push the knob inversion.)	**0.25**
A.2.a	The angular frequency of the voltage is $\omega = 100\pi$ rad/s; or the period is $T = \dfrac{2\pi}{\omega} = 0.,02s = 20ms$; T covers 4 divisions on the screen $\Rightarrow S_h = \dfrac{20}{4} = 5 ms/div$.	**0.75**
A.2.b	T covers 4 divisions that correspond to an angle of 2π rad, the phase	**0.75**

	difference φ is represented by 1 division $\Rightarrow \varphi = \frac{2\pi\times 1}{4} = \frac{\pi}{2}$ rad.	
A.2.c	u_b leads u_R.	**0.25**
A.2.d	Because the voltage across the coil of zero resistance leads by $\frac{\pi}{2}$ the current that flows through it.	**0.50**
A.2.e	$RI_m = 4\text{ div}\times 1V/\text{div} = 4V \Rightarrow I_m = \frac{4}{100} = 0.04A$.	**0.50**
A.3	$u_b = L\frac{di}{dt} = 0.32\times 0.04\times 100\pi\cos(100\pi t) = 4\cos(100\,\pi t)$.	**0.75**
A.4	$i = \frac{dq}{dt} = C\frac{du_C}{dt} \Rightarrow u_C = \frac{1}{C}\times\text{primitive of } i = -\frac{I_m}{100\pi C}\cos(100\pi t)$ $\Rightarrow u_C = -\frac{1.28\times 10^{-4}}{C}\cos(100\,\pi t)$.	**0.75**
A.5	$u_g = u_C + u_b + u_R \Rightarrow$ $8\sin(100\,\pi t - \frac{\pi}{3}) = -\frac{1.28\times 10^{-4}}{C}\cos(100\,\pi t) + 4\cos(100\,\pi t) + 4\sin(100\,\pi t)$ For t = 0 we have : $-4\sqrt{3} = -\frac{1.28\times 10^{-4}}{C} + 4 + 0 \Rightarrow C = 11.7\times 10^{-6}$ F.	**1.25**
B.1.a	$u_C = u_b \Rightarrow u_C = L(\frac{di}{dt}) = -L\ddot{q} = -LC\ddot{u}_C \Rightarrow \ddot{u}_C + \frac{1}{LC}u_C = 0 \Rightarrow$ the solution of such form of differential equation is sinusoidal of period T.	**0.50**
B.1.b	The angular frequency ω of motion is such that $\omega^2 = \frac{1}{LC} \Rightarrow \omega = \frac{1}{\sqrt{LC}}$; the period is $T = \frac{2\pi}{\omega} = 2\pi\sqrt{LC}$.	**0.50**
B.2	From the waveform of figure 4 we have: $T = 6\text{ div}\times 2\text{ms}/\text{div} = 12\text{ ms} = 0.,012\text{s}$. $C = \frac{T^2}{4\pi^2 L} = \frac{144\times 10^{-6}}{12.5} = 11.5\times 10^{-6}$ F.	**0.75**
	Thierd exercise (7.5 points)	
A.1.a	F_1 and F_2 become synchronous and coherent	**0.50**
A.1.b	The interference fringes are bands that are equidistant, alternately dark and bright. These fringes are parallel to the slits	**0.75**
A.1.c	We have $\delta = 0$ then the radiations from $F_1$and F_2 arrive at O in phase thus they form at O a bright fringe.	**0.50**
A.2.a	For bright fringes: $\delta = k\lambda$ $\frac{ax}{D} = k\lambda \Rightarrow x_k = \frac{k\lambda D}{a}$;	**0.50**
A.2.b	$i = x_{k+1} - x_k = \frac{\lambda D}{a}$.	**0.50**
B.1	$\tau = \frac{e}{v}$	**0.5**
B.2	$d = c\tau = c\frac{e}{v} = ne$	**0.50**
B.3	the increase in the optical path for the light crossing the plate is: $ne - e = e(n-1)$ $\delta' = F_2M - (F_1M + e(n-1) = \frac{ax}{D}$.	**1.00**

C.1	For the central fringe: $\delta' = 0 \Rightarrow \frac{ax_0}{D} - e(n_1 - 1) = 0$; so that $x_0 = 4i_1 = 4\frac{\lambda_1 D}{a} \Rightarrow n_1 = 1 + \frac{4\lambda_1}{e} = 1.614$	**1.25**
C.2	$\mathbf{x_0 = 7.5\ i_2 \Rightarrow n_2 = 1 + \frac{7.5\lambda_2}{e} = 1.651}$	**0.75**
C.3	**Non :** $\lambda_1 \neq \lambda_2 \Rightarrow n_1 \neq n_2$ **Yes :** $\lambda_1 \neq \lambda_2 \Rightarrow n_1 \square\ n_2$	**0.75**
	Fourth exercise (7.5 points)	
A.1	${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{92}_{40}Zr + {}^{142}_{Z}Te + x\,{}^{1}_{0}n$. Conservation of mass number: $235 + 1 = 92 + 142 + x \Rightarrow x = 2$ Conservation of charge number: $92 = 40 + Z \Rightarrow Z = 52$.	**1.00**
A.2	$\Delta m = 234.964 - 91.872 - 141.869 - 1.008 = 0.215$ u or 3.57×10^{-28} kg. $E = \Delta m.c^2 = 3.21\times10^{-11}$J.	**1.25**
A.3	$E_1 = \frac{9\times10^8}{0.3} = 3\times10^9\ J/s.$ The energy for one year : $3\times10^9\times365\times24\times3600 = 9.46\times10^{16}$ J. The number of nuclei undergoing fission: $\frac{9.46\times10^{16}}{3.21\times10^{-11}} = 2.947\times10^{27}\ nuclei.$ Its mass : $2.947\times10^{27}\times234.964\times1.66\times10^{-27} = 1149.4$ kg.	**1.25**
B.1.a	$N_0(\text{Cs}) = \frac{1}{137\times1{,}66\times10^{-24}} = 4{,}4\times10^{21}$ nuclei. $N_0(\text{Rb}) = \frac{1}{87\times1{,}66\times10^{-24}} = 6{,}9\times10^{21}$ nuclei	**0.50**
B.1.b	$N = N_0\, e^{-\frac{0.693t}{T}}$. $\Rightarrow$ N(Cs) = 4.1×10^{21} nuclei. N (Rb) = 6.89×10^{21} nuclei. N(Br) = 0	**0.75**
B.1.c	number of disintegrations per day = λN (λ:d^{-1}) For Cs : $\frac{0.693\times4.1\times10^{21}}{30\times365} = 2.6\times10^{17}$. For (Rb) : $\frac{0.693\times6.89\times10^{21}}{5\times10^{11}\times365} = 2.6\times10^{7}$.	**1.00**
B.2	The more dangerous product is Cs, since its rate of disintegrations is greater.	**0.25**
c.1.a	Z is the charge number, A is the mass number.	**0.25**
C.2	$\frac{Z^2}{A} > 35 \Rightarrow \frac{Z^2}{Z + N} > 35$ $\Rightarrow Z(Z-35) > 35\ N \Rightarrow N \langle \frac{Z(Z-35)}{35}$.	**0.75**
C.3	$\frac{Z^2}{A} > 35 \Rightarrow A < \frac{Z^2}{35} = \frac{(92)^2}{35} \approx 242.$	**0.50**

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الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	

This exam is formed of four exercises in four pages numbered from 1 to 4.
The use of non-programmable calculator is allowed.

First exercise (7.5 points)

Response of an electric component submitted to a DC voltage

In order to study the response of the current in an electric component when submitted to a DC voltage, we use a coil of inductance L = 40 mH and of resistance r = 18 Ω, a capacitor of capacitance C = 100 μF, a resistor of resistance R = 2 Ω, a switch K and a DC generator delivering across its terminals a constant voltage E = 8 V.

A – Response of the electric component (R, L)

We connect the coil in series with the resistor across the terminals of the generator (Fig. 1).

At the instant $t_0 = 0$, we close K. The circuit thus carries a current i. With an oscilloscope, we display the variation of the voltage u_{AM} across the terminals of the resistor as a function of time (Fig. 2).

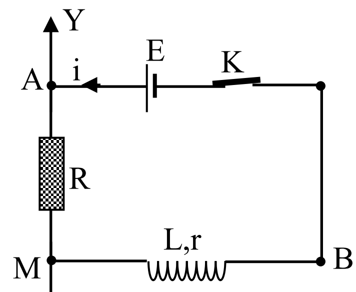


Figure 1

1) Express the voltage u_{AM} across the resistor and the voltage u_{MB} across the coil in terms of R, L, r, i and $\frac{di}{dt}$.
2) Derive the differential equation in i.
3) The solution of this differential equation is of the form:

   $i = I_0(1- e^{-\frac{t}{\tau}})$.

   a) Show that $I_0 = \frac{E}{R+r}$ and $\tau = \frac{L}{R+r}$.
   b) Calculate the values of I_0 and τ.
4) Using figure 2, determine the values of I_0 and that of τ.

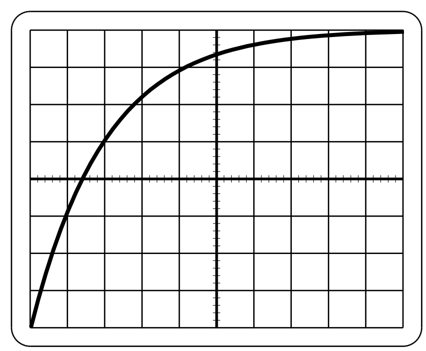


Figure 2
Horizontal sensitivity : 1 ms/div
Vertical sensitivity: 0.1 V/div

B – Response of the electric component (R,C)

We replace, in the previous circuit, the coil by the capacitor (Fig. 3).

At $t_0 = 0$, we close K. The circuit thus carries a current i. With the oscilloscope, we display the variation of the voltage u_{AM} as a function of time (Fig. 4).

1) Express the current i in terms of C and $\frac{du_C}{dt}$, where u_C is the voltage u_{MB} across the terminals of the capacitor.
2) Using the law of addition of voltages, show that the differential equation in i is of the form: $RC\frac{di}{dt} + i = 0$.

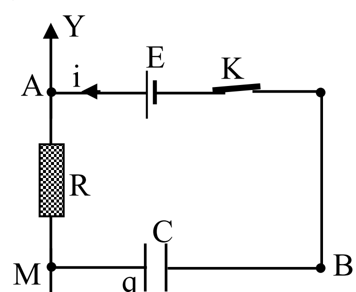


Figure 3

3) The solution of this differential equation is of the form:

$i = I_1 e^{-\frac{t}{\tau_1}}$. Determine, in terms of E, R and C, the expressions of the two constants I_1 and τ_1 and calculate their values.

4) Referring to figure 4, determine the value of I_1 and that of τ_1.

C – In each of the two previous circuits, we replace the resistor by a lamp. Explain the variation of the brightness of the lamp in each circuit.

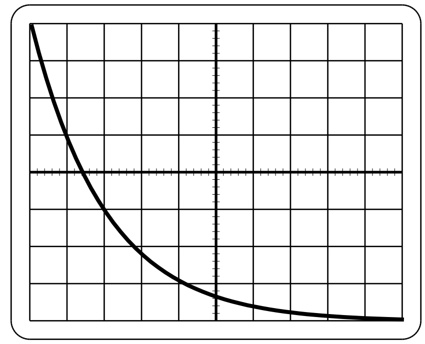


Figure 4

Horizontal sensitivity : 0.1 ms/div
Vertical sensitivity: 1 V/div

Second exercise (7.5 points)

(R,L,C) series circuit

Consider a capacitor of capacitance C = 5 μF, a resistor of resistance R = 40 Ω and a coil of inductance L and of resistance r, connected in series across the secondary of an ideal transformer.

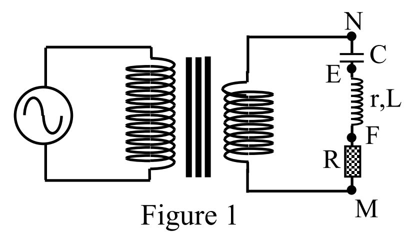


Figure 1

A – Physical quantities of the transformer

The primary coil of the transformer is connected to the mains (220 V; 50 Hz) (Fig.1). The secondary of the transformer delivers across its terminals a voltage: $u_{NM} = 3\cos\omega t$ (u in V ; t in s).

The circuit thus carries an alternating sinusoidal current $i = I_m\cos(\omega t - \varphi)$.

The secondary coil has 15 turns and cannot withstand a current of effective value greater than 10 A.

1) Give the value of the frequency of the alternating sinusoidal voltage across the secondary coil.
2) Determine the number of turns of the primary coil. Take $\sqrt{2} = 1.4$.
3) Calculate the maximum effective value of the current that the primary coil can withstand.

B – Determination of L and r

An oscilloscope, connected in the previous circuit, allows us to display on the channel Y_1 the voltage $u_1 = u_{NM}$ and on the channel Y_2 the voltage $u_2 = u_{FM}$ across the terminals of the resistor.

1) Redraw the circuit of figure 1 and show the connections of the oscilloscope.
2) The sensitivities of the oscilloscope are:
   Horizontal sensitivity: 4 ms/div
   Vertical sensitivity on both channels Y_1 and Y_2: 1 V/div.
   Using the waveforms of figure 2,
   show that $i = 0.05\cos(100\pi t - 0.2\pi)$; (i in A, t in s).
3) Calculate the average power consumed by the component NM.
4) Deduce the value of the resistance r of the coil.
5) Knowing that $u_{NM} = u_{NE} + u_{EF} + u_{FM}$ is verified for any value of time t, determine the value of L.

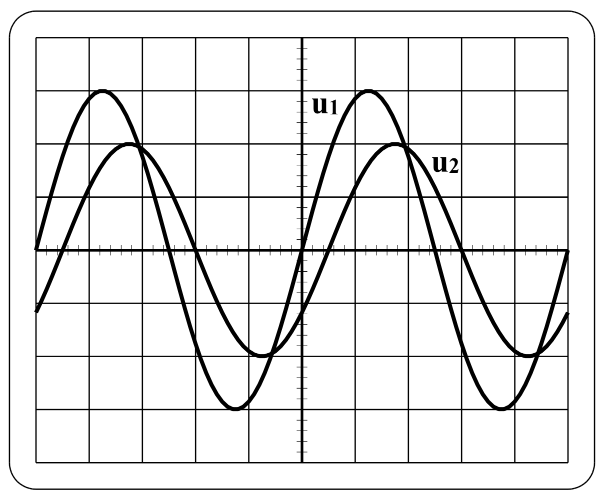
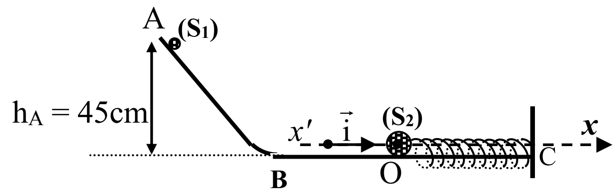


Figure 2

Third exercise **(7.5 points)**

Determination of the stiffness constant of a spring



To determine the stiffness constant k of a spring we attach to its extremity a solid (S_2), of mass m_2 = 200 g, which can slide without friction on the horizontal part BC of a track ABC situated in a vertical plane, the other extremity of the spring is fixed at C.

Another solid (S_1), of mass m_1 = 50 g, is released without initial velocity from a point A of the curved part of the track.

Point A is situated at a height h_A = 45 cm from the horizontal part of the track.

(S_2), initially at rest at point O, is thus hit by (S_1). (S_1) and (S_2) are supposed to be point masses.

The horizontal plane passing through BC is taken as a gravitational potential energy reference.

Take: $g = 10\ ms^{-2}$, $0.32\pi = 1$. Neglect all frictional forces.

1) Determine the value V_1 of the velocity $\overrightarrow{V_1}$ of (S_1) just before colliding (S_2).

2) After collision, (S_1) remains in contact with (S_2) and the two solids form a solid (S) of center of inertia G and of mass $M = m_1 + m_2$. Thus G performs oscillations around O with amplitude 3 cm on the axis x'Ox of origin O and unit vector $\vec{i}$.

a) Show that the value of the velocity $\overrightarrow{V_0}$ of G just after the collision is equal to 0.6 m/s.

b) Let x and v be respectively the abscissa and the algebraic value of the velocity of G at an instant t after

the collision. The instant of collision at O is considered as an origin of time $t_0 = 0$.

i) Write down, at an instant t, the expression of the mechanical energy of the system (S, spring, Earth) in terms of k, x , M and v.

ii) Deduce the second order differential equation in x that describes the motion of G.

iii) The time equation of oscillation of (S) is given by: $x = X_m \sin(\omega_0 t + \varphi)$. Determine the value of φ and the expressions of the constants X_m and ω_0 in terms of k, M and V_0.

iv) Deduce the value of the stiffness constant k of the spring.

3) In reality friction is not neglected. To ensure the value of k, the extremity C of the spring is attached to a vibrator of adjustable frequency f and which can vibrate in the same direction of the spring. We notice that the amplitude of the oscillations of (S) varies with f and attains a maximum value for f = 3.2 Hz.

a) Name the physical phenomenon that takes place when f = 3.2 Hz.

b) Calculate the value of k.

Fourth exercise (7.5 points)

The radionuclide Potassium 40

The isotope of potassium ${}^{40}_{19}K$, is radioactive and is β^+ emitter; it decays to give the daughter nucleus argon ${}^{A}_{Z}Ar$. The object of this exercise is to study the decay of potassium 40.

Given:

masses of nuclei: m (${}^{40}_{19}K$) = 39.95355 u ; m(${}^{A}_{Z}Ar$) = 39.95250 u ;

masses of particles: m (${}^{0}_{1}e$) = 5.5×10^{-4} u; m (neutrino) ≈ 0 ;

Avogadro's number: N = 6.02×10^{23} mol^{-1}; 1 u = 931.5 MeV/c^2 ;

Radioactive period of ${}^{40}_{19}K$: T = 1.5×10^{9} years; molar mass of ${}^{40}_{19}K$ = 40 g mol^{-1}.

1 MeV = 1.6×10^{-13} J.

A – Energetic study of the decay of potassium 40

1) **Energy liberated by one decay**

 a) Write down the equation of the decay of one potassium 40 nucleus and determine Z and A.
 b) Calculate, in MeV, the energy E_1 liberated by this decay.
 c) The daughter nucleus is supposed to be at rest. The energy carried by β^+ is, in general, smaller than E_1. Why?

2) **Energy received by a person**

The mass, of potassium 40 at an instant t, in the body of an adult is, on the average, equal to 2.6×10^{-3} % of its mass.

An adult person has a mass M = 80 kg.

 a) **i)** Calculate the mass m of potassium 40 contained in the body of that person at the instant t.
 ii) Deduce the number of potassium 40 nuclei in the mass m at the instant t.
 b) **i)** Calculate the radioactive constant λ of potassium 40.
 ii) Deduce the value of the activity A of the mass m at the instant t.
 c) Deduce, in J, the energy E liberated by the mass m per second.

B – Dating by potassium 40

Certain volcanic rocks contain potassium and part of it, is potassium 40. At the instant of its formation ($t_0 = 0$), the number of nuclei of potassium 40 is N_0 in the volcanic rock and that of argon is zero. At the instant t, the rock contains respectively N_K and N_{Ar} nuclei of potassium 40 and of argon 40.

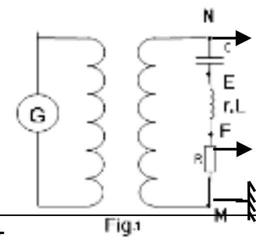
1) **a)** Write down the expression of N_K **,** that explains the law of radioactive decay, as a function of time.
 b) Deduce the expression of N_{Ar} as a function of time.

2) A geologist analyzes a volcanic rock. He notices that the number of argon 40 nuclei is twice less than the number of potassium 40 nuclei in this rock. Determine the age of this rock.

First exercise (7.5 points)

Part of the Q	Answer	Mark
A.1	$u_{AM} = Ri$ and $u_{MB} = L\frac{di}{dt} + ri$.	0.5
A.2	We have $E = Ri + L\frac{di}{dt} + ri \Rightarrow i + \frac{L}{R+r}\frac{di}{dt} = \frac{E}{R+r}$.	0.75
A.3.a	$\frac{di}{dt} = \frac{I_0}{\tau}e^{-\frac{t}{\tau}}$; $I_0 - I_0 e^{-\frac{t}{\tau}} + \frac{L}{R+r}\frac{I_0}{\tau}e^{-\frac{t}{\tau}} = \frac{E}{R+r}$ $\Rightarrow I_0 = \frac{E}{R+r}$ and $\frac{L}{R+r}\frac{I_0}{\tau} - I_0 = 0$; let $\tau = \frac{L}{R+r}$.	1.25
A.3.b	$I_0 = \frac{8}{18+2} = 0.4$ A and $\tau = \frac{0.04}{18+2} = 2\times10^{-3}$ s = 2 ms.	0.5
A.4	From graph 2: $u_R(max) = 0.1\times8 = 0.8$ V and $u_R(max) = R\times I_0$ $\Rightarrow I_0 = \frac{u_R(max)}{R} = 0.4$ A. Also, for $t = \tau$, $u_R = 0.63\,u_R(max) = 0.5$ V which corresponds to $\tau = 2$ divisions, $\tau = 2$ ms.	1.00
B.1	$i = \frac{dq}{dt} = C\frac{du_C}{dt}$.	0.25
B.2	$E = u_{AM} + u_{MB} \Rightarrow E = u_C + Ri$. By deriving with respect to time: $0 = \frac{du_C}{dt} + R\frac{di}{dt} \Rightarrow \frac{i}{C} + R\frac{di}{dt} = 0$ Thus : $RC\frac{di}{dt} + i = 0$	0.75
B.3	$i = I_1 e^{-\frac{t}{\tau_1}}$. For $t_0 = 0$, $u_C = 0$ and $i = I_1 \Rightarrow E = 0 + RI_1$ $\Rightarrow I_1 = \frac{E}{R} = \frac{8}{2} = 4$ A. $\frac{di}{dt} = -\frac{I_1}{\tau_1}e^{-\frac{t}{\tau_1}}$; by replacing: $-RC\frac{I_1}{\tau_1}e^{-\frac{t}{\tau_1}} + I_1 e^{-\frac{t}{\tau_1}} = 0$ $\Rightarrow -RC\frac{I_1}{\tau_1} + I_1 = 0 \Rightarrow \tau_1 = RC = 2\times10^0\times10^{-6} = 2\times10^{-4} = 0.2$ ms.	1
B.4	$u_R(max) = 8$ V $= RI_1 \Rightarrow I_1 = 8/2 = 4$ A and for $t = \tau_1$, $u_R = 0.37\,u_R(max) = 3$ V $\Rightarrow \tau_1 = 0.2$ ms.	0.5
C	In A: after closing the switch the brightness of the lamp increases and reaches after a very short time a stable brightness. In B : at the instant of closing the switch the lamp shines then the brightness decreases and vanishes after a short time	1

Second exercise (7.5 points)

Part of the Q	Answer	Mark
A.1	f = 50 Hz	0.5
A.2	$\frac{U_2}{U_1} = \frac{N_2}{N_1} \Rightarrow \frac{3/\sqrt{2}}{220} = \frac{15}{N_1} \Rightarrow$ N_1 = 1540 turns.	0.75
A.3	$\frac{I_2}{I_1} = \frac{N_1}{N_2} \Rightarrow \frac{10}{I_1} = \frac{1540}{15} \Rightarrow$ I_1 = 97 mA	0.75
B.1	 Fig.1	0.25
B.2	T = 5 div × 4 ms/div = 20 ms = 0.02 s ⇒ $\omega = \frac{2\pi}{0,02} = 100\pi$ rad/s. $(U_R)_{max} = RI_{max} \Rightarrow I_{max} = \frac{2}{40}$ = 0.05 A. φ = 0.5 × 2π/5 = 0.2 π rad. i is in lag on u_{NM} ⇒ i = 0.05 cos(100πt – 0.2 π)	1.5
B.3	P = UIcos φ = $\frac{3}{\sqrt{2}} \times \frac{0.05}{\sqrt{2}} \times \cos 0.2\pi$ = 0.061 W.	0.75
B.4	$P = R_{total} I^2 \Rightarrow R_{totale} = \frac{0.061}{(0.05/\sqrt{2})^2}$ = 48.8 Ω = R + r = 40 + r => r = 8.8 Ω	1
B.5	$u_{NE} = u_C$ = 1/C primitive (i) = 100/ π sin(1ooπt – 0.2 π) u_{EF} = ri + Ldi/dt u_{EF} = 8,8 × 0.,05cos(100πt – 0.2 π) - L × 5 π sin(100πt – 0,.2 π). u_{FM} = Ri = 2 cos(100πt – 0.2 π). 3cosωt = 100/ π sin(ωt – 0.2 π) + 8,8 × 0.05cos(100πt – 0.2 π) - L × 5 π sin(100πt– 0.2 π) + 2 cos(100πt – 0.2 π). For t = 0, we obtain L = 2.15 H.	2

Third exercise (7.5 points)

Part of the Q	Answer	Mark
1	Conservation of mechanical energy between A and B: $m_1gh_A+0 = 0+ \frac{1}{2} m_1 V_1^2$; $V_1 = \sqrt{2gh_A} = \sqrt{2\times10\times0.45} = 3$ m/s .	1.25
2.a	Conservation of linear momentum: $m_1 \vec{V}_1 + \vec{0} = (m_1 + m_2)\vec{V}_0$; projection : $V_0 = \frac{m_1}{m_1+m_2} V_1 = \frac{0.05}{0.05+0.2} 3 = 0.6$ m/s	1.00
2.b. i	$ME = \frac{1}{2} M v_G^2 + \frac{1}{2} kx^2$; $(M = m_1 + m_2)$.	0.50
2.b.ii	ME is conserved: Derivative w.r.t time $\frac{d(ME)}{dt} = 0$ $\Rightarrow Mv\dot{v} + kx\dot{x} = 0 \Rightarrow \ddot{x} + \frac{k}{M}x = 0$	1.00
2.b.iii	$\dot{x}$ $x' = \omega_0 X_m\cos(\omega_0 t + \varphi)$ and $\ddot{x} = -\omega_0^2.X_m\sin(\omega_0 t + \varphi)$. By replacing : $-\omega_0^2 X_m\sin(\omega_0 t + \varphi) + \frac{k}{M} X_m\sin(\omega_0 t + \varphi) \Rightarrow \omega_0^2 = \frac{k}{M} \Rightarrow \omega_0 = \sqrt{\frac{k}{M}}$; At t = 0: $x = 0 \Rightarrow X_m\sin\varphi = 0 \Rightarrow \varphi = 0$ or π. At t = 0: $v = V_0 \Rightarrow \omega_0 X_m\cos\varphi = V_0 > 0 \Rightarrow \varphi = 0$, $X_m = \frac{V_0}{\omega_0} = V_0\sqrt{\frac{M}{k}}$	2.00
2.b.iv	$X_m = X_0 = V_0\sqrt{\frac{M}{k}} \Rightarrow k = \frac{V_0^2 M}{X_m^2} = \frac{0.36\times0.25}{0.03^2} = 100$ N/m.	0.75
3.a	Resonance.	0.25
3.b	$\omega_0 = \omega = 2\pi f = \sqrt{\frac{k}{M}}$; $4\pi^2 f^2 = \frac{k}{M} \Rightarrow k = 4\pi^2 f^2 M = 100$ N/m	0.75

Fourth exercise (7.5 points)

Part of the Q	Answer	Mark
A.1.a	${}^{40}_{19}K \rightarrow {}^{A}_{Z}Ar + {}^{0}_{1}e + {}^{0}_{0}\nu$. Z = 18; A = 40.	z0.75
A.1.b	$\Delta m = 39.95355 - 39.95250 - 5.5\times 10^{-4} = 5\times10^{-4}$ u. $E_1 = mc^2 = 5\times10^{-4}\times 931.5$ MeV/$c^2 \times c^2 = 0.47$ MeV.	1.00
A.1.c	Because $E_1 = E(\beta^+) + E({}^{0}_{0}\nu) + E(\gamma)$	0.50
A.2.a.i	$m = \dfrac{80\times 2.6\times10^{-3}}{100} = 2.1\times10^{-3}$ kg = 2,1 g	0.50
A.2.a.ii	$N = \dfrac{m}{M}$ **N** $= 3.16\times10^{22}$ nuclei.	0.50
A.2.b.i	$\lambda = \dfrac{0.693}{1.5\times10^{9}\times365\times24\times3600} = 1.46\times10^{-17}\ s^{-1}$	0.5
A.2.b.ii	$A = \lambda N = 1.46\times10^{-17}\times3.16\times10^{22} = 4.61\times10^{5}$ Bq	0.75
A.2.c	The energy received in each second: $E = 4.16\times10^{5}\times0.47 = 2.17\times10^{5}$ MeV $= 3.47\times10^{-8}$ J.	07.5
B.1.a	$N_K = N_0e^{-\lambda t}$	0.50
B.1.b	$N_{Ar} = N_0 - N_K = N_0(1-e^{-\lambda t})$	0.50
B.2	$\dfrac{N_{Ar}}{N_K} = \dfrac{1}{2} \Rightarrow \dfrac{1-e^{-\lambda t}}{e^{-\lambda t}} = \dfrac{1}{2} \Rightarrow e^{\lambda t} = \dfrac{3}{2}$ $\Rightarrow t = \dfrac{T}{0.693}\ln\dfrac{3}{2} \Rightarrow t = 8.8\times10^{8}$ years	1.25

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الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	

<u>This exam is formed of three exercises in three pages.</u>

<u>The Use of non-programmable calculators is recommended.</u>

First exercise (7 points) Harmonic oscillator

In order to study a harmonic oscillator, we consider a solid (S) taken as a particle of mass m= 100g and two identical springs (R_1) and (R_2) of un-jointed turns each of stiffness k and of free length L_0. The oscillator thus formed is represented in figure 1.

At equilibrium, (S) is at the origin 0 of the axis x'x on which $\vec{i}$ is a unit vector and the length of each spring is L_0.

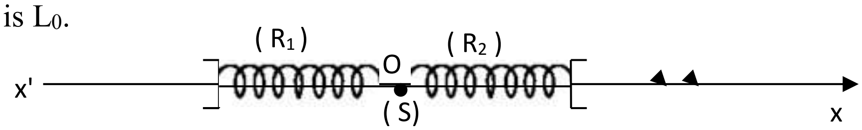


Fig 1

(S) is shifted from this position by a distance d to the right and then released without velocity at the instant $t_0 = 0$. At an instant t , the abscissa of (S) is x, the algebraic value of its velocity is v = x' and that of its acceleration is x".

(S) would thus oscillate, without friction , on the axis x'x; the horizontal plane containing this axis is taken as a gravitational potential energy reference.

A- Differential equation

1) Write, at the instant t, the expression of the mechanical energy of the system [(S), springs]
2) Derive the differential equation that governs the motion of (S).
3) Deduce the expression of the proper angular frequency ω_0 of the motion in terms of k and m.

B- Values of some physical quantities

A convenient apparatus is used to trace the curve of the variations of the acceleration as a function of the abscissa

x" = f (x) (figure 2)

1)Show that the curve representing the acceleration x" = f{x) agrees the differential equation just derived .

2)Referring to the graph :

a) Give the value of the amplitude X_m of the motion.
b) Give th value of the acceleration x" for x = -X_m;
c) Find the value of the proper angular frequency ω_0 of the motion.

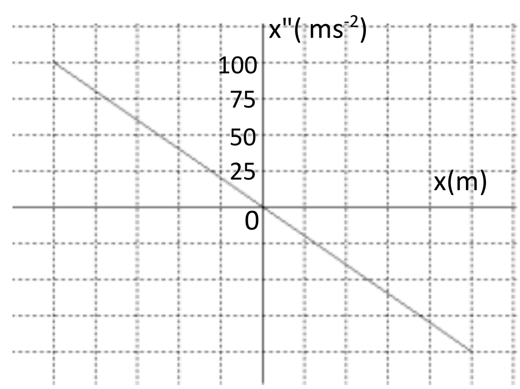


Fig. 2

3) a) Show that the speed of (S) is maximum when it passes through its equilibrium position.
b) Deduce the value V_{max} of the maximum speed.
4) Calculate the value of the spring constant k.

Second exercise (7 points) RLC series circuit

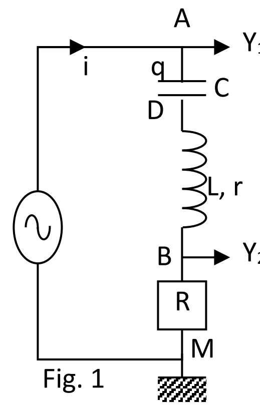


Fig. 1

The object of this exercise is to determine the approximate values of the characteristics of a capacitor and a coil.
We consider then the electric circuit represented by figure 1. This circuit contains, in series, a capacitor of capacitance C, a coil of inductance L and of resistance r and a resistor of resistance R = 20 Ω . The setup thus formed is connected across a generator delivering an alternating sinusoidal voltage u of adjustable frequency f . An alternating sinusoidal current i passes then in the circuit. An oscilloscope conveniently branched allows us to display the voltageu = u_{AM} across the terminals of the generator on channel Y_1 and the voltage u_{BM} across the terminals of the resistor on channel Y_2. The adjustments of the oscilloscope are as follows:
Horizontal sensitivity(time base): : Sb = 2ms/div Vertical sensitivity : - On channel Y_1 : S_{V1} = 2V/div
- On channel Y_2 : S_{V2}= 0.25V/div

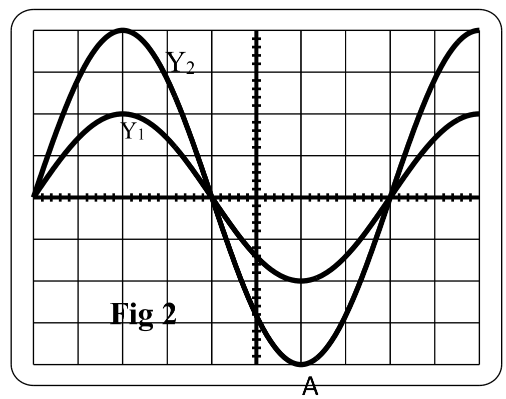


Fig 2

1) We vary the value f of the frequency. For a value f_0 of f, we observe on the screen of the oscilloscope the waveforms represented by figure 2.
a) The waveforms show that the circuit is the seat of a physical phenomenon .Name this phenomenon and give, in this case, the relation among f_0 , Land C.
b) Determine the value of f_0 .
c) Determine U_m the maximum value of u and Im that of i.
d)The circuit is equivalent to a resistor of resistance $R_t = R + r$. Determine R t and r .
2)The coil is replaced by a resistor of resistance r' = 60 Ω (Fig. 3). The voltage across the terminals of the generator is u = $U_m\cos2\pi f_0 t$
On the screen, we observe the waveforms represented in figure 4.
The adjustments of the oscilloscope are the same as the previous ones.
a)The voltage u_{AM} lags u_{BM}. Why?
b) Calculate the phase difference φ between u_{AM} and u_{BM}.

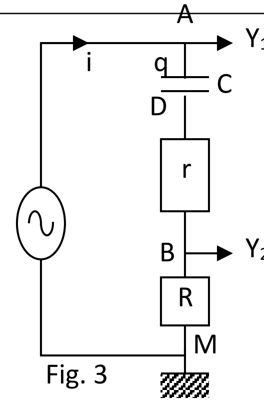


Fig. 3

2

c) Determine the instantaneous expression of u_{BM} .

d) Calculate the maximum value Im of the current i and determine its instantaneous expression.

e) Verify that the expression of the voltage across the terminals of the capacitor is given by:

$$u_{AD} = \frac{8.9\ x\ 10^{-5}}{C} \sin\left(125\pi t + \frac{\pi}{4}\right)$$

f)Applying the law of addition of voltages and giving t a particular value, calculate the value of C.

f) Using the relation found in *(1,a)* , calculate L.

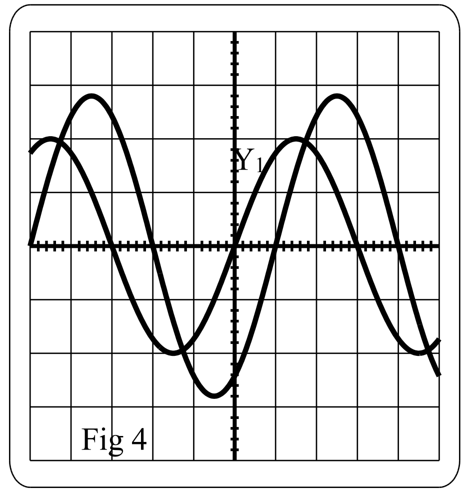


Fig 4

Third exercise (6 points) The Orion Nebula

The great Orion Nebula is composed of four very hot stars emitting ultraviolet radiation whose wavelength in vacuum is less than 91.2 nm, within a large «cloud» of interstellar gas formed mainly of hydrogen atoms. The diagram of figure 1 represents some of the energy levels En of the hydrogen atom. Given: Planck's constant: h = 6.626x 10-^{34} J.s; speed of light in vacuum: c = 2.998x 10^8 ms-]; 1 eV = 1.602x 10^{-19} J; spectrum of rosy color: 640 nm ≤ λ ≤ 680 nm; visible spectrum: 400 nm ≤ λ ≤ 800 nm.

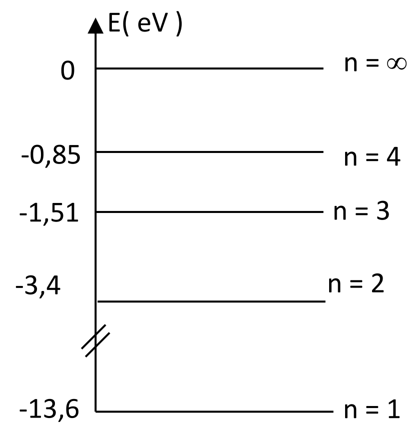


Fig. 1

A-1) By convention, the energy of the hydrogen atom in the ionized state is considered zero.

Use this convention to justify the (-) sign of En.

2) The hydrogen atom is in its fundamental [ground] state.

a) Show that the minimum value of the energy needed to ionize this atom is equal to: $E_i = 2.178x\ 10^{-18}$ J.

b) Calculate the wavelength λ_i of the wave associated to the photon whose energy is equal to E_i

c) Show that the light, emitted by the very hot stars in the Orion Nebula, can ionize the hydrogen atoms of the interstellar gas.

Specify the dynamic state of these extracted electrons.

B- The interstellar gas in the Orion Nebula being ionized, some extracted electron are captured by protons at rest (ionized hydrogen atoms) to form hydrogen atoms in an excited state. An excited hydrogen atom undergoes then a progressive downward transition.

1) Color of the Orion Nebula

Out of the possible transitions, we consider the transition of the atom from level 3 to level 2.

a) Calculate the wavelength , in vacuum, of the radiation corresponding to this transition.

b) This radiation is visible. Why?

c) Justify then the rosy color of the Nebula.

2) Maximum temperature on the surface of the Orion nebula

The electron before it is captured by the hydrogen ion H^+ has a kinetic energy KE. The total energy of the system (ion + electron) E = 0 + KE is conserved.

When the atom undergoes a downward transition, after capturing the electron, it passes to an excited state characterized by its energy level En, by emitting a photon of frequency v so that: $K.E = E_n + h\nu$.

a) Show that for n = 2, we have: $\nu = \frac{KE}{h} + 8.22 \times 10^{14}$ (ν in Hz)

b) The average kinetic energy of the electrons is related to the temperature on the surface of the star by : $K.E = \frac{3}{2} kT$. ($k = 1.38 \times 10^{-23}$ SI); and T is the temperature in Kelvin.

We notice that the smallest wavelength, in the emission band of rays of the Orion Nebula, is $\lambda = 245$ nm in vacuum.

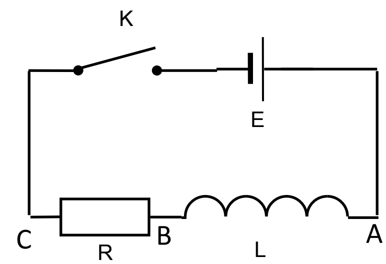
i) Show that this ray corresponds to (K.E) max. Calculate (K.E)max.

ii) Deduce the maximum value of T.

Fourth exercise (7.5 pts) An analogy

A- R-L series circuit

An electric circuit is formed of a coil of inductance L and of negligible resistance, a switch K and a resistor of resistance R all connected in series across an ideal generator of e.m.f. E as shown in the adjacent figure. At the instant $t_0 = 0$, we close K. At the instant t, the circuit carries a current i in the transient state.



1)Show that the differential equation that governs the variation of the current i as a function of time is given by the expression:

$$E = R i + \frac{L\,di}{dt}$$

2) Verify that the expression $i = \frac{E}{R}(1 - e^{\frac{-R}{L}t})$ is a solution of this differential equation.

3)Find the expression of I_{max}, the current carried by the circuit in the steady state (after a long time).

4) Determine, in terms of Rand L, the expression of the duration t] at the end of which the current i becomes equal to $0.63 I_{max}$.

5) Draw the shape of the curve that represents the variations of i as a function of time, and indicate on it t_1 and I max .

B- Vertical fall in a liquid

A metallic ball, of mass m, released from rest, falls vertically in a liquid. We suppose that the only force resisting the motion of the ball in the liquid is given by the expression $\vec{f} = -h\,\vec{v}$

$\vec{v}$ being the instantaneous velocity of the ball and h a positive constant.

1) Give a list of the forces acting on the ball during its vertical fall.
2) Applying Newton's second law, show that the differential equation that governs the variations of the algebraic value v of the velocity ~ is given by : $mg == hv + m\frac{dv}{dt}$. (2)

C- An analogy

1) By comparing the differential equations (1) and (2), give the convenient mechanical quantity corresponding to each of the electric quantities E, R, L, i and $\frac{di}{dt}$.

2) Deduce, using the analogy between the physical quantities:

a) The solution of the differential equation (2).

b) The expression $V_{limiting}$ of the velocity after a very long time.

c) Determine, in terms of f and m , the expression of the duration t_1' at the end of which the value of v becomes equal to 0.63 $V_{limiting}$

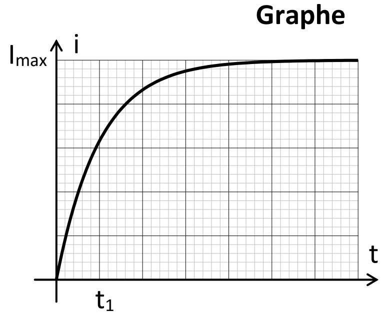
3) Draw the shape of the curve that represents the variations of vas a function of time and indicate on it t_1' and $V_{limiting}$.

Partie de la Q.	Corrigé	Note
	Premier exercice (7 points)	
A.1	$E_m = 1/2\ mv^2 + kx^2$	**0.5**
A.2	$\frac{dE_m}{dt} = mx'x'' + 2kxx' = 0 \Rightarrow x'' + \frac{2k}{m}x = 0.$	**0. 5**
A.3	Cette équation est de la forme : $x'' + \omega_0^2 x = 0$ $\omega_0 = \sqrt{\frac{2k}{m}}$.	**0,75**
B.1	$x'' = -\omega_0^2 x$ est bien une droite de coefficient directeur $-\omega_0^2$	**0,5**
B.2.a	$X_m = 10$ cm.	**0.25**
B.2.b	$x'' = 100\ m/s^2$	**0.75**
B.2.c	L'équation différentielle s'écrit : $x'' + \omega_0^2 x = 0 \Rightarrow x'' = -\omega_0^2 x$; le coefficient directeur de la droite est : $\frac{100}{-0,1} = -1000\,s^{-2} \Rightarrow \omega_0 = \sqrt{1000} = 31,6\ rad/s$	**1**
B.3a	En passant par la position d'équilibre x = 0 ; le graphique montre que pour x = 0, x'' = 0 $\Rightarrow \frac{dV}{dt} = 0 \Rightarrow$ V est maximale.	**0.75**
B.3.b	Conservation de l'E_m $\Rightarrow \frac{1}{2}mV_{max}^2 = kX_m^2 \Rightarrow \lvert V_{max} \rvert = \omega_0 X_m \Rightarrow V_{max} = 3,16\ m/s.$	**0,75**
B.4	$\omega_0^2 = \frac{2k}{m} \Rightarrow k = 50\ N/m.$	**1,25**
	Deuxième exercice (7 points)	
1.a	Résonance d'intensité , car la tension aux bornes du générateur et celle aux bornes du conducteur ohmique (image du courant) sont en phase. $f_o = \frac{1}{2\pi\sqrt{LC}}$	**0.75**
1.b	$T_o = 8 \times 2 = 16$ ms	**0.50**

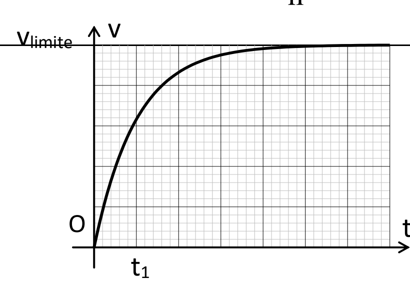
	$\Rightarrow$ $f_o = \frac{1}{T_o} = \frac{1}{16x10^{-3}} = 62{,}5Hz$ et $\omega_o = 2\pi f_o = 125\ \pi$ rd/s	
1.c	$U_m = 2 \times 2 = 4$ V $U_{Rm} = 4 \times 0{,}25 = 1$ V $\Rightarrow$ $I_m = \frac{U_{Rm}}{R} = \frac{1}{20} = 0{,}05$ A	**0,75**
1.d	Car u et i sont en phase . $U_m = R_t\ I_m$ $\Rightarrow$ $R_t = \frac{4}{0{,}05} = 80\ \Omega$ $r = R_t - R = 60\ \Omega$.	**1**
2.a	u_{BM} (image de i) est en avance de phase sur $u_{AM} = u_g$. Ceci est prévu car le circuit est capacitif .	**0.25**
2.b	2π rd $\rightarrow$ 8 div ϕ $\rightarrow$ 1div $\Rightarrow$ $\phi = \frac{2\pi}{8} = \frac{\pi}{4} rd$	**0.25**
2.c	$U_{BMmax} = 2{,}8x0{,}25 = 0{,}7$ V ; $\omega_o = 125\ \pi$ rd $\Rightarrow$ $u_{BM} = 0{,}7 \cos(125\ \pi\ t + \pi/4)$ (u_{BM} en V , t en s) $U_m = 2x2 = 4$ V alors $u = 4 \cos 125\ \pi\ t$ (u en V ,t en s)	**0.75**
2.d	$I_m = \frac{U_{BM\max}}{R} = \frac{2{,}8x0{,}25}{20} = 0{,}035$ A $\Rightarrow$ $i = 0{,}035 \cos(125\ \pi\ t + \frac{\pi}{4})$ (i en A , t en s)	**0.50**
2.e	$i = \frac{dq}{dt}$ et $q = C\ u_c$ $\Rightarrow$ $i = C \frac{du_c}{dt}$ $\Rightarrow$ $C \frac{du_c}{dt} = I_m \cos(125\ \pi\ t + \frac{\pi}{4})$ $\Rightarrow$ $u_c = \frac{I_m}{C}\int \cos(125t + \frac{\pi}{4})dt = \frac{I_m}{125\pi C}\sin(125\pi t + \frac{\pi}{4})$ $u_c = \frac{8{,}9x10^{-5}}{C}\sin(125\pi t + \frac{\pi}{4})$	**0.75**
2.f	Additivité des tensions : $u_{AM} = u_{AD} + u_{DB} + u_{BM}$	**1.00**

	$\Rightarrow$ 4 cos 125 π t = $\frac{8,9x10^{-5}}{C}\sin(125\pi t+\frac{\pi}{4})$ +80×0,035 cos (125 πt + $\frac{\pi}{4}$) Pour 125 π t = $\frac{\pi}{2}$ on a : 0 = $\frac{8,9x10^{-5}}{C}\sin(\frac{\pi}{2}+\frac{\pi}{4})+2,8\cos(\frac{\pi}{2}+\frac{\pi}{4})\Rightarrow$ $-\frac{8,9\times10^{-5}}{C}\times\frac{\sqrt{2}}{2}=2,8(-\frac{\sqrt{2}}{2})\Rightarrow C=32\times10^{-6}F=32\ \mu F$	
2.g	LC = 6,49 x 10^{-6} $\Rightarrow$ L = $\frac{6,49\times10^{-6}}{32\times10^{-6}}=0,2\ H$	**0.50**
	Troisième exercice (6 points)	
A.1	Pour ioniser un atome d'hydrogène, pris dans un état d'énergie E_n, il faut lui fournir une énergie W telle que: W + E_n = 0. Or W est sûrement > 0, donc E_n **< 0.**	**0.50**
A.2.a	Puisqu'il s'agit de l'énergie minimale donc l'électron arraché est au repos; alors : $E_i = E_\infty - E_1 = E_1$ = 13,6 eV = 13,6×1,602×10^{-19} = 2,178×10^{-18} J.	**0.75**
A.2.b	$\lambda_i = \frac{hc}{E_i} = \frac{6,626\times10^{-34}\times2,999\times10^{8}}{2,178\times10^{-18}}$ **= 91,24×10^{-9} m = 91,24 nm**	**0.75**
A.2.c	Comme λ de la lumière rayonnée par les étoiles chaudes est < λ_i $\Rightarrow$ E > E_i alors les atomes d'hydrogène du gaz interstellaire sont ionisés et les électrons arrachés possèdent de l'E_C**.**	**0.75**
B.1.a	$\lambda_{32} = \frac{hc}{E_3 - E_2}$ **= 656,3×10^{-9} m = 656,3 nm.**	**0.75**
B.1.b	Oui elle est visible car 400 nm ≤ λ_{32} ≤ 800 nm.	**0.25**
B.1.c	Parce que 640 nm ≤ λ_{32} ≤ 680 nm	**0.25**
B.2.a	$E_C = E_2 + h\nu \Rightarrow \nu = \frac{E_C}{h} - \frac{E_2}{h} = \frac{E_C}{h} + \frac{3,4\times1,602\times10^{-19}}{6,626\times10^{-34}}.$	**0.75**

8

	ν = $\frac{E_C}{h} + 8,22\times10^{14}$ Hz	
B.2.b.i	Comme il s'agit de λ_{min} $\Rightarrow$ ν_{max} $\Rightarrow$ $(E_C)_{max}$. $\frac{c}{\lambda_{min}} = \frac{(E_C)_{max}}{h} + 8,22\times10^{14}$ $\Rightarrow$ $(E_C)_{max} = 2,66\times10^{-19}$ **J.**	**0.75**
B.2.b.ii	$E_C = \frac{3}{2}kT$ $\Rightarrow$ T_{max} = 12850 K.	**0.50**
	Quatrième exercice (7.5 points)	
A.1	**E = $u_R + u_L$. E = Ri + L$\frac{di}{dt}$ (1) .**	**0.50**
A.2	$\frac{di}{dt} = \frac{E}{R}\times(\frac{R}{L})e^{-\frac{R}{L}t} = \frac{E}{L}e^{-\frac{R}{L}t}$ **, en remplaçant dans l'équation différentielle on obtient : E = R**$\frac{E}{R}(1-e^{-\frac{R}{L}t})$ **+L(**$\frac{E}{L}e^{-\frac{R}{L}t}$**) = E.**	**0.75**
A.3	**Si t → ∞ ,** $e^{-\frac{R}{L}t}$ **→ 0** $\Rightarrow$ **i =** $\frac{E}{R}$ **=** I_{max}**.**	**0.50**
A.4	**i =** $\frac{E}{R}(1-e^{-\frac{R}{L}t_1})$ **=** $0,63I_{max}$ **=0,63**$\frac{E}{R}$ $\Rightarrow$ $1-e^{-\frac{R}{L}t_1}$ **= 0,63**$\Rightarrow$ $e^{-\frac{R}{L}t_1}$ **= 1-0,63=0,37** $\Rightarrow$ **-**$\frac{R}{L}t_1 = \ln 0,37 = -0,99$ **≈ -1**$\Rightarrow$ **t_1 =** $\frac{L}{R}$ **.**	**0.75**
A.5	**Graphe**  	**0.75**

9

B.1	Le poids de la bille $m\vec{g}$: force verticale descendante La force de frottement $\vec{f} = -h\vec{v}$: force verticale ascendante.	**0.25**
B.2	$\frac{\overrightarrow{dP}}{dt} = m\frac{\overrightarrow{dv}}{dt} = \Sigma\overrightarrow{F_{ext}} = m\vec{g} - h\vec{v}$. Par projection sur un axe vertical orienté positivement dans le sens du mouvement on obtient : $m\frac{dv}{dt} = mg - hv \Rightarrow mg = hv + m\frac{dv}{dt}$ (2).	**1**
C.1	E correspond à mg ; R correspond à h ; i correspond à v ; L correspond à m ; $\frac{di}{dt}$ correspond à l'accélération $\frac{dv}{dt}$.	**1.25**
C.2.a	Par analogie, on peut déduire que : $v = \frac{mg}{h}(1 - e^{-\frac{h}{m}t})$	**0.50**
C.2.b	Si $t \to \infty$, $e^{-\frac{h}{m}t} \to 0 \Rightarrow v = \frac{mg}{h} = v_{limite}$.	**0.50**
C.2.c	$v = 0{,}63v_{limite} = 0{,}63\frac{mg}{h} = \frac{mg}{h}(1 - e^{-\frac{h}{m}t_1}) \Rightarrow$ $0{,}63 = 1 - e^{-\frac{h}{m}t_1} \Rightarrow e^{-\frac{h}{m}t_1} = 0{,}37 \Rightarrow -\frac{h}{m}t_1 = \ln 0{,}37 = -0{,}99 \approx -1 \Rightarrow t_1 = \frac{m}{h}$.	**0.50**
C.3	Graphe 	**0.25**

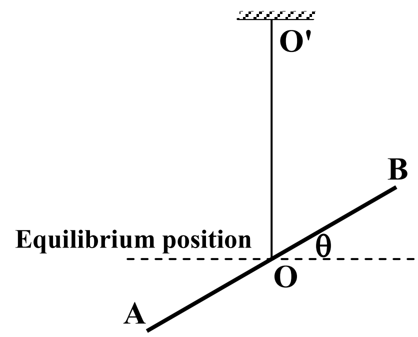
10

وزارة التربية والتعليم العالي المديرية العامة للتربية دائرة الامتحانات	امتحانات الشهادة الثانوية العامة الفرع : علوم عامة	الدورة العادية للعام 2009
	مسابقة في مادة الفيزياء المدة ثلاث ساعات	الاسم: الرقم:

This exam is formed of four exercises in four pages numbered from 1 to 4.
The use of non-programmable calculator is recommended

<u>First Exercise:</u> (7 ½ points)

Torsion pendulum



The object of this exercise is to determine the moment of inertia I of a homogeneous rod AB with respect to an axis perpendicular to the rod at its midpoint and the torsion constant C of a wire OO' of negligible mass.
The rod has a mass M and a length AB = ℓ = 60 cm.
A torsion pendulum [P] is obtained by fixing the mid-point of AB to one end O of the wire while the other end O' is fixed to a support .
The rod is shifted, from its equilibrium position, by a small angle θ_m in the horizontal plane and it is released from rest at an instant $t_0 = 0$ .The rod thus may turn in the horizontal plane about an axis (Δ) passing through OO'.

At an instant t during motion, the angular abscissa of the rod is θ and its angular velocity is $\dot{\theta} = \frac{d\theta}{dt}$

The horizontal plane containing the rod is taken as a gravitational potential energy reference.
We neglect any force of friction and take $\pi^2 = 10$.

***A* – Theoretical study**

1) Give, at the instant t, the expression of the mechanical energy M.E of the system [(P), Earth] in terms of I, C, θ and $\dot{\theta}$.

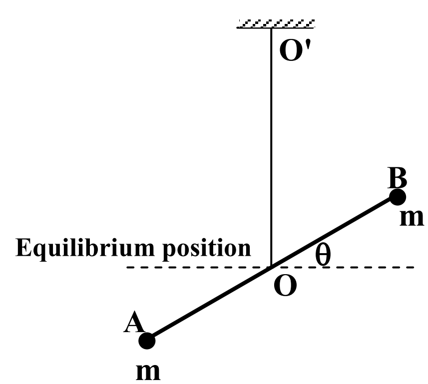
2) ***a)*** Write the expression of M.E when $\theta = \theta_m$
b) Determine , in terms of C, θ_m and I, the expression of the angular speed of [P] as it passes through its equilibrium position .

3) Derive the second order differential equation in θ that governs the motion of [P].

4) Deduce that the motion of [P] is sinusoidal.

5) Determine the expression of the proper period T_1 of the pendulum in terms of I and C.

***B* – Experimental study**



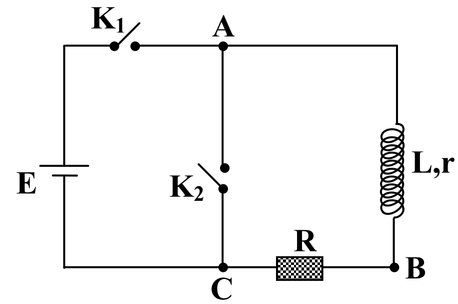
1) By means of a stopwatch, we measure the duration t_1 of 20 oscillations and we obtain t_1 = 20 s. Determine the relation between I and C.

2) At each extremity of the rod we fixe a particle of mass m = 25g . We thus obtain a new torsion pendulum [P'] whose motion is also rotational sinusoidal of proper period T_2.
a) Determine the moment of inertia I' of the system (rod + particles) with respect to the axis (Δ) in terms of I, m, and ℓ .
b) Write down the expression of T_2 in terms of I , C , m and ℓ .
c) By means of a stopwatch, we measure the duration t_2 of 20 oscillations and we obtain t_2 = 40 s.
Find a new relation between I and C.

3) Calculate the values of I and C.

Second Exercise: (7 ½ points)

The phenomenon of self-induction



The set up represented by the adjacent figure consists of an ideal generator of emf $E = 12$ V, a coil of resistance $r = 10\ \Omega$ and of inductance $L = 40$ mH, a resistor of resistance $R = 40\ \Omega$ and two switches K_1 and K_2.

A – At the instant $t_0 = 0$, we close the switch K_1 and we leave K_2 open. At an instant t, the circuit carries a current i_1 in the transient state.

1) Derive the differential equation that governs the variation of i_1 as a function of time.

2) I_0 is the current in the steady state. Determine the expression of I_0 in terms of E, r and R and calculate its value.

3) The solution of the differential equation is of the form: $i_1 = I_0(1 - e^{\frac{-t}{\tau}})$.

- ***a)*** Determine the expression of τ in terms of L, r and R and calculate its value.
- ***b)*** Give the physical significance of τ.

4) **a)** Determine the expression of the self-induced emf e_1 as a function of time t.
b) Calculate the algebraic value of e_1 at the instant $t_0 = 0$.

B – After a few seconds, the steady state being reached, we open K_1 and we close K_2 at the same instant. We consider the instant of closing K_2 as a new origin of time $t_0 = 0$. The circuit (L, R, r) thus carries an induced current i_2 at an instant t.

1) Determine the direction of i_2.

2) Derive the differential equation that governs the variation of i_2 as a function of time.

3) Verify that $i_2 = I_0 e^{\frac{-t}{\tau}}$ is the solution of this differential equation.

4) Calculate the algebraic value of the self-induced emf e_2 at the instant $t_0 = 0$.

C – Compare e_1 and e_2 and deduce the role of the coil in each of the two previous circuits.

Third Exercise: (7 ½ points)

Characteristics of an (R, L, C) circuit

In order to determine the characteristics of an (R, L, C) circuit, we connect the circuit represented in figure 1. This circuit is formed of a resistor of resistance R= 650 Ω, a coil of inductance L and of negligible resistance and a capacitor of capacitance C, all connected in series across a function generator (LFG) delivering across its terminals a sinusoidal alternating voltage u_g of the form:

$u_g = u_{AM} = U_m \cos(2\pi f)t$.

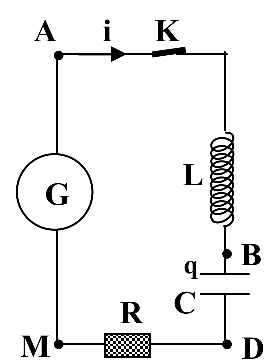


Fig.1

A –The frequency of the voltage u_G is adjusted on the value f_1 .
We display, on the screen of an oscilloscope, the variations , as a function of time, of the voltage u_{AM} across the generator on the channel (Y_1) and the voltage u_{DM} across the resistor on the channel (Y_2) .
The waveforms obtained are represented in figure 2.

Vertical sensitivity on both channels is: 2 V/div.

Horizontal sensitivity is: 0.1 ms /div.

1) Redraw figure (1) showing on it the connections of the oscilloscope.

2) Referring to the waveforms, determine:

a) The value of the frequency f_1.

b) The absolute value of φ_1 the phase difference between u_{AM} and u_{DM}.

3) The current i carried by the circuit has the form:

$i = I_m \cos(2\pi f_1 t - \varphi_1)$.

a) Write down the expressions of the voltages: u_{AB}, u_{BD} and u_{DM} as a function of time.

b) The relation: $u_{AM} = u_{AB} + u_{BD} + u_{DM}$ is valid for any instant t . Show, by giving t a particular value, that:

$$\tan \varphi_1 = \frac{L(2\pi f_1) - \frac{1}{C(2\pi f_1)}}{R}$$

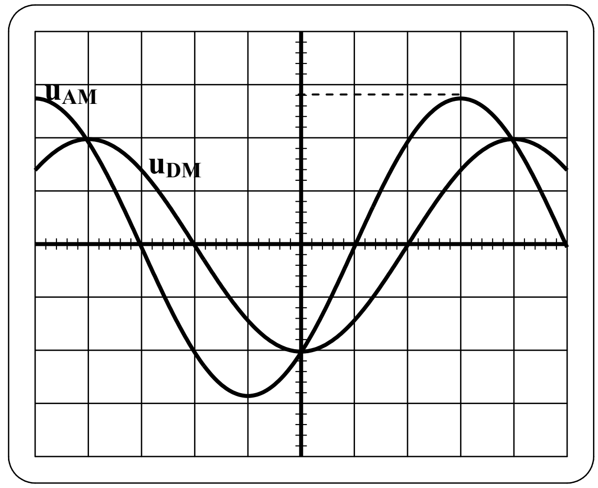


Fig.2

B – Starting from the value f_1, we decrease continuously the frequency f . We notice that, for f_0 = 500 Hz the circuit is the seat a of current resonance phenomenon.

Deduce from what preceded a relation between L, C and f_0.

C – We keep decreasing the frequency f . For a value f_2 of f we find that the phase difference between u_{AM} and u_{DM} is φ_2 such that $\varphi_2 = - \varphi_1$.

1) Determine the relation among f_1, f_2 and f_0 .

2) Deduce the value of f_2.

D – Deduce from what is preceded the values of L and C.

<u>Fourth Exercise</u>: (7 ½ points)

Energy levels of the hydrogen atom

The energies of the various levels of the hydrogen atom are given by the relation:

$E_n = -\frac{E_0}{n^2}$, where E_0 is a positive constant and n is a positive whole number.

Given:

Planck's constant $h = 6.62\times10^{-34}$ J.s; 1 eV = 1.6×10^{-19} J; 1 nm = 10^{-9} m.

Speed of light in vacuum: $c = 3\times10^{8}$ m/s

1) ***a)*** The energy of the hydrogen atom is quantized. What is meant by "*quantized energy*"?
b) Explain why the absorption or emission spectrum of hydrogen consists of lines.

2) A hydrogen atom, initially excited, undergoes a downward transition from the energy level E_2 to the energy level E_1. It then emits the radiation of wavelength in vacuum: $\lambda_{2\to1} = 1.216\times10^{-7}$ m.
Determine, in J, the value:
a) of the constant E_0;
b) of the ionization energy of the hydrogen atom taken in its ground state.

3) For hydrogen, we define several series that are named after the researchers who contributed in their study . Among these series we consider that of Balmer, which is characterized by the downward transitions from the energy level $E_p > E_2$ (p >2) to the energy level E_2 (n = 2).
To each transition $p \to 2$ corresponds a line of wave $\lambda_{p\to2}$.
a) Show that $\lambda_{p\to2}$, expressed in nm, is given by the relation:. $\frac{1}{\lambda_{p\to2}} = 1.096\times10^{-2}\left[\frac{1}{4}-\frac{1}{p^2}\right]$
b) The analysis of the emission spectrum of the hydrogen atom shows four visible lines.
We consider the three lines H_α , H_β and H_γ of respective wavelengths in vacuum are λ_α = 656.28 nm ; λ_β = 486.13 nm and λ_γ = 434.05 nm.
To which transition does each of these radiations correspond?
c) Show that the wavelengths of the corresponding radiations tend ,when $p\to\infty$, towards a limit λ_0. whose value is to be calculated.

4) Balmer, in 1885, knew only the lines of the hydrogen atom that belong to the visible spectrum. He wrote the formula**:** $\lambda = K\frac{p^2}{p^2-4}$, where K is a positive constant and p a positive whole number.
Determine the value of K using the numerical values and compare its value with that of λ_0.

First exercise (7.5 points)

A – 1) $ME = KE + P.E_g + PE_e = \frac{1}{2}I\theta'^2 + 0 + \frac{1}{2}C\theta^2$ **(¾)**

2) a) for max. deviation, $\theta = \theta_m$ and $\theta' = 0$.

$E_m = \frac{1}{2}C\theta^2_m$ **(½)**

b) At equilibrium position, $E_m = \frac{1}{2} I\theta'^2_m$

$\Rightarrow \theta' = \pm\theta_m\sqrt{\frac{C}{I}}$ **(¾)**

3) M.E is conserved since no friction thus the derivative of M.E w.r.t time is zero

$I\theta'\theta'' + C\theta\theta' = 0$, $\theta' \neq 0$ thus $\theta'' + \frac{C}{I}\theta = 0$ **(¾)**

4) Equation has the form $\theta'' + \omega^2\theta = 0$

It has a sinusoidal solution where $\omega^2 = \frac{C}{I}$: **(¼)**

5) $\omega^2 = \frac{C}{I}$

$\omega = \frac{2\pi}{T}$ thus $T_1 = 2\pi\sqrt{\frac{I}{C}}$ **(¾)**

B – 1) $t_1 = 20T_1 = 20s$ thus $T_1 = 1 = 2\pi\sqrt{\frac{I}{C}}$

and $40\frac{I}{C} = 1$ then $C = 40 I$ **(1)**

2) a) $I' = I + 2m(\frac{\ell}{2})^2 = I + m\frac{\ell^2}{2} = I + 0.0045$ **(¾)**

b) Same law of motion thus $T_2 = 2\pi\sqrt{\frac{I'}{C}} = 2\pi\sqrt{\frac{I+\frac{m\ell^2}{2}}{C}}$ **(½)**

c) $T_2 = 2$ thus $10\frac{I'}{C} = 1$ or $C = 10 I' = 10(I + 0.0045) = 10 I + 0.045$ **(¾)**

3) $C = 40 I = 10I + 0.045 \Rightarrow I = 1.5\times10^{-3}$ kg.m^2 and $C = 0.06$ N×m **(¾)**

Second exercise (7.5 points)

A – 1) $E = ri_1 + L\frac{di_1}{dt} + Ri_1 \Rightarrow E = (r+R)\,i_1 + L\frac{di_1}{dt}$. **(½)**

2) When the steady state mode is established, i_1 becomes constant and $\frac{di_1}{dt} = 0$;

the current is then I_0 such that: $E = (r+R)\,I_0 \Rightarrow I_0 = \frac{E}{R+r}$.

$I_0 = \frac{12}{40+10} = 0.24$ A **(1)**

3) a) $\frac{di_1}{dt} = I_0/\tau\,(e^{\frac{-t}{\tau}}) \Rightarrow E = (r+R)\,I_0(1 - e^{\frac{-t}{\tau}}) + L\,I_0/\tau\,(e^{\frac{-t}{\tau}})$

$\Rightarrow L/\tau = (r+R) \Rightarrow \tau = \frac{L}{R+r} = \frac{0.04}{50} = 0.8$ ms. **(1)**

b) The time constant characterizes the duration of the growth of the current in a (R+r, L) component **(¼)**

4) a) $e_1 = -L\frac{di_1}{dt} = -L\,I_0/\tau\,(e^{\frac{-t}{\tau}}) = -E\,e^{\frac{-t}{\tau}}$. **(½)**

b) For $t = 0$, $e_1 = -E = -12$ V. **(¼)**

B – 1) According to Lenz law, the coil carries a current i_2 of the same direction as that of i_1. **(½)**

2) $u_{AC} = u_{AB} + u_{BC} \Rightarrow 0 = ri_2 + L\frac{di_2}{dt} + Ri_2 \quad \Rightarrow L\frac{di_2}{dt} + (R+r)\,i_2 = 0$ **(¾)**

3) $\frac{di_2}{dt} = -I_0/\tau\,e^{\frac{-t}{\tau}} \Rightarrow -L\,I_0/\tau\,e^{\frac{-t}{\tau}} + (R+r)\,I_0\,e^{\frac{-t}{\tau}} = 0$ **(1)**

4) $e_2 = -L\frac{di_2}{dt} = -L(-I_0/\tau\,e^{\frac{-t}{\tau}}) = E\,e^{\frac{-t}{\tau}}$.

At $t = 0$, $e_2 = E = 12$ V. **(¾)**

C – $e_1 = -e_2$.

When K_1 is closed, the self-induced emf opposes the growth of the current in the circuit $\Rightarrow e_1 < 0$ (the coil plays the role of a generator in opposition).

When K_2 is closed, the self-induced emf opposes the decay of the current in the circuit $\Rightarrow e_2 > 0$ (the coil plays the role of a generator). **(1)**

Third exercise (7.5 points)

A – 1) Connections of the oscilloscope. **(¼)**

2) a) $T_1 \rightarrow 8$ div $\Rightarrow T_1 = 0,8$ ms

$f_1 = 1/T_1 = 1/\ 0.8 \times 10^{-3} = 1250$ Hz **(½)**

b) $|\varphi_1| = 2\pi\ 1/8 = \pi/4$ rad. **(¼)**

3) a) $i = I_m \cos(2\pi f_1 \cdot t - \varphi_1)$; $u_{AB} = L\, di/dt = -LI_m(2\pi f_1)\sin(2\pi f_1 t - \varphi_1)$

$u_C = 1/C \int i\, dt = I_m/C \int \cos(2\pi f_1 t - \varphi_1)\, dt$

$u_C = (I_m / C.2\pi f_1)\sin(2\pi f_1 t - \varphi_1)$

$u_R = Ri = R\, I_m \cos(2\pi f_1 t - \varphi_1)$ **(1)**

b) $U_m \cos 2\pi f_1 t = R\, I_m \cos(2\pi f_1 t - \varphi_1) + (I_m / C.2\pi f_1)\sin(2\pi f_1 t - \varphi_1) -$

$LI_m(2\pi f_1)\sin(2\pi f_1 t - \varphi_1)$

$2\pi f_1 t = \pi/2 \Rightarrow 0 = RI_m \sin\varphi_1 + (I_m / C.2\pi f_1)\cos\varphi_1 - L\, I_m(2\pi f_1)\cos\varphi_1$

$\Rightarrow R\sin\varphi_1 = [L(2\pi f_1) - 1/(C(2\pi f_1))]I_m \cos\varphi_1$

$$tg\varphi_1 = \frac{L(2\pi f_1) - \dfrac{1}{C(2\pi f_1)}}{R}$$ **(¾)**

B – Current resonance $\Rightarrow \varphi = 0 \Rightarrow tg\varphi = 0 \Rightarrow L2\pi f_0 - 1/C(2\pi f_0) = 0$

$\Rightarrow LC4\pi^2 f_0^2 = 1.$ **(¾)**

C – 1) $tg\varphi_1 = -tg\,\varphi_2 \Rightarrow \dfrac{L(2\pi f_1) - \dfrac{1}{C(2\pi f_1)}}{R} = \dfrac{\dfrac{1}{C2\pi f_2} - L2\pi f_2}{R}$

$\Rightarrow L2\pi f_1 + L2\pi f_2 = 1/C\,[1/(2\pi f_1) + 1/(2\pi f_2)]$

$LC = 1/\ 4\pi^2 f_1 f_2 = 1/\ 4\pi^2 f_0^2 \Rightarrow f_0^2 = f_1 f_2$ **(1½)**

2) $f_2 = (500^2)/\ 1250 = 250000/1250 = 200$ Hz **(½)**

D – $\varphi_1 = \pi/4 \Rightarrow L2\pi(1250) - 1/(C \times 2\pi \times 1250) = 650$

$LC = 1/(4\pi^2 500^2) = 10^{-7} \Rightarrow LC \times 4\pi^2 \times 1250^2 - 1 = 650 \times C \times 2\pi \times 1250$

$\Rightarrow C = 5.25/(650 \times 2\pi \times 1250) = 10^{-6}$ F = 1 μF

$L = 10^{-7}/\ 10^{-6} = 10^{-1}$ H = 0.1 H **(2)**

Fourth exercise (7.5 points)

1) a) The energies of the hydrogen atom can take only well defined values (discrete) **(½)**

b) For an electronic transition p $\rightarrow$ n the emitted photon (or absorbed) has a wavelength:

$\lambda_{p,n} = \dfrac{hc}{E_p - E_n}$. As E_p and E_N are quantized then $(E_p - E_N)$ is quantized too; which means that the $\lambda_{p,n}$ has a well determined value, which corresponds to a line.; **(1)**

1) a) $E_2 = -\dfrac{E_o}{4}$ and $E_1 = E_o \Rightarrow E_2 - E_1 = \dfrac{3E_0}{4} = \dfrac{hc}{\lambda_{2,1}}$

$$\Rightarrow E_0 = \frac{4 \times 6.62 \times 10^{-34} \times 3 \times 10^8}{3 \times 1.216 \times 10^{-7}} = 2.177 \times 10^{-18}$$ **(1½)**

b) $E_i = E_\infty - E_1 = E_0 = 2.177 \times 10^{-18}$ J. **(½)**

3) a)

$$E_p - E_2 = -\frac{E_0}{p^2} + \frac{E_0}{4} = \frac{hc}{\lambda_{p,2}} \Rightarrow \frac{1}{\lambda_{p,2}} = \frac{E_0}{hc}\left(\frac{1}{4} - \frac{1}{p^2}\right)$$

$$= \frac{2.177 \times 10^{-18} \times 10^{-9}}{6.62 \times 10^{-34} \times 3 \times 10^8}\left(\frac{1}{4} - \frac{1}{p^2}\right) = 1.096 \times 10^{-2}\left(\frac{1}{4} - \frac{1}{p^2}\right)$$ **(1½)**

b) $\lambda_\alpha = 656.28$ nm $\Rightarrow$ p= 3, then it is the downward transition $3 \rightarrow 2$.

λ_β ; $4 \rightarrow 2$ and λ_γ ; $5 \rightarrow 2$. **(¾)**

c) when $p \rightarrow \infty \Rightarrow \lambda \rightarrow \lambda_0 = \dfrac{4}{1.096 \times 10^{-2}} = 364.96$ nm **(½)**

4) For $\lambda_\alpha = 656.28$ nm, p = 3 ; $K = \lambda \dfrac{p^2 - 4}{p^2} = 364.6$ nm, $K \cong \lambda_0$ **(1¼)**

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

This exam is formed of four exercises in four pages
The use of non-programmable calculator is recommended

First Exercise (7.5 points) Interference of light

Consider Young's double slit apparatus that is represented in the adjacent figure 1. S_1 and S_2 are separated by a distance a = 1mm.
The planes (P) and (E) are at a distance D = 1m. I is the midpoint of S_1S_2 and O the orthogonal projection of I on (P). On the perpendicular to IO at point O and parallel to S_1S_2 , a point M is defined by its abscissa OM = x.

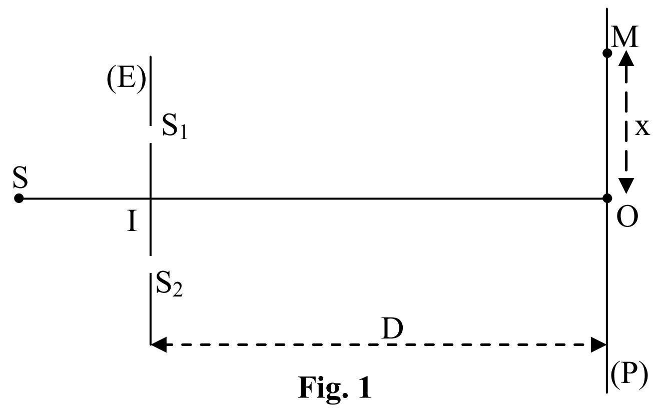


Fig. 1

1) S_1 and S_2, illuminated by two lamps, emit synchronous radiations. Do we observe interference fringes on the screen? Why?
2) S_1 and S_2 are illuminated by a point source S put on IO.
   S emits a monochromatic radiation of wavelength λ in vacuum (or in air).
   a) Is the fringe obtained at O bright or dark? Why?
   b) Give, at point M ,the expression of the optical path difference δ between the two radiations emitted by S, one passing through S_1 and the other through S_2, in terms of D, x and a.
   c) Derive the relation giving the abscissas of the centers of the bright fringes and that giving the abscissas of the centers of the dark fringes.
   d) For x = 2.24 mm, M is at the center of the fourth bright fringe (bright fringe of order 4). Calculate λ.
3) The source S emits now white light.
   a) At O, we observe a white light. Why ?
   b) Calculate the wavelengths of the visible radiations that give at M, of abscissa OM = x = 2.24mm, dark fringes.
   Visible spectrum: $0.400\ \mu m \le \lambda \le 0.800\ \mu m$.

Second Exercise (7.5 points) Determination of the half-life of Polonium 210

Polonium 210 nucleus ($^{210}_{84}Po$) is an α emitter, and it is the only polonium isotope that exists in nature; it was found by Pierre Curie in 1898 in an ore. It is also obtained from the decay of a bismuth 210 nucleus ($^{210}_{83}Bi$).
Masses of the nuclei: m (Bi) = 209.938445 u ; m(Po) = 209.936648 u
mass of the electron : m_e = 0.00055 u
1 u = 931.5 MeV / c^2 = 1.66 10^{-27} kg.
Here is a part of the periodic table of elements: $_{81}Th$; $_{82}Pb$; $_{83}Bi$; $_{84}Po$; $_{85}At$; $_{86}Rn$.

A –The polonium 210

1) **a)** Write down the equation of the decay of bismuth 210.
   b) Identify the emitted particle and specify the type of this decay.
2) Calculate the energy liberated by this decay.

3) The decay of the bismuth 210 nucleus is accompanied with the emission of a γ photon of energy $E(\gamma) = 0.96$ MeV and an antineutrino of energy 0.02 MeV. Knowing that the daughter nucleus is practically at rest, calculate the kinetic energy of the emitted particle.

B – Half-life of polonium 210

1) **a)** Write down the equation of the decay of polonium 210.
b) Identify the daughter nucleus.

2) In order to determine the radioactive period T (half-life) of $^{210}_{84}Po$, we consider a sample of this isotope containing N_o nuclei at the instant $t_o = 0$. Let N be the number of the non-decayed nuclei at an instant t.
a) Write down the expression of the law of radioactive decay.
b) Determine the expression of $-\ln(\frac{N}{N_0})$ as a function of t.

3) A counter allows to obtain the measurements that are tabulated in the following table :

t (days)	0	40	80	120	160	200	240
$\frac{N}{N_0}$	1	0.82	0.67	0.55	0.45	0.37	0.30
$-\ln(\frac{N}{N_0})$	0		0.4		0.8		1.2

a) Complete the table.
b) Trace, on the graph paper, the curve giving the variation of $-\ln(\frac{N}{N_0})$ as a function of time.

Scale: 1 cm on the abscissa axis corresponds to 40 days.
1 cm on the ordinate axis corresponds to 0.2.

c) Is this curve in agreement with the expression found in the question (B – **2**, b) ? Justify.
d) **i)** Calculate the slope of the traced curve.
ii) What does this slope represent for the polonium 210 nucleus?
iii) Deduce the value of T.

Third Exercise (7.5 points) Exchanged Energy

We connect up the circuit formed of a resistor of resistance R = 2.2 kΩ, an ideal generator of e.m.f E = 8 V, a coil of inductance L = 0.8 H and of negligible resistance ,a resistor of adjustable resistance r and two switches K_1 and K_2 (Fig.1).

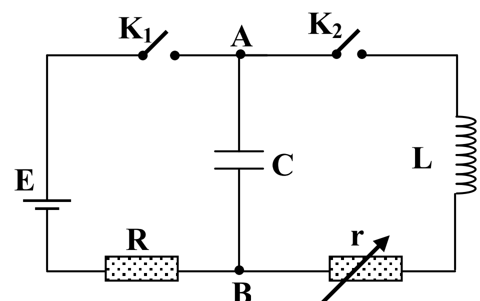


Fig. 1

A – (RC) Series circuit

At an instant taken as an origin of time, ($t_0 = 0$), we close the switch K_1, and K_2 remains open.
We study the charging of the capacitor through the variation of the voltage $u_{AB} = u_C$ as a function of time.

1) Show that the differential equation in u_C is:

$$E = u_C + RC\frac{du_C}{dt}.$$

2) Knowing that $u_C = E(1- e^{\frac{-t}{\tau}})$ is the solution of this differential equation, determine the expression of the time constant τ in terms of R and C.
3) The curve of figure 2 shows the variation of u_C as a function of time. Using this curve, determine the time constant τ (indicating the method used).
4) Calculate the value of C.

5) **a)** Give, in ms, the duration t_1 at the end of which the voltage across the capacitor will no longer practically vary.

b) Calculate the charge of the capacitor and the energy W_0 stored at the end of the duration t_1.

B – (L,C) series circuit

We give r the value zero. The voltage across the capacitor is 8 V. At an instant taken as an origin of time ($t_0 = 0$), we open the switch K_1 and we close the switch K_2.

1) Derive the differential equation that describes the variation of the voltage u_C as a function of time.
2) The circuit is the seat of electric oscillations of proper period T_0. The solution of this differential equation is: $u_C = E\cos(\frac{2\pi}{T_0}t)$. Determine the value of T_o .
3) Trace the shape of the curve representing the variation of u_C as a function of time.
4) Specify the energy exchanges that take place in the circuit.

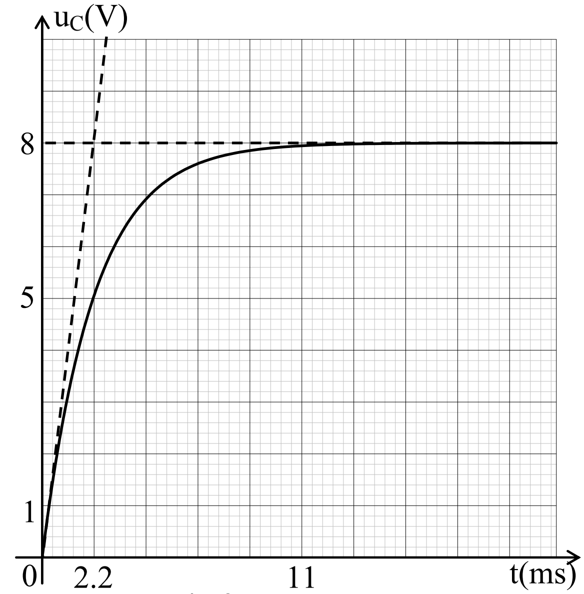


Fig.2

C – (r, L, C) series circuit

We give r a certain value. The voltage across the terminals of the capacitor is 8 V. We open K_1 and we close K_2 at the instant $t_0 = 0$. The waveform of figure 3 shows the variation of the voltage u_C as a function of time.

1) Specify the energy exchanges that take place in the circuit.
2) **a)** Referring to figure 3, find the pseudo-period T of the electric oscillations.

   b) Compare T and T_0.
3) At the end of the duration $t_n = nT$ (n being a whole number), the energy dissipated by Joule's effect is 98.6 % of the energy W_0 initially stored in the capacitor.

   a) At the instant $t_n = nT$, the energy stored in the circuit is purely electric. Why?

   b) We denote by W_0 and W_n the electric energy of the oscillator at the instants t_0 and t_n respectively. Calculate W_n.

   c) Determine n.

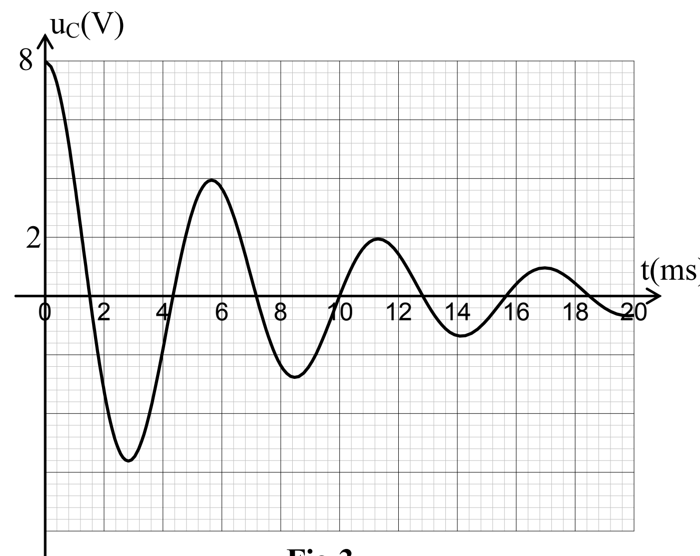


Fig.3

<u>Fourth Exercise</u> (7.5 points) Compound Pendulum

The aim of this exercise is to study the variation of the proper period T of a compound pendulum as a function of the distance a , of adjustable value, separating the axis of oscillation from the center of mass of this pendulum, and to show evidence of some properties associated to this distance a .

We consider a homogeneous disc (D) of mass m = 200g, free to rotate without friction around a horizontal axis (Δ) perpendicular to its plane through a point O (Fig. 1).

I_0 is the moment of inertia of (D) about the axis (Δ_0) parallel to (Δ) and passing through its center of mass G and I its moment of inertia about the axis (Δ), (Δ_0) being at a distance a = OG from (Δ) , so that: $I = I_0 + ma^2$.

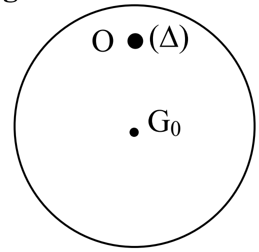


Fig 1

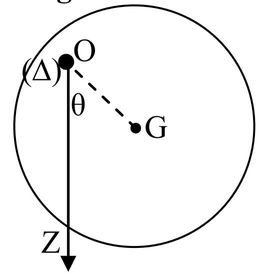


Fig 2

The gravitational potential energy reference is the horizontal plane passing through the center of mass G_0 of (D) when (D) is in the position of stable equilibrium (Fig.1).
(D) is made to oscillate around (Δ) and we measure the value of the proper period corresponding to each value of a.

Take: $g = 10\ m/s^2$; $\pi^2 = 10$;

For small angles (θ in radian); $1-\cos\theta=\frac{\theta^2}{2}$ and $\sin\theta = \theta$.

A – Theoretical study

(D) is shifted from its stable equilibrium position by a small angle θ_m and is then released from rest at the instant $t_0 = 0$. (D) thus oscillates around the axis (Δ) with a proper period T.

At an instant t, the angular abscissa of the pendulum is θ and its angular velocity is $\theta' = \frac{d\theta}{dt}$ (Fig. 2).

1) Write down, at the instant t, the expression of the mechanical energy of the system (pendulum, Earth) in terms of I, m, a, g, θ and θ'.

2) **a)** Derive the second order differential equation in θ that describes the motion of (D).

b) Deduce that the expression of the period T of this pendulum is given by: $T = 2\pi\sqrt{\frac{I}{mga}}$.

3) T_1 and T_2 are respectively the periods of the pendulum when it oscillates around (Δ) that passes successively through O_1 and O_2 where $O_1G = a_1$ and $O_2G = a_2$. The oscillations have the same period ($T_1 = T_2$). I_1 and I_2 are respectively the moments of inertia of the pendulum around (Δ) that passes successively through O_1 and O_2.

a) i) Find a relation among I_1, I_2, a_1 and a_2.

ii) Deduce that $I_0 = m\, a_1 a_2$.

b) The proper period T' of a simple pendulum of length ℓ, for oscillations of small amplitude, is given by the expression $T' = 2\pi\sqrt{\frac{\ell}{g}}$.

Show that, when the value of T' is equal to that of T_1, we obtain $\ell = a_1 + a_2$.

B – Experimental study

We measure the value of the period T of the pendulum for each value of a. The obtained measurements allow us to trace the curve giving the variation of T as a function of a. The straight line of equation T = 1.1s intersects this curve in two points A and B. (Fig. 3)

1) **a)** Referring to the curve, give the values of a_1 and a_2 corresponding to the period T = 1.1 s.

b) Deduce the value of I_0 and that of ℓ.

2) According to the curve of figure 3, T takes a minimum value ($T_{min} = 1.05$ s) for a certain value a' of a.

a) Give, using the curve, the value of a' corresponding to T_{min}.

b) Find, by calculation, the value of a' and that of T_{min}.

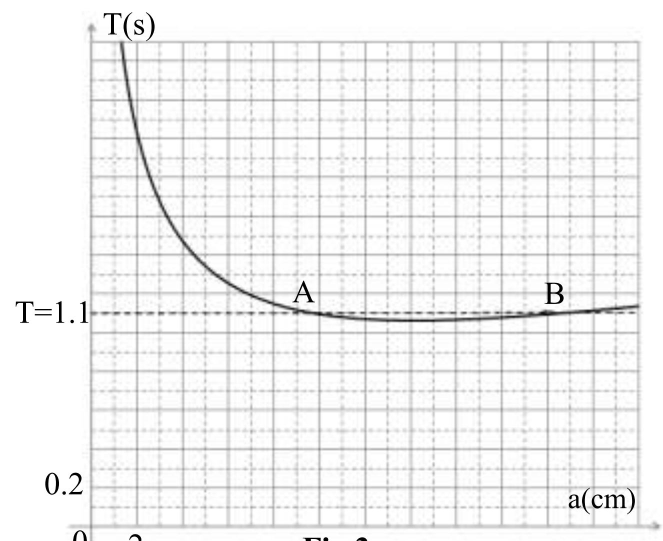


Fig.3

First exercise

1) We don't observe interference fringes since the two sources are not coherent. **(½)**

a) The two vibrations reach O in phase, the optical path difference at O is equal to zero :
$= (SS_1 + S_1O) - (SS_2 + S_2O) = 0$ (¾)

b) $\delta = \dfrac{ax}{D}$ **(½)**

c) Bright fringes : $\delta = k\lambda \Rightarrow \dfrac{ax}{D} = k\lambda \Rightarrow x = k\dfrac{\lambda D}{a}$

Dark fringes: $\delta = (2k+1)\dfrac{\lambda}{2} \Rightarrow \dfrac{ax}{D} = (2k+1)\dfrac{\lambda}{2}$

$\Rightarrow x = (2k+1)\dfrac{\lambda D}{2a}$ **(1½)**

d) $OM = x = 4i = 4\dfrac{\lambda D}{a}$

$\Rightarrow \lambda = \dfrac{ax}{4D} = \dfrac{1 \times 2.24}{4 \times 10^3} = 0.56 \times 10^{-3}$ mm = 560 nm **(1¼)**

2) **a)** Every radiation gives at O bright fringe and because of superposition of all colors $\Rightarrow$ white light. **(1)**

b) $\dfrac{ax}{D} = (2k+1)\dfrac{\lambda}{2} \Rightarrow \lambda = \dfrac{2ax}{(2k+1)D} = \dfrac{2 \times 1 \times 2{,}24}{(2k+1) \times 10^3} = \dfrac{4.48 \times 10^{-3}}{(2k+1)}$ mm $= \dfrac{4.48}{(2k+1)}$ µm

$0.4\mu m \le \lambda_V \le 0.8\mu m \Rightarrow 0.4 \le \dfrac{4{,}48}{(2k+1)} \le 0.8 \Rightarrow 5.6 \le (2k+1) \le 11.2 \Rightarrow (2k+1) \in \{7, 9, 11\}$

(2k + 1)	7	9	11
λµm	0.64	0.497	0.407

(2)

Second exercise

A – 1) a) $^{210}_{83}Bi \rightarrow {}^{210}_{84}Po + {}^{a}_{z}X$

Coservation laws : $210 = a + 0 \Rightarrow a = 0$

$83 = 84 + z \Rightarrow z = -1$ **(½)**

b) The emitted particle is electron $^{0}_{-1}e$; $^{210}_{83}Bi$ is a β^{-1} emitter **(¼)**

2) $E_{libe} =$ m × c^2 where m is the mass defect

$\Delta m = m_{before} - m_{after} = m(Bi) - m(Po) - m(e)$
$\Delta m = 209.938445$ u $- 209.936648$ u $- 0.00055$ u $= 1.247 \times 10^{-3}$ u

$E_{lib} = 1.247 \times 10^{-3} \times 931.5 \dfrac{MeV}{c^2} \times c^2 = 1.16$ MeV. **(1)**

3) $E_{lib} = E(Po) + E(\ ) + E(e) + E(\ )$

$\Rightarrow E_c = E(e) = 1.16 - 0.96 - 0.02 = 0.18$ MeV **(¾)**

B – 1) a) $^{210}_{84}Po \quad {}^{A}_{Z}X + {}^{4}_{2}He$

Conservation laws : $210 = A + 4 \Rightarrow A = 206$

$84 = Z + 2 \Rightarrow Z = 82$ **(½)**

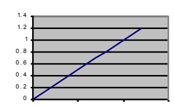
b) $^{a}_{z}X$ is $^{206}_{82}Pb$ **(¼)**

2) a) $N = N_o e^{-\lambda t}$ where λ is the radioactive constant **(½)**

b) $\dfrac{N}{N_0} = e^{-\lambda t} \quad \ell n\left(\dfrac{N}{N_0}\right) = -\lambda t \Rightarrow -\ell n\left(\dfrac{N}{N_0}\right) = \lambda t$ **(½)**

3) a) missing values in the table : 0.20 ; 0.60 ; 1 **(½)**

b) **(1¼)**



c) The curve is a straight line passing through the origin is an agreement with $-\ell n\left(\dfrac{N}{N_0}\right) = \lambda t$. **(¼)**

d) i) $\lambda = \dfrac{0.6}{120} = 5 \quad 10^{-3}$ day^{-1} **(½)**

ii) The slope of this line is the radioactive constant λ of polonium 210. **(¼)**

iii) $T = \dfrac{\ell n2}{\lambda} = 138.6$ days. **(½)**

Third exrcise

A – 1) $E = u_C + Ri$, $i = C\dfrac{du_C}{dt} \Rightarrow E = u_C + RC\dfrac{du_C}{dt}$ **(½)**

2) $u_C = E(1 - e^{-\frac{t}{\tau}}) \Rightarrow \dfrac{du_C}{dt} = \dfrac{E}{\tau}e^{-\frac{t}{\tau}} \Rightarrow E = E(1 - e^{-\frac{t}{\tau}}) + RC\dfrac{E}{\tau}e^{-\frac{t}{\tau}} \Rightarrow$

$\dfrac{RC}{\tau} = 1 \Rightarrow \tau = RC.$ **(¾)**

3) At instant $t = \tau$, $u_c = 0.63E = 0.63 \times 8 = 5.04$ V,

From graph : $t = \tau = 2.2$ ms for $u_c = 5.04$ V. **(½)**

4) $\tau = RC = 2.2\times 10^{3} = 2.2\times 10^{-3} \Rightarrow C = 10^{-6}F = 1\ \mu F$. **(½)**

5) a) During $t_1 = 5\tau = 11$ ms. **(¼)**

b) $Q = CE = 8\times 10^{-6}$ C ; $W_0 = ½\ CE^2 = 32\times 10^{-6}$ J. **(1)**

B – 1) $u_C = L\dfrac{di}{dt}$, $i = -\dfrac{dq}{dt} = -C\dfrac{du_C}{dt}$, $\Rightarrow u_C = -LC\ddot{u}_C \Rightarrow u_C + LC\ddot{u}_C = 0$ **(½)**

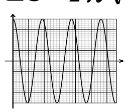
2) $u_C = E\cos(\dfrac{2\pi}{T_0}t) \Rightarrow \dot{u}_C = -E(\dfrac{2\pi}{T_0})\sin(\dfrac{2\pi}{T_0}t)$

$\Rightarrow \ddot{u}_C = -E(\dfrac{2\pi}{T_0})^2\cos(\dfrac{2\pi}{T_0}t)$;

By replacing u_C and $\ddot{u}_C$ in the differential equation : $E\cos(2\pi/T_0)t - LCE(2\pi/T_0)^2\cos(2\pi/T_0)t = 0$

$\Rightarrow 1 - LC(2\pi/T_0)^2 = 0$

$\Rightarrow T_0 = 2\pi\sqrt{LC} = 2\pi\sqrt{0.8\times 10^{-6}} = 5.62$ ms. **(¾)**

3)  **(¼)**

4) The electric energy W_0 of the capacitor passes to the coil that stores it in the form of magnetic energy and vice versa. **(¼)**

C – 1) The electric energy W_0 of the capacitor passes (partially) to the coil that stores it in the form of magnetic energy and the rest of this energy is dissipated in the form of the thermal energy. **(¼)**

2) a) $3T = 17$ ms $\Rightarrow T = 5.67$ ms **(¼)**

b) T slightly greater then T_0. **(¼)**

3) a) because u_C is max. $\Rightarrow i = 0 \Rightarrow W_{mag.} = 0 \Rightarrow$ energy of the circuit = electrical energy **(¼)**

b) $W_n = 0.014\ W_0 \Rightarrow \dfrac{W_n}{W_0} = 0.014 \Rightarrow W_n = 0.014\times 32\times 10^{-6} = 0.448\times 10^{-6}$ J. **(½)**

c) $W_n = ½\ Cu_n^2 \Rightarrow u_n = 0.95$ V . Curve gives $t = 17$ ms $= nT = n(5.62) \Rightarrow n = 3$ **(¾)**

Fourth exercise

A – 1) $E_m = \dfrac{1}{2}I\theta'^2 + mga(1-\cos\theta) = \dfrac{1}{2}I\theta'^2 + mga\dfrac{\theta^2}{2}$ **(¾)**

2) a) $\dfrac{dE_m}{dt} = 0 \Rightarrow I\theta'\theta'' + mga\theta\theta' = 0;\ \theta' \neq 0 \Rightarrow \theta'' + \dfrac{mga}{I}\theta = 0$ **(½)**

b) $\theta'' + \omega_0^2\theta = 0 \Rightarrow \omega_0^2 = \dfrac{mga}{I}$; $T = \dfrac{2\pi}{\omega_0} \Rightarrow T = 2\pi\sqrt{\dfrac{I}{mga}}$. **(½)**

3) a) i) $T_1 = 2\pi\sqrt{\dfrac{I_1}{mga_1}}$ and . $T_2 = 2\pi\sqrt{\dfrac{I_2}{mga_2}}$; $T_1 = T_2 \Rightarrow \dfrac{I_1}{I_2} = \dfrac{a_1}{a_2}$ **(½)**

ii) $\dfrac{I_0 + ma_1^2}{a_1} = \dfrac{I_0 + ma_2^2}{a_2} \Rightarrow I_0(a_2 - a_1) = ma_1a_2(a_2 - a_1) \Rightarrow I_0 = ma_1a_2$. **(¾)**

b) $T' = 2\pi\sqrt{\dfrac{\ell}{g}} = 2\pi\sqrt{\dfrac{I_1}{mga_1}}$ $T' = 2\pi\sqrt{\dfrac{I_0 + ma_1^2}{mga_1}}$

$T' = 2\pi\sqrt{\dfrac{ma_1a_2 + ma_1^2}{mga_1}} = 2\pi\sqrt{\dfrac{a_1 + a_2}{g}} \Rightarrow \ell = a_1 + a_2$. **(1)**

B – 1) a) $a_1 = 10$ cm and $a_2 = 20$ cm **(½)**

b) $I_0 = ma_1a_2 = 4\times 10^{-3}$ kgm^2 ; $\ell = a_1 + a_2 = 30$ cm. **(1)**

2) a) From graph : T_{min} for a' = 14 cm . **(½)**

b) $T = 2\pi\sqrt{\dfrac{I_0 + ma^2}{mga}}$ T is minimum when $\left(\dfrac{I_0}{mga} + \dfrac{a}{g}\right)$ is min. but

$\dfrac{I_0}{mga}\times\dfrac{a}{g} = \dfrac{I_0}{mg^2} = Cte$

thus T is min. when

$\dfrac{I_0}{mga} = \dfrac{a}{g} \Rightarrow a = \sqrt{\dfrac{I_0}{m}} = 14{,}1$ cm $\Rightarrow a = 14.1$ cm $\Rightarrow T_{min} = 1.05$ s **(1½)**

Or $T = 2\pi\sqrt{\dfrac{I_0 + ma^2}{mga}} = \dfrac{2\pi}{\sqrt{mg}}\sqrt{\dfrac{I_0}{a} + ma} = cte \Rightarrow \dfrac{dT}{da} = 0 \Rightarrow$

$\dfrac{2\pi}{\sqrt{mg}}\dfrac{(-\dfrac{I_0}{a^2} + m)}{2\sqrt{\dfrac{I_0}{a} + ma}} = 0 \Rightarrow I_0 = ma^2$

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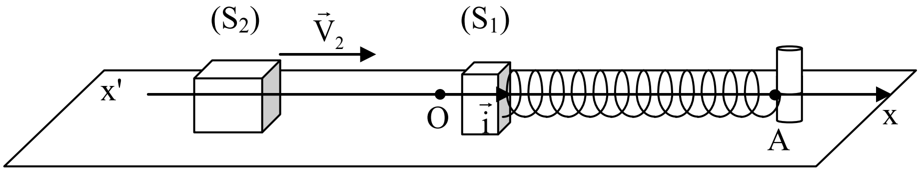
الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	

<u>This exam is formed of four exercises in four pages numbered from 1 to 4</u>
<u>The use of non-programmable calculator is recommended</u>

First Exercise *(7.5 points)* *Mechanical oscillator*

Two solids (S_1) and (S_2), of respective masses m_1 = 100 g and m_2 = 500 g, can slide on a horizontal table. The solid (S_1) is fixed to one end of a spring with un-jointed turns and of negligible mass and of stiffness k = 25 N/m, the other end A of the spring being fixed to a support as shown in the figure below. (S_2) is launched towards (S_1) and attains, just before impact, the velocity $\vec{V}_2 = V_2\,\vec{i}$ where V_2 = 0.48 m/s. Due to collision, (S_2) sticks to (S_1) thus forming a single solid (S), just after collision, at the instant t_0 = 0, whose center of inertia G moves with the velocity $\vec{V}_0 = V_0\,\vec{i}$.
The horizontal plane through G is taken as a gravitational potential energy reference.



A- Theoretical Study
Neglect all forces of friction.
1) Show that V_0 = 0.40 m/s
2) After collision, (S), still connected to the spring, continues its motion. At an instant t, we define the position of G by its abscissa x on the axis (O, $\vec{i}$), $v = \frac{dx}{dt}$ being the algebraic measure of the velocity of G. The origin O of abscissas is the position of G at the instant t_0 = 0.
a) Calculate the mechanical energy of the system [(S), spring, Earth] at the instant t_0 = 0.
b) Give, at the instant t, the expression of the mechanical energy of the system [(S), spring, Earth] in terms of m_1 , m_2, k, x and v.
c) Deduce that the abscissa of G is 6.2 cm when v is equal to zero for the first time.
3) a) Derive the second order differential equation of the motion of G.
b) The solution of this differential equation is of the form: $x = X_m \sin(\omega_0 t + \varphi)$.
i) Determine the values of the constants X_m , ω_0 and φ.
ii) Calculate the value of the proper period T_0 of oscillations of G and deduce the time t_1 needed by G to pass from O to the position where v becomes zero for the first time.

B- Experimental study
In fact, (S), again shot with the velocity $\vec{V}_0$ at the instant t_0 = 0, performs oscillations of pseudo-period very close to T_0. The velocity of G becomes zero for the first time at the instant t_1 but the abscissa of G is just 6cm.
1) Determine the energy lost during t_1.
2) An apparatus (D), conveniently connected to the oscillator, provides energy in order to compensate for the loss. Calculate the average power provided by (D).
3) The oscillator is at rest. The apparatus (D) and the support are removed. The end A of the spring is connected to a vibrator, which vibrates along the spring, with an adjustable frequency f.
a) In steady state, (S) performs oscillations of frequency f. Why?
b) For a certain value f_1 of f, the amplitude of oscillations of (S) attains a maximum value.
i) Give the name of the phenomenon that thus took place.
ii) Calculate the value of f_1.

Second Exercise *(7.5 points)* *Duration of charging and discharging of a capacitor*

Consider the circuit whose diagram is shown in figure 1, where G is a generator delivering a square signal (E, 0) of period T (Fig. 2), D a resistor of resistance R = 10 kΩ and (C) a capacitor of capacitance C = 0.2 μF. An oscilloscope displays the voltage $u_g = u_{AM}$ across G and the voltage $u_C = u_{BM}$ across (C).

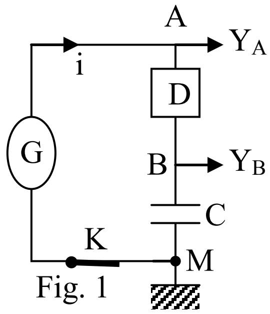


Fig. 1

A- Theoretical study

Charging of (C)

During the charging of (C), the voltage u_g has the value E and at an instant t , the circuit carries a current i.

1) Give the expression of i in terms C and $\frac{du_C}{dt}$.

2) Derive, for $0 \le t \le \frac{T}{2}$, the differential equation in u_C.

3) The solution of this differential equation has the form:

$u_C = A(1 - e^{-\frac{t}{\tau}})$, where A and τ are constants.

a) Determine, in terms of E, R and C, the expressions of A and τ.

b) Draw the shape of the graph representing the variation of u_C as a function of time and show, on this graph, the points corresponding to A and τ.

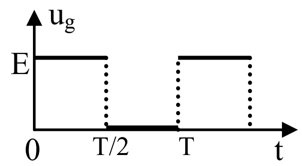


Fig.2

Discharging of (C)

4) During discharging of (C) the voltage u_g = 0. We consider the instant $\frac{T}{2}$ as a new origin of time.

Verify that $u_C = E\,e^{-\frac{t}{\tau}}$.

5) a) What must the minimum duration of charging be so that u_C reaches practically the value E?

b) What is then the minimum value of T?

B- Experimental study

1) On the screen of the oscilloscope, we observe the waveforms of figure 3.

a) Which curve corresponds to the charging of the capacitor? Justify the answer.

b) Calculate the value of E and that of the period T of the square signal.

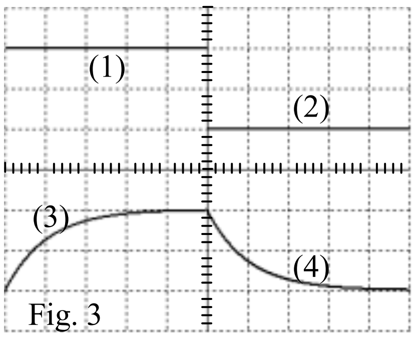


Fig. 3

S_V = 5 V/div; S_h = 2 ms/div.

2) a) We increase the frequency of the voltage delivered by G. The waveforms obtained are as in figure 4.

Determine the new period of the square signal.

Justify the shape of the waveform of u_C displayed.

b) We keep increasing the frequency of the voltage delivered by G. The waveform becomes almost triangular. Why?

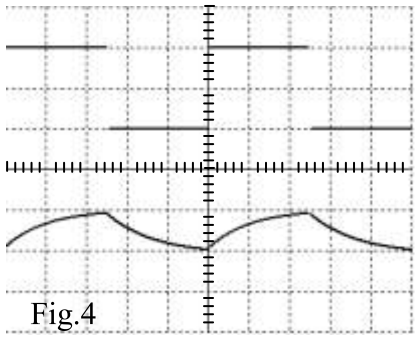


Fig.4

S_V = 5 V/div; S_h = 1 ms/div.

Third Exercise *(7.5 points)* *Energy levels of the hydrogen atom*

The energy levels of the hydrogen atom are given by the relation:

$E_n = -\dfrac{13.6}{n^2}$; where E_n is expressed in eV and n is a non-zero whole number.

Given: Planck's constant: $h = 6.62\times10^{-34}$ J.s; 1 eV = 1.6×10^{-19} J ; 1nm = 10^{-9} m

visible spectrum in vacuum: 400 nm $\leq \lambda \leq$ 750 nm; speed of light in vacuum $c = 3\times10^{8}$ m/s.

The Lyman series represents the set of radiations emitted by the hydrogen atom when it undergoes a downward transition from the level $n \geq 2$ to the ground state n = 1.

1) a) The energy of the hydrogen atom is said to be quantized.
What is meant by the term "quantized energy".

b) Write down the expression of the energy of a photon associated with a radiation of wavelength λ in vacuum.

2) a) Show that the wavelengths λ in vacuum of the radiations of the Lyman series are expressed in nm by the relation: $\lambda = 91.3\left(\dfrac{n^2}{n^2-1}\right)$.

b) i) Determine, in nm, the maximum wavelength λ_1 of the radiation of the Lyman series .

ii) Determine, in nm, the minimum wavelength λ_2 of the radiation of the Lyman series.

iii) Do the radiations of the Lyman series belong to the visible, ultraviolet or infrared spectrum? Justify your answer.

3) A hydrogen lamp illuminates a metallic surface of zinc whose threshold wavelength is λ_0 = 270 nm.

a) Define the threshold wavelength of a metal.

b) Electrons are emitted by the metallic surface of zinc. Why?

c) The maximum kinetic energy KE of an electron emitted by a radiation of the Lyman series is included between the values a and b: a $\leq$ KE $\leq$ b. Determine, in eV, the values of a and b.

d) The maximum kinetic energy of these emitted electrons is quantized. Why?

<u>Fourth Exercise</u> (7.5 points) A nuclear reactor "The breeder reactor"

Read carefully the following selection:

"*…..The nuclear reactors with fast neutrons use uranium 238 or plutonium 239 (or both at the same time) as fuels …….The principle of a breeder reactor is to produce, starting from uranium 238 an amount of fissionable material that is equal or exceeds what the reactor consumes since the final result would be the consumption of uranium 238 only which is more abundant than the uranium 235…..*"

Given :

Speed of light in vacuum: $c = 3 \times 10^8$ m/s. Mass of neutron ($_0^1n$): 1.0087 u.

$1\ u = 931.5\ MeV/c^2 = 1.66 \times 10^{-27}$ kg ; $1\ MeV = 1.6 \times 10^{-13}$ J.

Element	***Tellurium***	***Technetium***	***Molybdenum***	***Plutonium***	***Neptunium***
Nuclide	$_{52}^{135}Te$	$_{43}^{102}Tc$	$_{42}^{102}Mo$	$_{94}^{239}Pu$	$_{93}^{239}Np$
Mass (u)	***134.9167***	***101.9092***	***101.9103***	***239.0530***	***239.0533***

1) Draw from the selection an indicator showing that producing an equal amount of energy in a nuclear power plant, uranium 238 has an advantage over uranium 235.

2) In a breeder reactor, uranium 238 reacts with a fast neutron according to the following reaction:

$$_{92}^{238}U + _0^1n \rightarrow _Z^AX. \quad (1).$$

The nucleus $_Z^AX$ obtained is radioactive; it is transformed into fissionable plutonium according to the following equations

$$_Z^AX \rightarrow _{-1}^{0}e + _{Z_1}^{A_1}X_1 + _0^0\overline{\nu}. \quad (2)$$

$$_{Z_1}^{A_1}X_1 \rightarrow _{-1}^{0}e + _{94}^{239}Pu + _0^0\overline{\nu} \quad (3).$$

a) Identify $_Z^AX$ and $_{Z_1}^{A_1}X_1$.

b) Write down the global (over all) balanced equation of the nuclear reaction between a uranium 238 nucleus and a neutron leading to plutonium 239. [This reaction is denoted as reaction (4)].

c) Specify for each of the preceding reactions whether it is spontaneous or provoked.

3) The plutonium $_{94}^{239}Pu$ may react with a neutron according to the following reaction :

$$_{94}^{239}Pu + _0^1n \rightarrow _{42}^{102}Mo + _{52}^{135}Te + 3\,_0^1n. \quad (5)$$

a) Calculate, in MeV/c^2, the mass defect Δm in this reaction.

b) Deduce , in MeV, the amount of energy E liberated by the fission of one plutonium nucleus.

c) Calculate**,** in joules, the energy liberated by the fission of one kilogram of plutonium.

4) We suppose that each fission reaction produces 3 neutrons. Using the preceding reactions, show that the role of one of the three neutrons agrees with the statement of the selection: "…. *produce, starting from uranium 238 an amount of fissionable material that is equal or exceeds what the reactor consumes…"*

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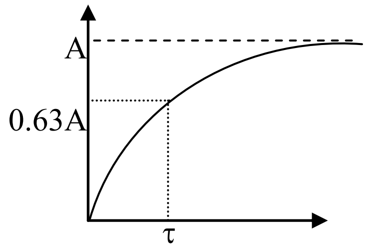
الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	مشروع معيار التصحيح

First exercise (7.5 points)

Part of the Q	Answer	Mark
A.1	The linear momentum of the system is conserved during the collision $m_2 \overrightarrow{V_2} + \vec{0} = (m_1 + m_2)\ \vec{V}_0$ $\Rightarrow V_0 = \dfrac{m_2}{m_1 + m_2} V_2$; $V_0 = \dfrac{500}{600} \times 0.48 = 0.40$ m/s	
A.2.a	$ME = ½\ Mv^2 + ½\ kx^2$; $PE_g = 0$, $t = 0 \Rightarrow x = 0$, $V = V_0$ $ME(t_0 = 0) = ½\ M V_0^2 = ½ \times 0.6 \times (0.4)^2 = 0.048$ J ;	
A.2.b	$ME = ½\ (m_1 + m_2)\ v^2 + ½\ kx^2$	
A.2.c	No friction $\Rightarrow$ ME = constant $\Rightarrow ½\ (m_1 + m_2)\ v^2 + ½\ kx^2 = ½\ (m_1 + m_2)\ V_0^2$. For v = 0, $X_m^2 = \dfrac{M}{k} V_0^2 = \dfrac{0.600}{25}(0.4)^2 \Rightarrow X_m = 0.062$ m = 6.2 cm.	
A.3a)	$ME = ½\ (m_1 + m_2)\ v^2 + ½\ kx^2$ = constant at any instant. $\dfrac{dME}{dt} = 0 = (m_1 + m_2)\ vx'' + kxv$ and $v \neq 0$ during oscillations $\Rightarrow x'' + \dfrac{k}{(m_1 + m_2)} x = 0$.	
A.3.b.i	$x = X_m \sin(\omega_0 t + \varphi)$; $v = x' = X_m\ \omega_0 \cos(\omega_0 t + \varphi)$; $x'' = -\ X_m\ \omega_0^2 \sin(\omega_0 t + \varphi)$. Replacing: $-\ X_m\ \omega_0^2 \sin(\omega_0 t + \varphi) + \dfrac{k}{M}\ X_m \sin(\omega_0 t + \varphi) = 0 \Rightarrow \omega_0^2 = \dfrac{k}{M}$ $\Rightarrow$ The proper angular frequency is $\omega_0 = \sqrt{\dfrac{k}{M}} = \sqrt{\dfrac{25}{0.6}} = 6.45$ rd/s. At the instant $t_0 = 0$, $V_0 = 0.40$ m/s $\Rightarrow 0.4 = X_m \times 6.45 \cos(\varphi)$ and $x_0 = 0$ $\Rightarrow A\sin\varphi = 0 \Rightarrow \sin\varphi = 0 \Rightarrow \varphi = 0$ or π But $\cos(\varphi) > 0 \Rightarrow \varphi = 0$ rd For $\varphi = 0$, $X_m = \dfrac{0.4}{6.45} = 0.062$ m = 6.2 cm. We obtain x (cm) = 6.2sin(6.45 t)	
A.3.b.ii	The proper period $T_0 = \dfrac{2\pi}{\omega_0} = 2\pi \dfrac{1}{6,45} = 0,974$ s $t_1 = T_0/4 = 0.243$ s.	

B.1	The loss of energy is $E = \lvert \Delta ME \rvert = ½ k(X_m^2 - X_{m1}^2) = 3.05\times10^{-3}$ J.	
B.2	Average power of the forces of friction: $P_{av} = \frac{E}{t_1} = 1.25\times10^{-2}$ W	
B.3.a	The frequency is f which is that of the vibrator, because the oscillator undergoes forced oscillations	
B.3.b.i	It is the phenomenon of resonance of amplitude.	
B.3.b.ii	$T \approx T_0$ and $f_1 \approx 1/T_0 \Rightarrow f_1 = 1.03$ Hz	

Second exercise (7.5 points)

Part of the Q	Answer	Mark
A.1	$i = \frac{dq_B}{dt} = C\frac{du_C}{dt}$.	
A.2	For $0 \le t \le T/2$, $u_g = E = u_R + u_C = Ri + u_C \Rightarrow RC\frac{du_C}{dt} + u_C = E$.	
A.3.a	$\frac{du_C}{dt} = A\frac{1}{\tau}e^{-\frac{t}{\tau}} \Rightarrow RC\,A\frac{1}{\tau}e^{-\frac{t}{\tau}} + A(1-e^{-\frac{t}{\tau}}). = E$ $\Rightarrow A\,e^{-\frac{t}{\tau}}(RC\frac{1}{\tau} - 1) + A - E = 0$, at any time $t \Rightarrow A = E$ and $\tau = RC$.	
A.3.b	See figure 	
A.4	For $T/2 \le t \le T$, $0 = u_R + u_C = Ri + u_C \Rightarrow RC\frac{du_C}{dt} + u_C = 0$. $u_C = E\,e^{-\frac{t}{\tau}}$ $\Rightarrow \frac{du_C}{dt} = -E\frac{1}{\tau}e^{-\frac{t}{\tau}}$ Replacing each quantity in the differential equation by its value, we obtain : $-RC\,E\frac{1}{\tau}e^{-\frac{t}{\tau}} + E\,e^{-\frac{t}{\tau}} = 0$; which is true, since $\tau = RC$.	
A.5.a	The minimum duration of charging mode or discharging mode so that u_C reaches its steady state must be 5τ.	
A.5.b	The minimum value of T must be 10τ	
B.1.a	The curve (3) corresponds to the charging mode of the capacitor since u_C increases with time.	
B.1.b	E = 5 V/div×2 div = 10V. The period T of the square signal = 2 ms/div×10 div = 20 ms.	
B.2.a	The period T of the square signal is now: 1ms/div×5 div = 5 ms. The duration of the charging and of the discharging is now less than 5τ. The capacitor has no more time to be completely charged and discharged.	
B.2.b	$T <<< 10\,\tau$, the curve becomes linear (straight line) during charging and	

	discharging.	

Third exercise (7.5 points)

Part of the Q	Answer	Mark
1.a	The energy of an atom can take only a certain number of discrete values	
1.b	$E = h\nu = \frac{hc}{\lambda}$.	
2.a	$E_n - E_1 = h\nu = \frac{hc}{\lambda} = -\frac{13.6}{n^2} - (-\frac{13.6}{1^2}) = 13.6\,(1 - \frac{1}{n^2}) = 13.6\,(\frac{n^2-1}{n^2})$ $\Rightarrow \lambda = \frac{hc}{13.6}(\frac{n^2}{n^2-1})$. $\lambda = \frac{6.62\times10^{-34}\times3\times10^{8}}{13.6\times1.6\times10^{-19}}(\frac{n^2}{n^2-1}) = 0.913\times10^{-7}(\frac{n^2-1}{n^2})$ m $\lambda = 91.3\,(\frac{n^2-1}{n^2})$ nm	
2.b.i	The energy of a photon being inversely proportional to its wavelength, minimum of energy corresponds to maximum $\lambda = \lambda_1$ $\Rightarrow$transition from n = 2 $\Rightarrow \lambda_1 = 91.3\,(\frac{4}{4-1}) = 122$ nm	
2.b.ii	maximum of energy corresponds to the largest n $\Rightarrow n = \infty \Rightarrow \lambda_2 = 91{,}3$ nm.	
2.b.iii	$91.3 \le \lambda(\text{nm}) \le 122$ $\Rightarrow$ The Lyman's series spectrum belongs to ultra-violet domain	
3.a	Is the maximum wavelength for the photoelectric effect to take place .	
3.b	The incident wavelength is such $91.3 \le \lambda(\text{nm}) \le 122$, it is then smaller than $\lambda_0 = 270$ nm, thus we have emission of electrons	
3.c	The relation of Einstein gives: $\frac{hc}{\lambda} = \frac{hc}{\lambda_S} + KE$ $\Rightarrow KE = \frac{hc}{\lambda} - \frac{hc}{\lambda_S} = hc(\frac{1}{\lambda} - \frac{1}{\lambda_S})$; $(KE)_{max} = b$ $b = hc(\frac{1}{\lambda_{min}} - \frac{1}{\lambda_S}) = 6.62\times10^{-34}\times3\times10^{8}(\frac{1}{91.3\times10^{-9}} - \frac{1}{270\times10^{-9}})$; $b = 0.725\times10^{-19}$ J = 0.453 eV $(E_C)_{min} = a$ $a = hc(\frac{1}{\lambda_{max}} - \frac{1}{\lambda_S}) = 6.62\times10^{-34}\times3\times10^{8}(\frac{1}{122\times10^{-9}} - \frac{1}{270\times10^{-9}})$; $a = 0.449\times10^{-19}$ J = 0.281 eV.	
3.d	In the relation $KE = \frac{hc}{\lambda} - \frac{hc}{\lambda_S}$; the values of λ are discrete $\Rightarrow$ the values KE form then a discontinuous succession $\Rightarrow$the kinetic energy of the electrons is then quantized	

Fourth exercise (7.5 points)

Part of the Q	Answer	Mark
1	*"… starting from uranium 238 an amount of fissionable material that is equal or exceeds what the reactor consumes since the final result would be the consumption of uranium 238 only which is more abundant than the uranium 235….."*	
2.a	$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{A}_{Z}X$. **(1)** A = 239 ; Z = 92 donc $^{A}_{Z}X$ est $^{239}_{92}U$ $^{239}_{92}U \rightarrow ^{0}_{-1}e + ^{A_1}_{Z_1}X_1 + ^{0}_{0}\bar{\nu}$. **(2)** A_1= 239 ; Z_1= 93, donc $^{A_1}_{Z_1}X_1$ est $^{239}_{93}N_P$	
2.b	**(1) +(2) +(3)** $\Rightarrow$ $^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{94}P_U + 2\,^{0}_{-1}e + 2\,^{0}_{0}\bar{\nu}$ **(4)**	
2.c	**(1) :** Provoked reaction ; **(2)** and **(3) :** spontaneous**;** **(4) :** provoked**.**	
3.a	$\Delta m = 0.2086\ u = 194.31\ MeV/c^2$	
3.b	$E = m\,c^2 = 194.31\ MeV$	
3.c	Mass of a plutonium 239nucleus is: $239\ u = 239\times 1.6605\times 10^{-27}\ kg = 396.86\times 10^{-27}\ kg$ Number of nuclei contained in 1 kg of plutonium 239 is : $\frac{1}{396.86\times10^{-27}} = 2.52\times10^{24}$ nuclei The energy liberated: $2.52\times 10^{24}\times 194.31 = 4.9\times 10^{26}\ MeV = 7.83\times 10^{13}\ J$.	
4	A neutron interacts with uranium 238 in order to form another nucleus of plutonium. This shows that the plutonium nuclei are in excess in the population of nuclei.	

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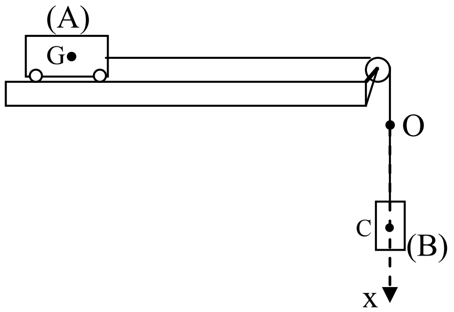
الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	

This exam is formed of four exercises in four pages
The use of non-programmable calculator is recommended

First Exercise: *(7 ½ points)* Moment of inertia of a pulley



In order to determine the moment of inertia of a pulley with respect to its axis of rotation, we use the system of the adjacent figure that is formed of a trolley (A), of mass M = 1 kg, connected to a block (B), of mass m = 0.18 kg, by means of an inextensible string of negligible mass. The string passes over a pulley of radius r = 5 cm.
A convenient device can record, at equal and successive intervals of time τ = 50 ms, the abscissa $x = \overline{OC}$ of the different positions of the center of inertia C of (B).
Neglect all forces of friction and use g = 10 m/s^2.
The table below gives the abscissa x of the position of C and its speed V at different instants.

t (ms)	t_0 = 0	t_1 = 50	t_2 = 100	t_3 = 150	t_4 = 200
x (cm)	0	0.175	0.7	1.575	2.8
V (m/s)	0	0.07	0.14	0.21	0.28

A – Energetic study

1) Calculate the kinetic energy of (B) at the instant t_4 = 200 ms.
2) Calculate the variation of the kinetic energy of (B) between the instants t_0 and t_4.
3) Applying the theorem of kinetic energy (ΔK.E = ΣW), calculate the work done by the tension $\vec{T}_1$ applied by the string on the block (B).
4) Show that the value T_1 of $\vec{T}_1$, supposed constant, is equal to 1.548 N.

B – Dynamical study

1) Calculate the values P_0, P_1, . ….. .P_4 of the linear momentum $\vec{P}$ of the trolley (A) at the instants t_0, t_1, . . . t_4 respectively.
2) ***a)*** Draw the graph representing the variation of P as a function of time.
b) Show that the equation of the corresponding graph may be written in the form:
P = k t + b where k and b are constants to be determined.
3) Applying Newton's second law on trolley (A):
a) determine the relation among the constants k, M and the algebraic value a of the acceleration of motion and deduce the value of a;
b) show that the value T_2 of the tension $\vec{T}_2$ applied by the string on the trolley (A) is equal to 1.40 N.

C – Determination of the moment of inertia of the pulley

1) Specify the forces acting on the pulley.
2) Applying the theorem of angular momentum, determine the moment of inertia of the pulley with respect to its axis of rotation.

Second Exercise: *(7 ½ points)* **Identifying two electric components**

Consider a generator G that maintains across its terminals a constant voltage E , a generator G' that maintains across its terminals an alternating sinusoidal voltage of expression:
$u = 5\sqrt{2}\sin 2\pi ft$ (u in V and t in s) of adjustable frequency f, an ammeter (A) of negligible resistance, a switch K , connecting wires and two electric components (D_1) and (D_2) where one of them is a coil of inductance L and of resistance r, and the other a capacitor of capacitance C. (Take $\frac{1}{\pi} = 0.32$)
In order to identify each of these two components and to determine their characteristics, we perform the following experiments, the measurements being taken after attaining the steady state in the circuit.

A – First experiment
Each of the two components, taken separately, is fed by the generator G.
In the steady state:

- the circuit containing (D_1) does not carry any current;
- the circuit containing (D_2) carries a current I = 1 A and consumes a power of 5 W.

1) Determine the nature of (D_1).
2) Determine the resistance r of the coil.

B – Second experiment
Each of the two components, taken separately, is fed by the generator G' , the voltage u being of frequency f = 50 Hz.
In the steady state:

- the circuit containing the capacitor carries an alternating sinusoidal current i_1 of effective value I_1 = 50 mA and does not consume any power (Fig. 1);
- the coil carries an alternating sinusoidal current i_2 of effective value $I_2 = \frac{\sqrt{2}}{2}$ A, and consumes an average power of 2.5 W (Fig. 2).

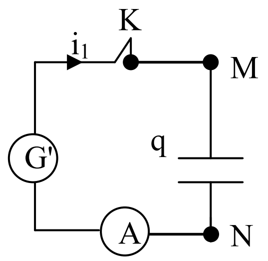


Fig1

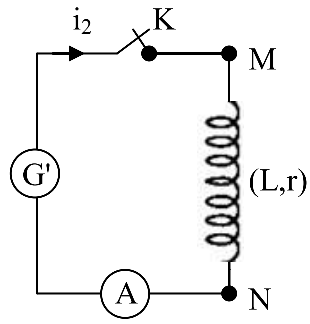


Fig 2

1) Determine the phase difference between i_1 and u and that between i_2 and u.
2) Write down, with justification, the expressions of i_1 and i_2 as a function of time.
3) ***a)*** Show that $i_1 = C\frac{du}{dt}$.
b) Deduce the value of C.
4) ***a)*** Write down the relation among u, i_2, r and L.
b) Using the expressions of u and i_2 as a function of time and giving t a particular value, determine the value of L.

C – Third experiment
In fact, the values of r and L are labeled on the coil. To verify the value of C, we connect the coil and the capacitor in series across G'. By giving f different values, we notice that the effective current in the circuit attains a maximum value for $f = f_0 = 225$ Hz
1) For the frequency f_0, the circuit is the seat of a particular electric phenomenon. Give the name of this phenomenon.
2) Determine the value of C.

Third Exercise: _(7 ½ points)_ **Wave aspect of light and its applications**

The object of this exercise is to show evidence of exploiting an optical phenomenon in the measurement of small displacements.

A- Diffraction

A laser beam illuminates, under normal incidence, a straight slit F, of width a, cut in an opaque screen (P). The light through F is received on a screen (E), parallel to (P) and found at 3 m from (P) (Fig.1).

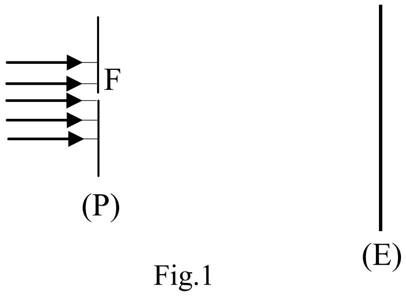


Fig.1

_1)_ Describe what would be observed on (E) in the two following cases:

_a)_ $a = a_1 = 1$ cm.

_b)_ $a = a_2 = 0.5$ mm.

_2)_ It is impossible to isolate a luminous ray by reducing the size of the slit. Why?

_3)_ We use the slit of width $a_2 = 0.5$ mm. The width of the central fringe of diffraction observed on (E) is 7.2 mm. Show that the wavelength of the light used is $\lambda = 600$ nm.

_4)_ We remove the screen (P). A hair of diameter d is stretched in the place of the slit F. We obtain on the screen a diffraction pattern. The measurement of the width of the central fringe of diffraction gives 12 mm. Determine the value of d.

B- Interference

In order to measure a small displacement of an apparatus, we fix the screen (P) on this apparatus. In a screen (P'), we cut two parallel and very thin slits F_1 and F_2 separated by 1 mm.

We repeat the previous experiment by introducing (P') between (P) and (E). (P) and (P') are parallel and are at a distance D' = 1 m from each other.

The slit F, cut in (P), is equidistant from the two slits F_1 and F_2. The slit F is illuminated by the laser source of wavelength $\lambda = 600$ nm. A phenomenon of interference is observed on the screen (E) located at a distance D = 2 m from (P').

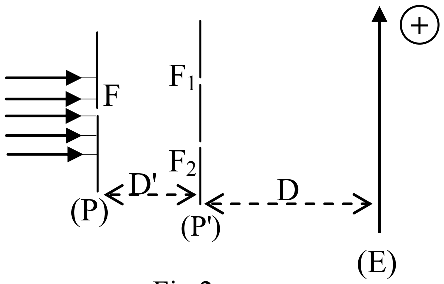


Fig.2

_1)_ Show on a diagram the region where interference fringes may appear.

_2)_ Specify, with justification, the position O, the center of the central fringe.

_3)_ A point M on the screen is at a distance d_1 from F_1 and at a distance d_2 from F_2 such that: $d_2 = d_1 + 1500$ nm. The point M is the center of the third dark fringe. Why?

_4)_ We count on (E) 11 bright fringes. Calculate the distance d between the centers of the farthermost bright fringes.

_5)_ We move the apparatus and hence the slit F a distance z to the side of F_2 normal to the perpendicular bisector of F_1F_2, the new position of F being denoted by F'. We observe that the central fringe occupies now the position that was occupied by the third bright fringe.

_a)_ Explain why the central fringe is displaced on the screen and determine the direction of this displacement.

_b)_ For a point N of (E), of abscissa x with respect to O, we can write:

$(F'F_2N) - (F'F_1N) = \frac{ax}{D} + \frac{az}{D'}$. Calculate the value of z.

***Fourth Exercise*: (7 ½ points)** **The neutrons and the nuclear fission in a reactor**

Given: m ($^{235}_{92}U$) = 234.99332 u; m (I) = 138.89700 u; m (Y) = 93.89014 u ; m_n = m($^{1}_{0}n$) = 1.00866 u; 1 u = 931.5 MeV/c^2.

In a uranium 235 reactor, the fission of a nucleus ($^{235}_{92}U$) under the impact of a thermal neutron gives rise to different pairs of fragments with the emission of some neutrons. The most probable pairs of fragments have their mass numbers around 95 and 140. One of the typical fission reactions is the one which produces the iodine ($^{A}_{53}I$), the yttrium ($^{94}_{Z}Y$) and 3 neutrons.

A – Determine Z and A.

B – ***1)*** Show that the mass defect in this reaction is Δm = 0.18886 u.

2) Determine, in MeV, the energy E liberated by this fission reaction.

3) Knowing that each neutron formed has an average kinetic energy E_0 = 1% E. Calculate E_0.

4) For a neutron, produced by the fission reaction, to trigger a new nuclear fission of a uranium nucleus 235, it must have a low kinetic energy around E_{th} = 0.025 eV (thermal neutron). In order to reduce the kinetic energy of a produced neutron from E_0 to E_{th}, this neutron must undergo successive collisions with heavier nuclei at rest of mass M = 2 m_n , called, "moderator" nuclei; these collisions are supposed elastic and all the velocities are collinear.

a) Using the laws of conservation of linear momentum and kinetic energy, show that after each collision, the neutron rebounds with one third (1/3) of its initial speed.

b) Determine, in terms of E_0, the expression of the kinetic energy E_1 of the neutron after the first collision. Deduce, in terms of E_0, the expression of the kinetic energy K.E of the neutron after the k^{th} collision.

c) Calculate the number k of collisions needed for the energy of a neutron to decrease from E_0 to 0.025 eV.

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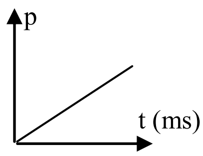
الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	مشروع معيار التصحيح

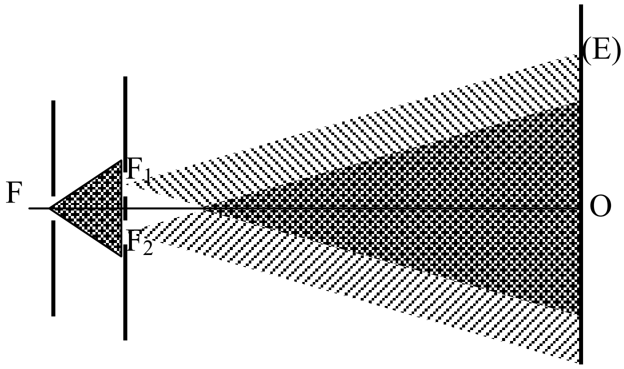
First exercise (7.5 points)

Part of the Q	Answer	Mark
A.1	$KE(t_4) = \frac{1}{2} m V_4^2 = \frac{1}{2} 0.18 \times 0.87^2 = 7.056 \times 10^{-3}$ J	0.5
A.2	Variation of the kinetic energy of B: $\Delta KE = 7{,}056 \times 10^{-3}$ J $-$ 0 $= 7.056 \times 10^{-3}$ J.	0.5
A.3	The forces acting on (B), are: the tension $\vec{T}_1$ upward and the weight $\vec{W}_1$ of (B) downward. $\Delta KE = W(\vec{T}_1) + W(\vec{W}_1) = W(\vec{T}_1) + mg(x_4 - x_0)$ $\Rightarrow 7.056 \times 10^{-3} = W(\vec{T}_1) + 0.18 \times 10 \times (2.8 \times 10^{-2} - 0)$ $\Rightarrow W(\vec{T}_1) = -43.344 \times 10^{-3}$ J	1
A.4	$W(\vec{T}_1) = -\vec{T}_1 \cdot \vec{x} = -T_1(x_4 - x_0) \Rightarrow -43.344 \times 10^{-3} = -T_1(2.8 \times 10^{-2})$ $\Rightarrow T_1 = 1.548$ N	0.5
B.1	$P = MV$; $P_0 = 0$ kg·m/s; $P_1 = 0.07$ kg·m/s; $P_2 = 0.14$ kg·m/s; $P_3 = 0.21$ kg·m/s; $P_4 = 0.28$ kg·m/s.	0.5
B.2.a		1
B.2.b	The graph of P as a function of time is a straight line: $P = kt + b$. For t = 0, P = 0 = b ; and k = slope of the graph = 1.40 kg·m/s^2.	1
B.3.a	$\sum \vec{F} = \frac{d\vec{P}}{dt} = k = Ma \Rightarrow a = 1.40$ m/s^2	1
B.3.b	The forces acting on the trolley are: $\vec{T}_2$ horizontal and $\vec{W}_2$ the weight of (A) and normal reaction $\vec{R}$. Applying Newton's second law: $\sum \vec{F} = \frac{d\vec{P}}{dt}$. $\vec{T}_2 + \vec{W}_2 + \vec{R} = \frac{d\vec{P}}{dt}$, Horizontal projection: $T_2 = \frac{dP}{dt} = 1.40$ N	0.5
C.1	Forces acting on the pulley: $\vec{T}'_1$, $\vec{T}'_2$, $\vec{W}_p$ and $\vec{R}_N$.	0.5
C.2	$\sum moments(\vec{F}_{ext}) = I\ddot{\theta}$ gives $(T_1 - T_2)\, r = I\ddot{\theta} = I\frac{a}{r}$, which gives $I = 2.643 \times 10^{-4}$ kg·m^2.	0.5

Second exercise (7.5 points)

Part of the Q	Answer	Mark
A.1	(D_1) is a capacitor, since under constant voltage, in the steady state mode, the circuit does not carry any current at the end of its charging.	0.5
A.2	$P = I_2^2 r \Rightarrow r = 5\ \Omega$	0.5
B.1	The power P = UIcosφ. - For the capacitor: $P = 0 \Rightarrow \cos\varphi_1 = 0 \Rightarrow \lvert\varphi_1\rvert = \frac{\pi}{2}$ rd. - For the coil : $P = 2.5$ W and $I_2 = \frac{\sqrt{2}}{2}$ A $\Rightarrow 2.5 = 5\frac{\sqrt{2}}{2}\cos\varphi_2$ $\Rightarrow \lvert\varphi_2\rvert = \frac{\pi}{4}$ rd.	0.5 0.5
B.2	In the case of C circuit only i leads u by $\frac{\pi}{2}$, $i_1 = 0.05\sqrt{2}\sin(100\pi t+\frac{\pi}{2})$; For a RL circuit i lags u by $\frac{\pi}{4}$, $i_2 = \frac{\sqrt{2}}{2}\sqrt{2}\sin(100\pi t-\frac{\pi}{4})$	0.5 0.5
B.3.a	$i_1 = \frac{dq}{dt}$ and $q = Cu \Rightarrow i_1 = C\frac{du}{dt}$.	0.5
B.3.b	$i_1 = C\frac{du}{dt} = 5\sqrt{2}C\times100\pi\cos100\pi t$ $\Rightarrow i_1 = 500\,\pi\,C\sqrt{2}\sin(100\pi t+\frac{\pi}{2})$ By comparing the amplitudes: $500\,\pi\,C\sqrt{2} = 0.05\sqrt{2}$ $\Rightarrow C = 32\times10^{-6}$ F or 32 μF	1.5
B.4.a	$u = ri_2 + L\frac{di_2}{dt}$.	0.5
B.4.b	$5\sqrt{2}\sin 100\pi t = 5\sin(100\pi t-\frac{\pi}{4}) + L\times100\pi\cos(100\pi t-\frac{\pi}{4})$ For t = 0: $0 = -5\frac{\sqrt{2}}{2} + L\times100\pi\frac{\sqrt{2}}{2} \Rightarrow L = 0.016$ H or 16 mH.	1
B.5.a	Current Resonance	0.5
B.5.b	$LC\omega_0^2 = 1 \Rightarrow C = \frac{1}{4\pi^2 f_0^2 L} \Rightarrow C = 31.6\ \mu F$	0.5

Third exercise (7.5 points)

Part of the Q	Answer	Mark
A.1.a	$a = a_1 = 1cm$: we observe a luminous spot.	0.5
A.1.b	$a = a_2 = 0.5$ mm: we observe a diffraction pattern: alternating bright and dark fringes located on both sides of a central fringe which is the brightest and of width double any other bright fringe.	0.75
A.2	To isolate a ray of light, a beam must pass through a tiny hole of very small diameter. Because of the diffraction of light, this beam diffracts and the ray is not isolated	0.25
A.3	The angular width of the central fringe of diffraction is : $\alpha = \frac{2\lambda}{a_2} = \frac{\ell}{D}$ + Figure $\Rightarrow \lambda = 600$ nm.	1
A.4	$\alpha = 2\frac{\lambda}{d} = \frac{\ell'}{D}$ $\Rightarrow d = 3\times10^{-4}$ m = 0.3 mm	0.5
B.1	See figure 	0.50
B.2	The central fringe is characterized by $\delta = 0$, hence its position O is the intersection of the perpendicular bisector of F_1F_2 with the screen. Nature: bright because $\delta = 0$ is justified by $\delta = k\lambda$ for $k = 0$.	0.5
B.3	$\delta = d_2 - d_1 = 1500$ nm; $\frac{\delta}{\lambda/2} = 5 = (2k + 1) \Rightarrow k = 2$; first dark fringe $\Rightarrow k = 0$; $k = 2 \Rightarrow 3^{rd}$ dark fringe,	1
B.4	$d = 10\, i = 10\, \frac{\lambda D}{a} = 12$ mm	0.5
B.5.a	Since the central fringe is characterized by $\delta = 0$ and since the path $OF_1F' > OF_2F'$, then the path difference at O is not zero, so the central fringe is no longer at O. Let O' be the new position: $O'F_1F' = O'F_2F'$, since FF_2 is smaller than FF_1 $\Rightarrow O'F_2$ must be larger than $O'F_1$, O' $\Rightarrow$ above O	1
B.5.b	If O 'coincides with N, then $\delta_N = 0$ and consequently $\frac{ax}{D} + \frac{az}{D'} = 0$ $\Rightarrow z = -\frac{D'x}{D}$; the bright fringe of order 3 forms at the point of of abscissa $x = 3\frac{\lambda D}{a} = 3.6\times10^{-3}$ m or 3.6 mm. Thus $z = \frac{-1\times 3.6}{2} = -1.8$ mm.	1

Fourth exercise (7.5 points)

Part of the Q	Answer	Mark
A	${}_0^1n + {}_{92}^{235}U \longrightarrow {}_{53}^{A}I + {}_{Z}^{94}Y + 3\,{}_0^1n$ $1 + 235 = A + 94 + 3 \Rightarrow A = 139$; $0 + 92 = 53 + Z + 0 \Rightarrow Z = 39$.	0.5
B.1	$\Delta m = 1.00866 + 234.99332 - 138.89700 - 93.89014 - 3\times1.00866$ $\Delta m = 0.18886$ u	2
B.2	The energy $E = \Delta m\, c^2 = 0.18886\times931.5 = 175.92$ MeV.	1
B.3	$E_0 = 1.759$ MeV.	0.5
4.a	Conservation of linear momentum: $m_nV_0 + 0 = m_nV_1 + 2m_n V' \Rightarrow V_0 - V_1 = 2V'$ (1); Elastic collision: $\frac{1}{2} m_n V_0^2 = \frac{1}{2} m_n V_1^2 + \frac{1}{2} 2m_nV'^2 \Rightarrow V_0^2 - V_1^2 = 2V'^2$ (2); (1) and (2) $\Rightarrow V_1 = \frac{-V_0}{3}$	2
4.b	$\frac{1}{2} m_n V_1^2 = \frac{1}{2} m_n \frac{V_0^2}{9} \Rightarrow E_1 = \frac{E_0}{9}$ and $E_k = (\frac{1}{9})^k E_0 = \frac{E_0}{9^k}$	1
4.c	$0.025 = \frac{1.76\times10^6}{9^k} \Rightarrow (k)\ln9 = \ln(\frac{1.76\times10^6}{0.025}) \Rightarrow k = 8$.	0.5

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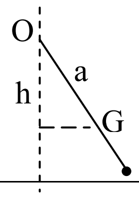
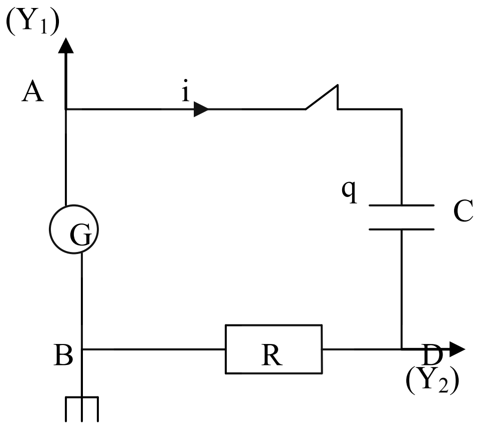
مشروع معيار التصحيح	مسابقة في مادة الفيزياء المدة ثلاث ساعات	الاسم: الرقم:

First exercise (7.5 points)

Part of the Q	Answer	Mark
A.1.a	$\Sigma M = M(\text{weight}) + M(\text{reaction of the axis}) + M$ The weight & the reaction meet the axis of rotation: $\Sigma M = 0 + 0 + M = M$	0.75
A.1.b	$\frac{d\sigma}{dt} = \Sigma M = M = I_0 . \theta'' = \text{cte} \Rightarrow \theta'' = \text{cte}$, initial speed being null $\Rightarrow$ the rotational motion of the rod is uniformly accelerated.	0.5
A.1.c	$\theta'' = \text{cte} = \frac{M}{I_0} \Rightarrow \theta' = \frac{M\,t}{I_0}$. $\sigma = I_0\,\theta' = M\,t$	0.5
A.2	$\theta' = 2\pi N \Rightarrow$ At t_1: $2\pi N\, I_0 = M\,t_1 \Rightarrow I_0 = \frac{0.1\times 10}{2\pi\times 8} = 1.99\times 10^{-2} \approx 0.02\ \text{kg.m}^2$	1
B.1.a	$a = \frac{m\times 0 + m'\frac{\ell}{2}}{(m+m')} = \frac{m'\ell}{2(m+m')}$.	0.5
B.1.b	$I = I_0 + m'\frac{\ell^2}{4}$	0. 5
B.2	$ME = KE + PE_g = ½\, I(\theta')^2 - (m + m')g\,h$ $h = a\cos\theta \Rightarrow ME = ½ I(\theta')^2 - (m + m')g\,a\cos\theta$.  	1
B.3.a	$\frac{dME}{dt} = 0 = I\,\theta''\,\theta' + (m + m')g\,a\,\theta'\sin\theta$. θ is small, $\sin\theta \approx \theta \Rightarrow \theta'' + \frac{(m+m')ga}{I}\theta = 0$.	1
B.3.b	The differential equation characterizes a simple harmonic motion of angular frequency $\omega = \sqrt{\frac{(m+m')ga}{I}}$. The expression of the proper period is: $T = 2\pi\sqrt{\frac{I}{(m+m')ga}} = 2\pi\sqrt{\frac{I_0 + m'\frac{\ell^2}{4}}{(m+m')g\frac{m'\ell}{2(m+m')}}}$ $T = 2\pi\sqrt{\frac{I_0 + m'\frac{\ell^2}{4}}{g\frac{m'\ell}{2}}} = \sqrt{\frac{8I_0 + 2m'\ell^2}{m'\ell}}$.	1
B.4	$T = 1.732\ \text{s} = \sqrt{3}\ \text{s} \Rightarrow 3 = \frac{8I_0 + 0.32}{0.16} \Rightarrow I_0 = \frac{0.16}{8} = 0.02\ \text{kg.m}^2$.	0.75

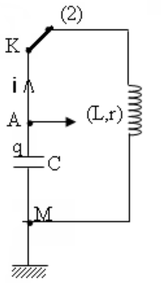
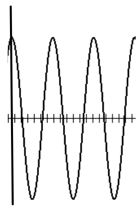
Second exercise (7.5 points)

Part of the Q	Answer	Mark
A.1.a	$i = \frac{dq}{dt} \Rightarrow i = C\frac{du_C}{dt}$.	0.5
A.1.b	$u_C = \frac{1}{C}\int i dt \Rightarrow u_C = -\frac{I\sqrt{2}}{C\omega}\cos(\omega t + \varphi)$.	0.5
A.1.c	$U_C = \frac{I}{C\omega}$	0.25
A.2	$U\sqrt{2}\sin\omega t = RI\sqrt{2}\sin(\omega t + \varphi) - \frac{I\sqrt{2}}{C\omega}\cos(\omega t + \varphi)$ For $t_0 = 0 \Rightarrow 0 = RI\sqrt{2}\sin\varphi - \frac{I\sqrt{2}}{C\omega}\cos\varphi \Rightarrow \tan\varphi = \frac{1}{RC\omega}$.	1.25
B.1.a	Connections of the oscilloscope  Fig 1	0.5
B.1.b.i	$T \to 6$ ms $\Rightarrow f = 166.67$ Hz	0.5
B.1.b.ii	(a) leads (b)	0.5
B.1.b.iii	In the (RC) circuit, the current (or u_R) leads the voltage u_G , thus (a) displays the voltage u_{DB}.	0.5
B.1.b.iv	$\lvert\varphi\rvert = \frac{2\pi\times 1}{6} = \frac{\pi}{3}$ rad.	0.5
B.1.c	$tg\varphi = \frac{1}{RC\omega} = \sqrt{3}$ $\Rightarrow$ **C =** $\frac{1}{250\times\sqrt{3} \times 166.67\times 2\pi} = 2.2\times10^{-6}$ F = 2.2 μF	1.25
B.2	$U_R = RI$ and $U_C = \frac{I}{C\omega} \Rightarrow \frac{U_C}{U_R} = \frac{1}{RC\omega}$ $\Rightarrow C = \frac{2.2}{3.2\times 250\times 2\pi\times 200} = 2.19\times10^{-6}$ F = 2.2 μF	1.25

Third exercise (7.5 points)

Part of the Q	Answer	Mark
I – A.1	Diffraction	0.25
I – A.2	$\tan\theta_1 = \frac{x/2}{D} = \frac{x}{2D} = 0.02 \approx \sin\theta_1 = \theta_1$ But for the 1st dark fringe: $\sin\theta_1 = \frac{\lambda}{a}$ then $a = \frac{\lambda}{0.02}$ but $\lambda = \frac{c}{\upsilon} = \frac{3\times10^{8}}{6.163\times10^{14}}$ =0.4868 μm thus a = 24 μm	1.25
I – B	Alternate bright – dark fringes , rectilinear, parallel to each other and to the slits and equidistant The interfringe $i = \frac{\lambda D}{a}$, in mm we get i = 0.4868×2 = 0.97mm≈ 1mm.	1.25
I – C	Wave aspect of light.	0.25
II – A.1.a	$W_0 = h\nu_o$ thus the threshold frequency is $\nu_o = \frac{W_0}{h} = 4.568\times10^{14}$ Hz	0. 5
II – A.1.b	$\nu > \nu_o$ thus there is emission of electrons	0.25
II – A.2	Maximum kinetic energy $KE_m = h\nu - W_0$ $KE_m = (6.163\times10^{14}\times6.62\times10^{-34})-(1.89\times1.6\times10^{-19}) = 1.056\times10^{-19}$J	0.75
II – B.1	$h\nu = \frac{(6.163\times10^{14}\times6.62\times10^{-34}}{(1.6\times10^{-19})} = 2.55$eV. If the photon is absorbed, we obtain: –13.6 + 2.55= –11.05 eV. This level does not exist. This photon is not absorbed.	1
II – B.2.a	– 3.4 + 2.55 = - 0.85eV which matches the level n = 4	0.5
II – B.2.b	- The visible radiations correspond to Balmer series - The two possible transitions :4 $\rightarrow$2 or 3$\rightarrow$2 - λ(max) corresponds to $\Delta E = (E_n - E_2)_{min}$ $\Rightarrow$ Transition 3$\rightarrow$2	1.25
II – C	The corpuscular aspect of light.	0.25

Fourth exercise (7.5 points)

Part of the Q	Answer	Mark
A.1	At the end of the charging, $u_{AM} = E = U_0 = 3$ V.	0.50
A.2	$W_0 = \frac{1}{2} CE^2 = 4{,}5\times 10^{-6}$ J.	0.50
B.1.a	Arbitrary direction for i 	0.50
B.1.b	$u_C = ri + L\frac{di}{dt}$, $i = -\frac{dq}{dt} = -C\frac{du_C}{dt}$ => $\mathbf{u_C = -LC\ u''_C}$ => $LC\ u''_C + u_C$ $\mathbf{= 0 =>}$ $u''_C + \frac{1}{LC}$ $\mathbf{u_C = 0.}$	1.5
B.1.c	$\omega_0^2 = \frac{1}{LC} => T_0 = 2\pi\sqrt{LC} = 1.99$ ms.	1
B.1.d		0.50
B.1.e	The free oscillations are undamped.	0.25
B.2.a	The free oscillations are damped.	0.25
B.2.b	The total energy in the circuit is not constant because of resistance of the coil which dissipates energy in the form of heat.	0.50
B.2.c.i	$T = \frac{10}{5} = 2$ ms	0.25
B.2.c.ii	$T > T_0$	0.25
B.2.c.iii	Around 0.	0.25
B.3.a	Around E = 3 V.	0.25
B.3.b	T = 2 ms.	0.25
B.3.c,i	For $0{,}5 \text{ ms} \le t \le 1$ ms u_C increases and i decreases $\Rightarrow$ the coil gives energy to the capacitor.	0.25
B.3.c.ii	For $1\text{ms} \le t \le 1.5$ ms: u_C decreases and i increases $\Rightarrow$ the capacitor gives energy to the coil.	0.25
B.3.c.iii	For $0 \le t \le 0.5$ ms : u_C increase and i increases $\Rightarrow$ no exchange of energy between the coil and the capacitor.	0.25

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الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	

This exam is formed of four exercises in four pages
The use of non-programmable calculator is recommended

First Exercise (7.5 points) Moment of inertia of a rod

Consider a homogeneous and rigid rod AB of negligible cross-section, of length ℓ = 1 m and of mass m = 240 g. This rod may rotate about a horizontal axis (Δ) perpendicular to it through its midpoint O. The object of this exercise is to determine, by two methods, the moment of inertia I_0 of the rod about the axis (Δ). The vertical position CD of the rod is considered as an origin of angular abscissa. Neglect all friction.

Take: $g = 10\ m/s^2$; $\pi^2 = 10$; $\sqrt{3} = 1.732$; $\sin\theta \approx \theta$ and $\cos\theta \approx 1 - \frac{\theta^2}{2}$ for small angles θ measured in radians.

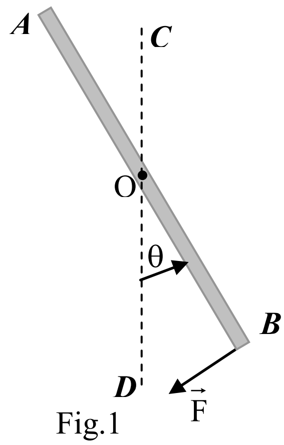


Fig.1

A – First method

The rod, starting from rest at the instant $t_0 = 0$, rotates around (Δ) under the action of a force $\vec{F}$ whose moment about (Δ) is constant of magnitude $\mathbf{M}$ = 0.1 m.N (Fig.1).

At an instant t, the angular abscissa of the rod is θ and its angular velocity is θ'.

1) ***a)*** Show that the resultant moment of the forces acting on the rod about (Δ) is equal to $\mathbf{M}$.

b) Determine, using the theorem of angular momentum, the nature of the motion of the rod between t_0 and t.

c) Deduce the expression of the angular momentum σ of the rod, about (Δ), as a function of time t.

2) Determine the value of I_0, knowing that at the instant t_1 = 10 s, the rotational speed of the rod is 8 turns/s.

B – Second method

We fix, at point B, a particle of mass m' = 160 g. The system (S) thus formed constitutes a compound pendulum whose center of mass is G. (S) may oscillate freely, about the axis (Δ).

We shift (S), from its stable equilibrium position, by a small angle and we release it without velocity at the instant $t_0 = 0$.

At an instant t, the angular abscissa of the pendulum is θ and its angular velocity is $\theta' = \frac{d\theta}{dt}$.

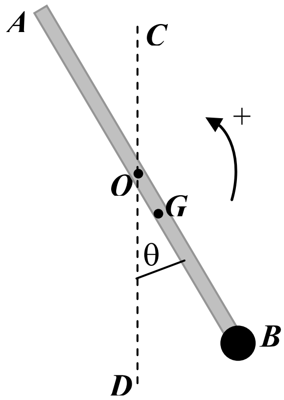


Fig.2

The horizontal plane through O is taken as a gravitational potential energy reference.

1) Determine:

a) The position of G relative to O (a = OG), in terms of m, m' and ℓ;

b) The moment of inertia I of (S) about (Δ), in terms of I_0, m' and ℓ.

2) Determine, at the instant t, the mechanical energy of the system [(S), Earth], in terms of I, θ', θ, m, m', a and g.

3) ***a)*** Derive the second order differential equation that describes the motion of (S).

b) Deduce the expression of the proper period T of the oscillations of (S), in terms of I_0, m', ℓ and g.

4) The duration of 10 oscillations of the pendulum is 17.32 s.
Determine the value of I_0.

Second exercise *(7.5 points)* ***Determination of the capacitance of a capacitor***

In order to determine the capacitance C of a capacitor, we consider the following components:

- A generator G delivering across its terminals an alternating sinusoidal voltage of effective value U and of adjustable frequency f;
- A resistor of resistance R = 250 Ω;
- An oscilloscope;
- Two voltmeters V_1 and V_2;
- A switch;
- Connecting wires.

We connect up the circuit whose diagram is represented in figure 1.

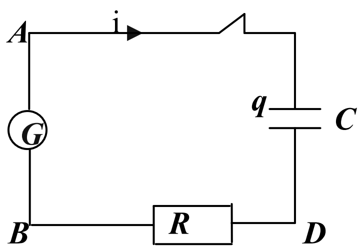


Fig 1

A – Theoretical study

The voltage across the generator is $u_{AB} = U\sqrt{2}\sin \omega t$. In the steady state, the current i carried by the circuit has the form: $i = I\sqrt{2}\sin(\omega t + \varphi)$, where I is the effective value of i.

1) a) Give the expression of the current i in terms of C and $\frac{du_C}{dt}$ with $u_C = u_{AD}$.

b) Determine the expression of the voltage u_C in terms of I , C, ω and t.

c) Deduce the expression of effective value U_C of u_C in terms of I, C and ω.

2) Applying the law of addition of voltages and giving t a particular value, show that $\tan\varphi = \frac{1}{RC\omega}$.

B – Determination of C

1) Using the oscilloscope

The oscilloscope, conveniently connected, displays on channel (Y_1) the voltage u_{AB} across the generator and on channel (Y_2) the voltage u_{DB} across the resistor. On the screen of the oscilloscope, we obtain the waveforms represented in figure 2.

Time base [horizontal sensitivity]: 1 ms / div.

a) Redraw figure 1 showing on it the connections of the oscilloscope.

b) Referring to figure 2,

i) determine the frequency of u_{AB};

ii) which of the waveforms, (a) or (b), leads the other?

iii) the waveform (a) displays u_{DB} . Why?

iv) determine the phase difference between the voltages u_{AB} and u_{DB}.

c) Calculate the value of C.

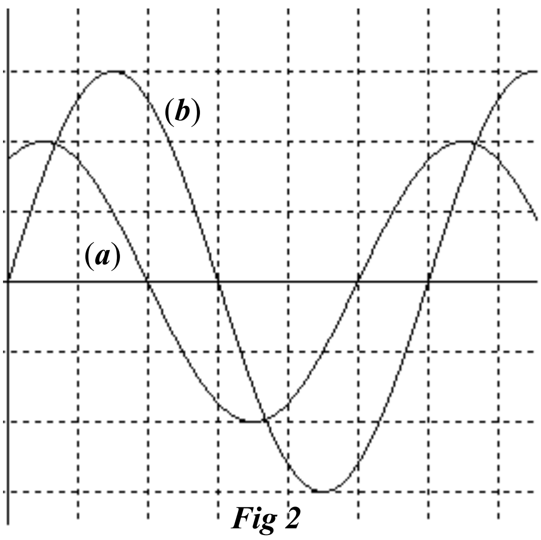


Fig 2

2) Using the voltmeters

The oscilloscope is removed and the frequency f is adjusted to the value 200 Hz. We then connect V_1 across the resistor and V_2 across the capacitor. V_1 and V_2 reads then the values 2.20 V and 3.20 V respectively.

Using these obtained measured values and the results of part A, determine the value of C.

Third Exercise *(7.5 points)* ***Aspects of light***

Consider a source (S) emitting a monochromatic luminous visible radiation of frequency $\nu = 6.163\times10^{14}$ Hz.

Given: $c = 3\times10^{8}$ m/s ; $h = 6.62\times10^{-34}$ J·s ; $1\text{eV} = 1.6\times10^{-19}$ J.

I – First aspect of light

A – This source illuminates a very thin slit that is at a distance of 10 m from a screen. A pattern, extending over a large width, is observed on the screen.

1) Due to what phenomenon is the formation of this pattern?

2) Determine the width of the slit knowing that the linear width of the central fringe is 40cm.

B – The same source illuminates now the two slits of Young's double slit apparatus, these slits are vertical and are separated by a distance $a = 1$ mm. A pattern is observed on a screen placed parallel to the plane of the slits at a distance $D = 2$ m from this plane.

Describe the observed pattern and calculate the interfringe distance i.

C – What aspect of light do the two preceding experiments show evidence of ?

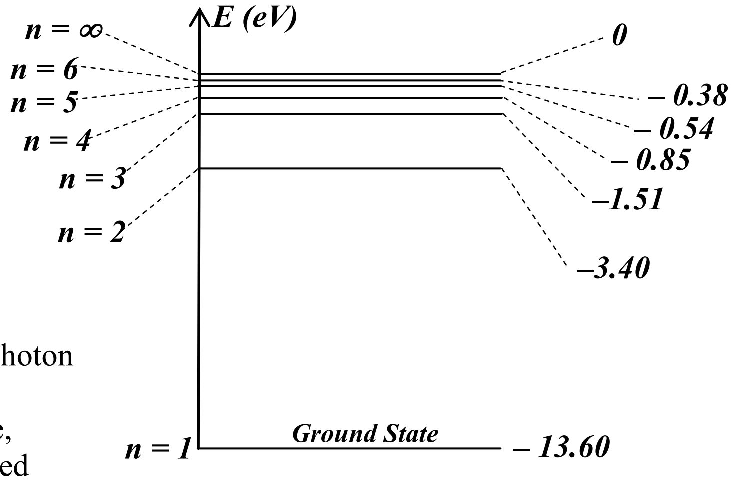
II – Second aspect of light

A – A luminous beam emitted by (S) falls on a cesium plate whose extraction energy is $W_0 = 1.89$ eV.

1) a) Calculate the threshold frequency of cesium.

b) Deduce that the plate will emit electrons.

2) Determine the maximum kinetic energy of an emitted electron.



B – The adjacent figure represents the energy diagram of a hydrogen atom.

The energy of the hydrogen atom is given by

$$E_n = \frac{-13.6}{n^2}$$

(E_n is in eV and n is a non-zero positive integer).

1) A hydrogen atom, in its ground state, receives a photon from (S). This photon is not absorbed. Why?

2) The hydrogen atom, found in its first excited state, receives a photon from (S). This photon is absorbed and the atom thus passes to a new excited state.

a) Determine this new excited state.

b) The atom undergoes a downward transition. Specify the transition that may result in the emission of the visible radiation whose wavelength is the largest.

C – What aspect of light do the parts A and B show evidence of ?

Fourth Exercise *(7.5 points)* ***Electromagnetic Oscillations***

The object of this exercise is to show evidence of the phenomenon of electromagnetic oscillations in different situations.

For this purpose, we consider an ideal generator G of e.m.f E = 3 V, an uncharged capacitor of capacitance C =1μF, a coil of inductance L= 0.1 H and of resistance r, a resistor of resistance R, an oscilloscope, a double switch K and connecting wires.

A – Charging of a capacitor

We connect up the circuit whose diagram is represented in figure1.

The oscilloscope is connected across the capacitor.

The switch K is in position (1). The capacitor is totally charged and the voltage across it is then $u_{AM} = U_0$.

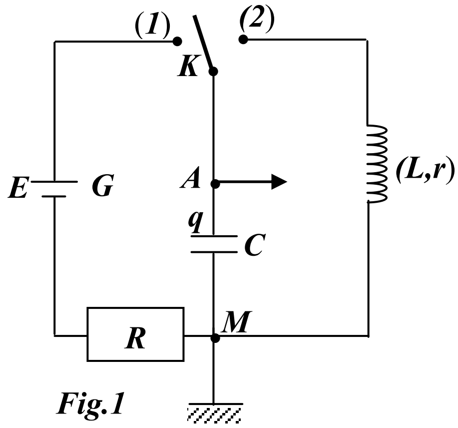


Fig.1

1) Determine the value of U_0.

2) Calculate the electric energy W_0 stored in the capacitor at the end of charging.

B – Electromagnetic oscillations

The capacitor being totally charged, we turn the switch K to position (2) at the instant $t_0 = 0$. The circuit is then the seat of electromagnetic oscillations. At an instant t, the circuit carries a current i.

1) *First situation (ideal circuit)* In the ideal circuit, we neglect the resistance r of the coil.

a) Redraw figure 1 showing on it an arbitrary direction of i.

b) Derive the differential equation that governs the variation of the voltage $u_{AM} = u_C$ across the capacitor as a function of time.

c) Deduce, then, the expression of the proper period T_0 of the electric oscillations in terms of L and C and calculate its value in ms with 2 digits after the decimal . Take $\pi = 3.14$

d) Draw a rough sketch of the curve representing the variation of the voltage u_C as a function of time.

e) Specify the mode of the electric oscillations that take place in the circuit.

2) *Second situation (real circuit)* The variation of the voltage $u_{AM} = u_C$ is displayed on the screen of the oscilloscope as shown in the waveform of figure 2.

a) Specify the mode of the electric oscillations that take place in the circuit.

b) Give an energetic interpretation of the obtained phenomenon.

c) Referring to the waveform of figure 2,

i) Give the duration T of one oscillation;

ii) Compare T and T_0;

iii) Specify the value around which the voltage u_C varies.

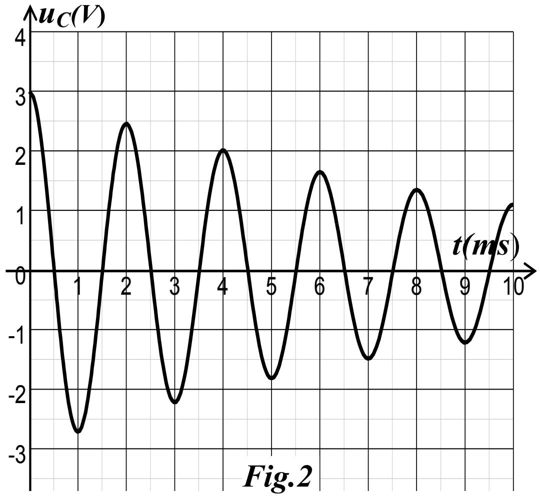


Fig.2

3) *Third situation*

We connect up a new circuit in which the coil, the uncharged capacitor and the switch K are connected in series across the generator G (Figure 3).

We close K at the instant $t_0 = 0$. At an instant t, the circuit carries a current i.

Figure 4 gives the variations, as a function of time, of i (Fig. 4a) and u_C (Fig. 4b).

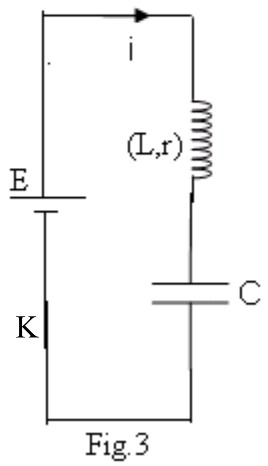


Fig.3

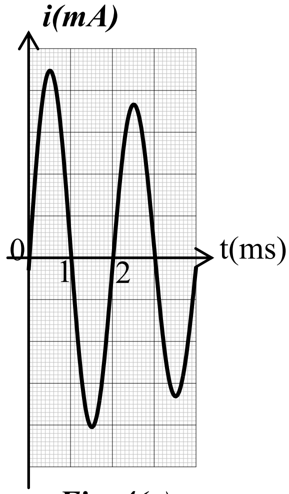


Fig. 4(a)

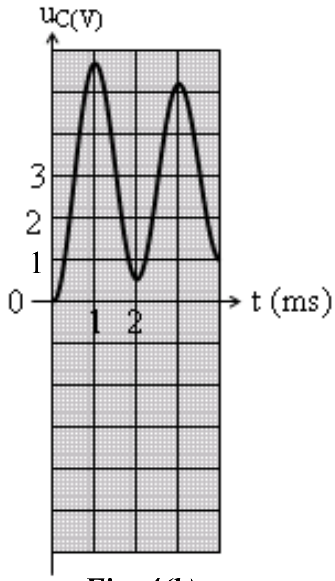


Fig. 4(b)

a) Specify the value around which the voltage u_C varies.

b) Give the duration of one oscillation.

c) We consider the following 3 intervals of time : $0 \leq t \leq 0.5$ ms ; 0.5 ms $\leq t \leq 1$ ms ; 1 ms $\leq t \leq 1.5$ ms.

Referring to the curves of figure 4, specify, with justification, the interval in which:

i) The coil supplies energy to the capacitor;

ii) The capacitor supplies energy to the coil;

iii) No energy exchange takes place between the coil and the capacitor.

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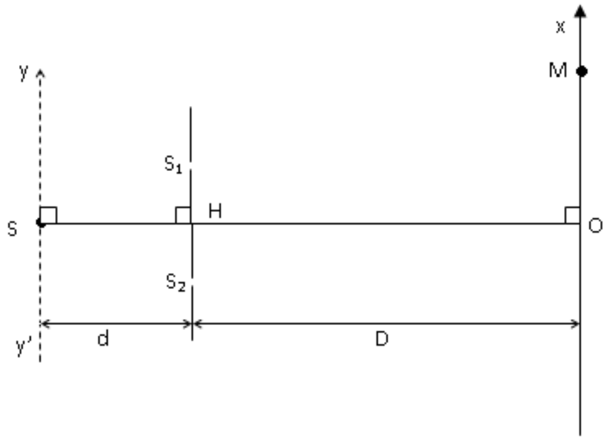
<u>This exam is formed of four exercises in four pages.</u>
<u>The use of non-programmable calculator is allowed.</u>

<u>First Exercise</u> ***(6 points)***

<u>Interference of Light</u>

The object of this exercise is to show how to use Young's double slit apparatus to measure very small displacements.
A source put at a point S, emitting a monochromatic radiation of wavelength λ in air, illuminates the two slits S_1 and S_2 that are separated by a distance a. The screen of observation is placed at a distance D from the plane of the slits.



1. Describe the aspect of the interference fringes observed on the screen.

2. At a point M of abscissa x = $\overline{OM}$, the optical path difference is given by the relation:

$$\delta = MS_2 - MS_1 = \frac{ax}{D}$$

a) At the point O, we observe a bright fringe, called central bright fringe. Why?
b) What condition must δ satisfy in order to observe, at M, a dark fringe?
c) Give the expression of x in terms of a, D and λ, so that M is the center of a bright fringe.
d) Given: $\lambda = 0.55$ μm ; a = 0.2 mm; D = 1.5 m ; d = 10 cm.
We take x = 1.65 cm. Are the waves interfering at M in phase or out of phase? Justify your answer.

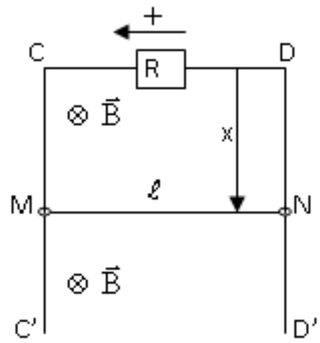
3. We move the source from S to point S' vertically up on the axis y'y perpendicular to the horizontal axis of symmetry SO, by the distance b = SS'. In this case ,we can write

$$S'S_2 - S'S_1 = \frac{ab}{d}.$$

a) The central bright fringe is no longer at O but at point O'.
i) Justify this displacement.
ii) Specify, with justification, the direction of this displacement.
b) Determine the value of b, knowing that OO' = 1cm.

<u>Second Exercise</u> ***(8 points)***

<u>Motion of a conductor in two fields</u>



Two vertical rails CC' and DD' are connected by a resistor of resistance R.
A conducting rod MN, of mass m and length ℓ, can slide without friction along these rails and remains horizontally in contact with these rails.
The whole set-up is placed within a uniform and horizontal magnetic field $\vec{B}$ that is perpendicular to the plane of the rails.
The rod MN, released from rest at the instant $t_0 = 0$, is found at an instant t at a distance x from CD, moving with a velocity whose algebraic value is v (v > 0) (adjacent figure).

1. Determine, at the instant t, the expression of the magnetic flux due to $\vec{B}$ through the circuit CMND in terms of B, ℓ and x, taking into consideration the arbitrary positive direction as shown on the figure.

2. a) Determine the expression of:

i) The e.m.f "e" induced across the rod MN, in terms of v, B and ℓ.

ii) The induced current i in terms of R, B, ℓ and v.

b) Indicate, with justification, the direction of the current.

3. Show that the electric power dissipated by the resistor, at the instant t, is given by : $P_{el} = \frac{B^2\ell^2}{R}v^2$.

4. The rod MN is acted upon by two forces: its weight $m\vec{g}$ and the Laplace's force $\vec{F}$ of magnitude F = i ℓ B.

a) Applying Newton's second law, show that the differential equation in v is given by:

$$\frac{dv}{dt} + \frac{B^2\ell^2}{mR}v = g .$$

b) The solution of this differential equation is: $v = A(1 - e^{-\frac{t}{\tau}})$. Show that:

$$A = \frac{mgR}{B^2\ell^2} \text{ and } \tau = \frac{mR}{B^2\ell^2} .$$

c) Show that v would attain a limiting value V_{lim}.

d) i) Give the expression of v as a function of V_{lim} at the instant t = τ.

ii) Deduce the time at the end of which v attains practically its limiting value.

e) Calculate the value of V_{lim} and that of τ, knowing that: ℓ = 20 cm, m = 10 g, R = 0.1 Ω, B = 0.5 T and g = 10 m/s^2.

5. In the steady state, starting from the instant when $v = V_{lim}$, the mechanical energy of the system (MN in the field $\vec{B}$, Earth) decreases.

a) Explain this decrease.

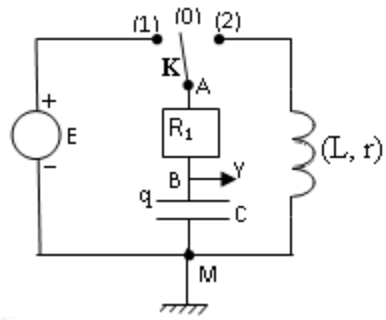
b) In what form is this energy dissipated?

c) Calculate the power dissipated.

<u>Third Exercise</u> *(8 points)*

<u>Study of Charging and Discharging of a Capacitor</u>

The adjacent circuit allows to study the variation of the voltage $u_C = u_{BM}$ across a capacitor of capacitance C during charging and discharging.
We consider a generator delivering a constant voltage E, a resistor of resistance R_1 = 25 Ω and a coil of inductance L and of resistance r.
Initially, the switch K is in position (0) and the capacitor is uncharged. An oscilloscope allows displaying the variation of u_C as a function of time.



A – Charging of the capacitor

At the instant t_0 = 0, the switch is in position (1) and the capacitor starts charging. At an instant t, the circuit carries a current i and the capacitor carries the charge q.

1. a) Redraw the diagram of the circuit indicating on it the real direction of i.

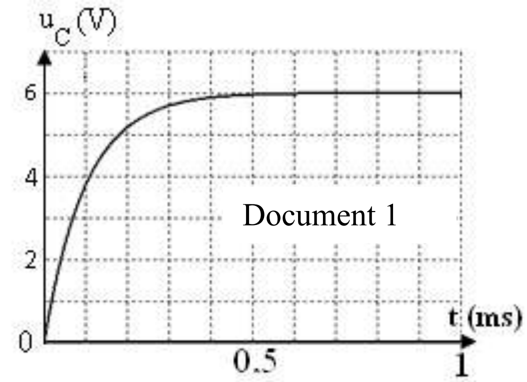
b) Write down the relation between i and u_C.

2. a) Derive the differential equation in u_C.

b) The solution of this differential equation is of the form:

$$u_C = A + Be^{-\frac{t}{\tau_1}} .$$

Determine the expressions of the constants A, B and τ_1.



Document 1

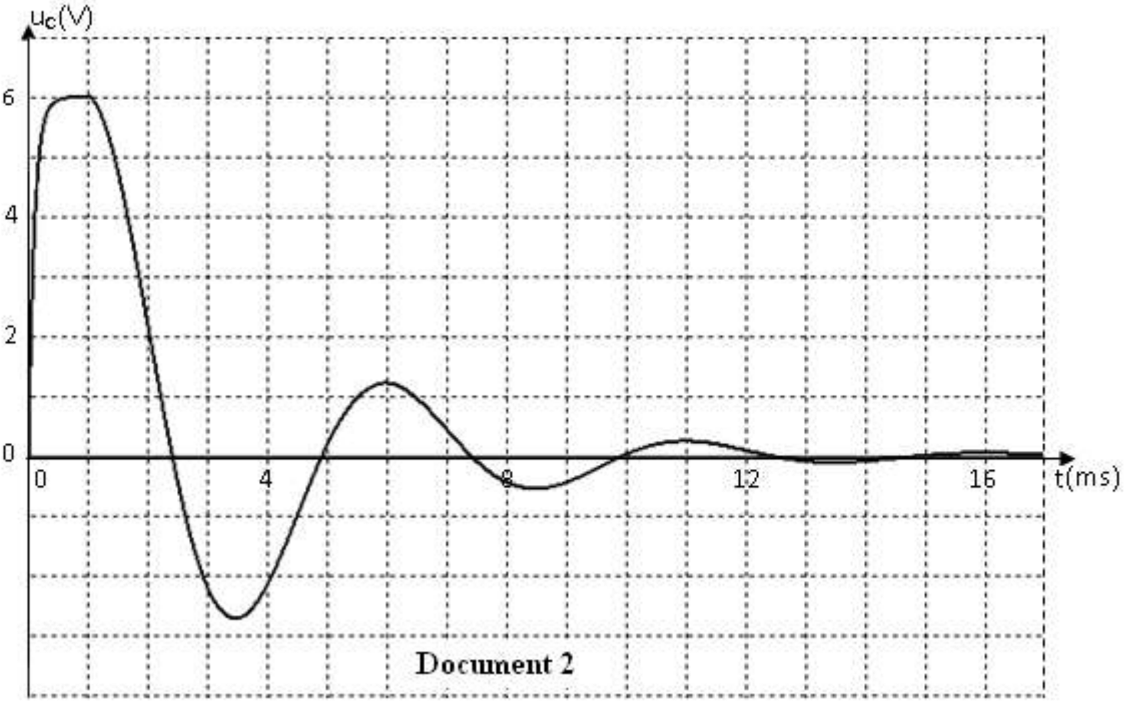
c) Referring to the graph of document 1, determine:

i) The values of E and τ_1. Deduce that the value of C is 4μF.

ii) The minimum duration at the end of which the capacitor is practically completely charged.

B – Discharging of the capacitor through a coil

K is moved from position (1) at the instant t_l = 0.6 ms and becomes in position (2) at the instant t_2 = 1 ms. The document 2 shows the variation of u_C between the instants 0 and 17ms.



Document 2

1. The voltage u_C remains constant between the instants t_l and t_2 .Why?
2. Starting from the instant t_2 = 1 ms, the circuit is the seat of electric oscillations. Referring to the graph of document 2, give the value of the pseudo period T of the electric oscillations.

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3. *a)* Write down the expression of the proper period T_0 in an LC circuit.

   b) Knowing that L = 0.156 H and $\left(\frac{2\pi}{T}\right)^2 = \left(\frac{2\pi}{T_0}\right)^2 - \left(\frac{r+R_1}{2L}\right)^2$, calculate r.
4. *a)* Determine, referring to document 2, the value of u_C at the instant t = 6 ms.

   b) Calculate the value of the loss in electric energy in the circuit at the end of the first oscillation.

Fourth Exercise* (8 points) *Mechanical Oscillators

The parts A and B are independent. We neglect friction in all this exercise.

A- Simple pendulum

A simple pendulum (P) is formed of a particle G of mass m connected to one end of an inextensible string, of negligible mass and of length L ; the other extremity is connected to a fixed point A. The pendulum is shifted by an angle θ_m from its equilibrium position AG_0 to the position AG_i, then released from rest at the instant t_0 = 0s ; thus it oscillates with the amplitude θ_m.

At an instant t, the position of AG is defined by θ, the angular abscissa relative to its equilibrium position, and v is the algebraic measure of the velocity of G (Fig.1).

Take the horizontal plane through G_0 as a gravitational potential energy reference.

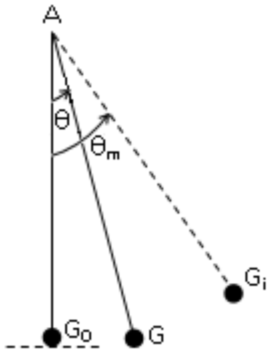


Fig. 1

1. Find the expression of the mechanical energy of the system [(P), Earth] in terms of m, g, L, v and θ.
2. Derive the second order differential equation in θ that governs the motion of this pendulum.
3. a) What condition must θ satisfy in order to have a simple harmonic motion?
   b) Deduce, in this case, the expression of the proper period T_0 of the oscillations.
   c) Write down the time equation of motion, in the case $\theta_m = 0.1$ rad.
   Take : $g = 10 m/s^2$; $L = 1m$ and $\pi^2 = 10$.

B- Horizontal elastic pendulum

A solid (S) of mass m may slide on a horizontal plane; it is connected to a spring (R) of stiffness k = 4 N/m. When (S) is in equilibrium, its center of mass G is found vertically above the point O, taken as origin on the horizontal axis of abscissa.

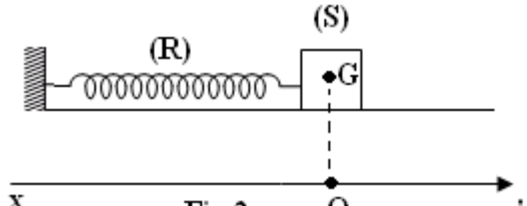


Fig.2

(S), shifted from its equilibrium position, is released from rest at the instant $t_0 = 0$. At an instant t, the abscissa of G is x and the algebraic value of its velocity is v.
A convenient apparatus gives the variation of x as a function of time (Fig. 3).
The horizontal plane containing G is taken as a gravitational potential energy reference.

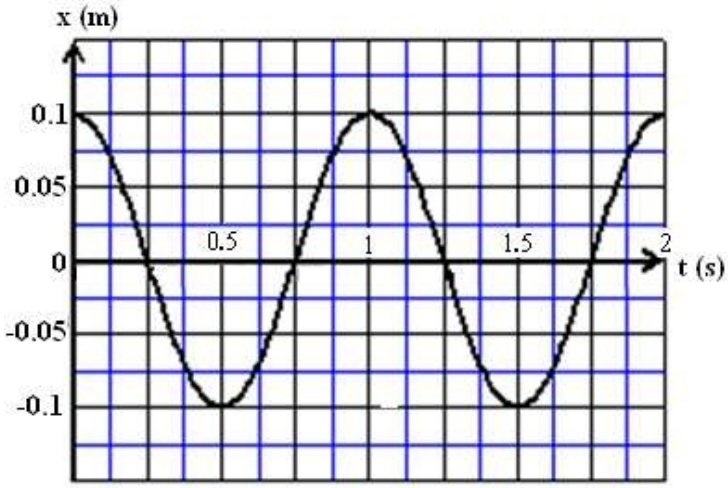


Fig. 3

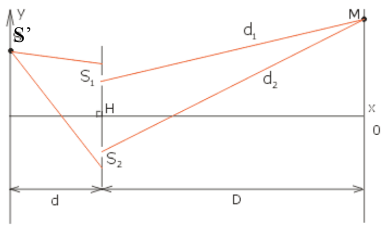
1. Derive the second order differential equation in x that governs the motion of G.
2. The solution of this differential equation is of the form : $x = X_m \cos(\frac{2\pi}{T_0} t + \varphi)$, where X_m, T_0 and φ are constants .Referring to the graph of figure (3), give the values of X_m and T_0 and determine φ .
3. a) Determine the expression of the proper period T_0 in terms of m and k.
   b) Deduce m.
4. a) Referring to the graph of figure (3), give the instants at which the elastic potential energy is maximum.
   b) Calculate then the value of the mechanical energy of the system [(S), (R), Earth].

C- Behavior of the pendulums on the Moon

We suppose that the two preceding pendulums are now on the Moon.
Tell, with justification, for each pendulum, which of the statements in the following table is true .

Statement 1	**Statement 2**	**Statement 3**
T_0 does not vary	T_0 increases	T_0 decreases

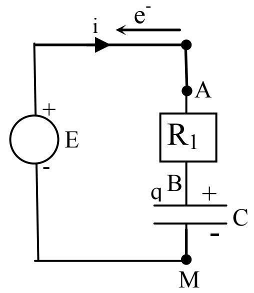
First exercise (6 points)

Part of the Q	Answer	Mark
1	Fringes are: alternating bright and dark- parallel to each other and to the slits- rectilinear- equidistant.	¼ ¼ ¼ ¼
2.a	At point O, $\delta = 0$, all the waves arriving to O are in phase: we observe at O a bright fringe.	½
2.b	At point M of abscissa x, we observe a dark fringe if the path difference δ at this point is such that: $\delta = (2k+1)\frac{\lambda}{2}$ with k an integer	½
2.c	The abscissa x of the point M is obtained from the expression of the difference of path: $\delta = k\lambda = \frac{ax}{D} \Rightarrow x = \frac{k\lambda D}{a}$	½
2.d	$\delta = \frac{ax}{D} = \frac{0.2\times 16.5}{1.5\times 10^{3}} = 2.2\times 10^{-3}$mm. $\frac{\delta}{\lambda} = \frac{2.2\times 10^{-3}}{0.55\times 10^{-3}} = 4$, thus δ is a multiple integer of wavelengths: the waves that interfere at M are in phase.	½ ½
3.a.i	If O remains the center of the central bright fringe : $\delta' = (S'S_2 + S_2O) - (S'S_1 + S_1O) = (S'S_2 - S'S_1) \neq 0$ But for the C.B.F we have : $\delta' = 0 \Rightarrow$ O displaced to O'.	½
3.a.ii	$\delta' = (S'S_2 + S_2O') - (S'S_1 + S_1O') = 0 \Rightarrow (S'S_2 - S'S_1) + (S_2O' - S_1O') = 0$ $\Rightarrow (S'S_2 - S'S_1) = -(S_2O' - S_1O')$; $(S'S_2 - S'S_1) > 0 \Rightarrow (S_2O' - S_1O') < 0 \Rightarrow S_2O' < S_1O'$ $\Rightarrow$ O displaced downward. **Another meth.** $\delta' = \frac{ab}{d} + \frac{ax}{D} = 0 \Rightarrow \frac{b}{d} = -\frac{x}{D} \Rightarrow x = -\frac{bD}{d} < 0 \Rightarrow$ The C.B.F displaced downward.	½
3.b	The central fringe on the screen corresponds to a zero path difference at this point M: $\delta' = SS_2 + S_2M - (SS_1 + S_1M)$ $\delta' = (SS_2 - SS_1) + (S_2M - S_1M)$ $\delta' = \frac{ab}{d} + \frac{ax}{D}$.  The central fringe corresponds to $\delta' = 0$; its position is defined by: $\frac{ab}{d} + \frac{ax}{D} = 0$ so: $b = -\frac{d}{D}x \Rightarrow b = \frac{d}{D}\lvert x\rvert = \frac{10\times(1)}{1.5\times 10^{2}} = 0.0667$ cm = 0.667 mm	¾ ¾

Second exercise (8 points)

Part of the Q	Answer	Mark
1	The magnetic flux $\phi = \vec{B} \cdot S\vec{n} = -BS = -B\ell x$.	¼ ¼
2.a.i	The induced emf $e = -\frac{d\phi}{dt} = B\ell\frac{dx}{dt} = B\ell v$.	¼ ¼
2.a.ii	The value of the current $i = \frac{e}{R} = \frac{B\ell v}{R}$.	¼ ¼
2.b	i > 0, then i passes from M to N in the rod.	½
3	The dissipated electric power: $P_{el} = Ri^2 = R(\frac{B\ell v}{R})^2 = \frac{B^2\ell^2}{R}v^2$.	½
4.a	$m\vec{g} + \vec{F} = \frac{d\vec{P}}{dt}$; with $F = iBL = \frac{B^2\ell^2}{R}v$ Project vertically downward: $mg - \frac{B^2\ell^2}{R}v = \frac{dP}{dt} = m\frac{dv}{dt}$. $\Rightarrow \frac{dv}{dt} + \frac{B^2\ell^2}{mR}v = g$	¼ ¼ ½ ½
4.b	$\frac{dv}{dt} = \frac{A}{\tau}e^{-\frac{t}{\tau}}$; $\frac{A}{\tau}e^{-\frac{t}{\tau}} + A\frac{B^2\ell^2}{mR} - A\frac{B^2\ell^2}{mR}e^{-\frac{t}{\tau}} = g. \Rightarrow A\frac{B^2\ell^2}{mR} = g$ and $\frac{A}{\tau} = A\frac{B^2\ell^2}{mR}$ $A = \frac{mgR}{B^2\ell^2}$ and $\tau = \frac{mR}{B^2\ell^2}$	½ ½
4.c	When t increases, the term $e^{-\frac{t}{\tau}}$ tends towards zero and v tends towards A. Thus $V_{lim} = A = \frac{mgR}{B^2\ell^2}$.	½
4.d.i	For $t = \tau$, $v = V_{lim}(1 - e^{-1}) = 0.63\ V_{lim}$.	½
4.d.ii	The conductor MN reaches practically its limiting speed for $t = 5\tau = 0.5$ s.	½
4.e	$V_{lim} = \frac{10^{-2} \times 10 \times 0.1}{0.5^2 \times 0.2^2} = 1$ m/s and $\tau = \frac{10^{-2} \times 0.1}{0.5^2 \times 0.2^2} = 0.1$ s	¼ ¼
5.a	The kinetic energy does not vary since the speed of MN remains constant while the gravitational potential energy decreases	¼
5.b	It is dissipated as Joule's effect in the resistor.	¼
5.c	$P = \frac{B^2\ell^2}{R}v_{lim}^2 = \frac{0.5^2 \times 0.2^2}{0.1}1^2 = 0.1$ W.	¼ ¼

Third exercise (8 points)

Part of the Q	Answer	Mark
A.1.a	Circuit and direction of i 	¼
A.1.b	$i = C\frac{du_c}{dt}$	½
A.2.a	From the law of addition of voltages: $u_{AM} = u_{AB} + u_{BM} \Rightarrow E = R_1 i + u_C$ $\Rightarrow R_1C\frac{du_C}{dt} + u_C = E$	½ ½
A.2.b	$u_C = A + B\ e^{-\frac{t}{\tau_1}}$ At $t = 0 \Rightarrow u_C = 0 \Rightarrow A + B = 0 \Rightarrow A = -B \Rightarrow u_C = A - A e^{-\frac{t}{\tau_1}}$ $\frac{du_C}{dt} = \frac{A}{\tau_1}e^{-\frac{t}{\tau_1}} \Rightarrow A\frac{R_1C}{\tau_1}e^{-\frac{t}{\tau_1}} + A - Ae^{-\frac{t}{\tau_1}} = E$; $\Rightarrow A = E$ and $\frac{R_1C}{\tau_1} - 1 = 0 \Rightarrow \tau_1 = R_1C$.	½ ½ ½
A.2.c.i	$(u_C)_\ell = E = 6$ V. For $t = \tau_1$, $u_C = 0.63\ E = 3.78$ V. From the graph: $\tau_1 = 0.1$ ms. $\tau_1 = R_1C \Rightarrow C = 4\times10^{-6}$ F.	¼ ½ ¼
A.2.c.ii	$t_{min} = 5\tau_1 = 0.5$ ms $= 5\times10^{-4}$ s.	¼ ¼
B.1	During the passage from (1) to (2), the circuit is open and the voltage u_C does not vary and retains the value of 6 V between $t_1 = 0.6$ ms and $t_2 = 1$ ms	½
B.2	$T = 5$ ms $= 5\times10^{-3}$ s	½
B.3.a	$T_0 = 2\pi\sqrt{LC}$.	¼
B.3.b	$T_0 = 2\pi\sqrt{LC} \approx 4.96 \times 10^{-3}$ s, replace in the given equation to get $r \approx 23\ \Omega$	¼ ½
B.4.a	At the instant $t = 6$ ms, $u_C = 1.25$ V	½
B.4.b	$W = W_0 - W_1 = \frac{1}{2}C(E^2 - u_c^2) = \frac{1}{2}\times4\times10^{-6}(36 - 1.25^2) = 6.89\times10^{-5}$ J	½ ¼

Fourth exercise (8 points)

Part of the Q	Answer	Mark
A.1	ME = $KE_k + PE_g = ½ mv^2 + mgL(1 - \cos\theta)$.	¼ ½
A.2	$\frac{dME}{dt} = 0 = mvx'' + mgL\theta' \sin\theta = mL^2\theta'\theta'' + mgL\theta' \sin\theta \Rightarrow \theta'' + \frac{g}{L}\sin\theta = 0$.	½
A.3.a	θ_m should be $< 10^o$. $\forall t$.	¼
A.3.b	$\theta_m < 10^o \Rightarrow \theta < 10^o \Rightarrow \sin\theta = \theta$ in rad ; in this case: the differential equation is: $\theta'' + \frac{g}{L}\theta = 0$ $\Rightarrow$ The proper angular frequency ω_0 is such that $(\omega_0)^2 = \frac{g}{L} \Rightarrow \omega_0 = \sqrt{\frac{g}{L}}$. The proper period is $T_0 = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{L}{g}}$.	½ ¼ ¼
A.3.c	Let $\theta = \theta_m \sin(\omega_0 t + \varphi)$; with $\theta_m = 0.1$ rad and $\omega_0 = \sqrt{\frac{g}{L}} = \pi$ rad/s ; at t = 0 we have: $\theta = \theta_m \sin\varphi = \theta_m \Rightarrow \sin\varphi = 1$ $\Rightarrow \varphi = \frac{\pi}{2}$ rad $\Rightarrow \theta = 0.1\sin(\pi t + \frac{\pi}{2})$	¼ ¼ ¼
B.1	ME = $KE + PE_{elastic} + PE_g = ½ mv^2 + ½ kx^2 + 0 = const.$ $\frac{dME}{dt} = 0 = mvx'' + kxv \Rightarrow x'' + \frac{k}{m}x = 0$.	¼ ¼
B.2	$X_m = 0.1$ m ; $T_0 = 1$ s ; if t = 0, $x = X_m\cos\varphi = X_m \Rightarrow \cos\varphi = 1 \Rightarrow \varphi = 0$.	¼ ¼ ¼
B.3.a	$x = X_m\cos(\frac{2\pi}{T_0}t + \varphi) \Rightarrow v = -X_m \frac{2\pi}{T_0}\sin(\frac{2\pi}{T_0}t + \varphi)$ $\Rightarrow x'' = -X_m \frac{2\pi}{T_0}\frac{2\pi}{T_0}\cos(\frac{2\pi}{T_0}t + \varphi)$; replacing in the differential equation, we obtain: $- X_m \frac{2\pi}{T_0}\frac{2\pi}{T_0}\cos(\frac{2\pi}{T_0}t + \varphi) + \frac{k}{m}X_m\cos(\frac{2\pi}{T_0}t + \varphi) = 0 \Rightarrow \frac{2\pi}{T_0} = \sqrt{\frac{k}{m}} \Rightarrow$ $T_0 = 2\pi\sqrt{\frac{m}{k}}$.	1
B.3.b	$T_0 = 1$ s and k = 4 N/kg we obtain: m = 0.1 kg	½
B.4.a	$E_{pe} = ½ kx^2$, E_{pe} is max. if $\lvert x \rvert$ is max. $\Rightarrow x = \pm 0.1$ m $\Rightarrow$ at the instants 0, 0,5s, 1s, 1,5s, 2s .	¼ ¼
B.4.b	For $P.E_g$ max, KE = 0 $\Rightarrow$ ME = $P.E_g = ½ k(X_m)^2 = 2\times10^{-2}$ J.	¼ ¼ ¼
C	For the simple pendulum $T_0 = 2\pi\sqrt{\frac{L}{g}}$; but $g_{moon} < g_{earth} = g$ so T_0 increases. Statement (2) For the elastic pendulum $T_0 = 2\pi\sqrt{\frac{m}{k}}$; T_0 does not vary on the Moon.(Statement 1)	½ ¼

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This exam is formed of four exercises in four pages numbered from 1 to 4.
The use of a non-programmable calculator is recommended.

First exercise: (8 points) **Oscillation and rotation of a mechanical system**

A rigid rod AB, of negligible mass and of length L = 2 m, may rotate, without friction, around a horizontal axis (Δ) perpendicular to the rod through its midpoint O. On this rod, and on opposite sides of O, two identical particles (S) and (S′), each of mass m = 100 g, may slide along AB.

Take: the gravitational acceleration on the Earth $g = 9.8\ m/s^2$;

for small angles: $\cos\theta = 1 - \frac{\theta^2}{2}$ and $\sin\theta = \theta$ in rad.

A – Oscillatory motion

The particle (S) is fixed on the rod at point C at a distance $OC = \frac{L}{4}$ and the particle (S′) is fixed at point B (Fig. 1). G is the center of gravity of the system (P) formed of the rod and the two particles. Let OG = a and I_0 be the moment of inertia of (P) with respect to the axis (Δ).

We shift (P) by a small angle θ_m, about (Δ), from its stable equilibrium position, in the positive direction as shown on the figure, and then released without initial velocity at the instant $t_0 = 0$; (P) thus oscillates, around the axis (Δ) with a proper period T. At an instant t, the angular abscissa of the compound pendulum, thus formed, is θ; (θ is the angle formed between the rod and the vertical passing through O), and its angular velocity is $\theta' = \frac{d\theta}{dt}$. We neglect all frictional forces and take the horizontal plane through O as a gravitational potential energy reference.

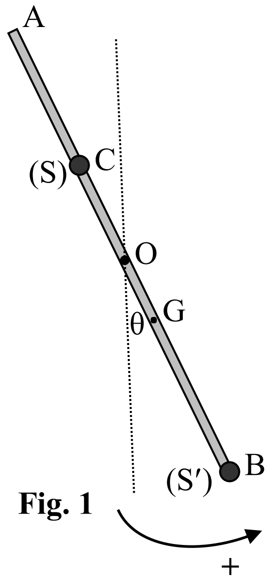


Fig. 1

1) Show that $a = \frac{L}{8}$.

2) Show that $I_0 = \frac{5mL^2}{16}$.

3) Write, at an instant t, the expression of the mechanical energy of the system [Earth, (P)] in terms of I_0 , m, a, g, θ and θ'.

4) Derive the second order differential equation in θ that describes the motion of (P).

5) Deduce, in terms of L and g, the expression of T. Calculate its value on the the Earth.

6) The system (P) oscillates now on the Moon. In this case, the proper period, for small oscillations, is T′. Compare, with justification, T′ and T.

B – Rotational motion

In this part, the particles (S) and (S′) are fixed at A and B respectively (Fig.2).

At the instant $t_0 = 0$, we launch the system (P′) thus formed, around (Δ) with an initial angular velocity $\theta'_0 = 2$ rad/s ; (P′) then turns, in the vertical plane around (Δ).

At an instant t, the angular abscissa of the rod, with respect to the vertical passing through O, is θ , and its angular velocity is $\theta' = \frac{d\theta}{dt}$. During rotation, (P′) is acted upon by a couple of forces of friction whose moment, with respect to (Δ) is $M = -h\ \theta'$, where h is a positive constant.

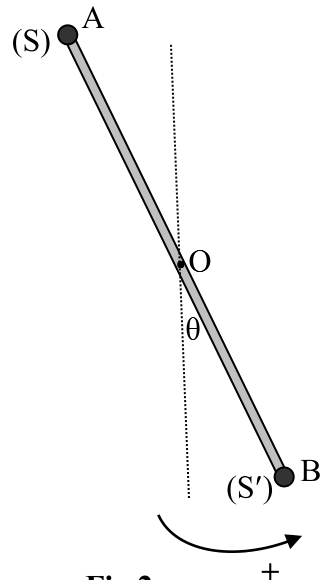


Fig.2

1) Give the name, at an instant t, of the couple and the forces acting on (P′).
2) Show that the resultant moment of the couple and of the forces, with respect to (Δ), is equal to the moment $M = -h\ \theta'$.
3) Show that the moment of inertia of (P′) about (Δ) is I = 0.2 kgm^2.
4) Using the theorem of angular momentum $\frac{d\sigma}{dt} = \Sigma M_{ext}$, show that the differential equation in σ is written as : $\frac{d\sigma}{dt} + \frac{h}{I}\sigma = 0$, σ is the angular momentum of (P′), about (Δ).

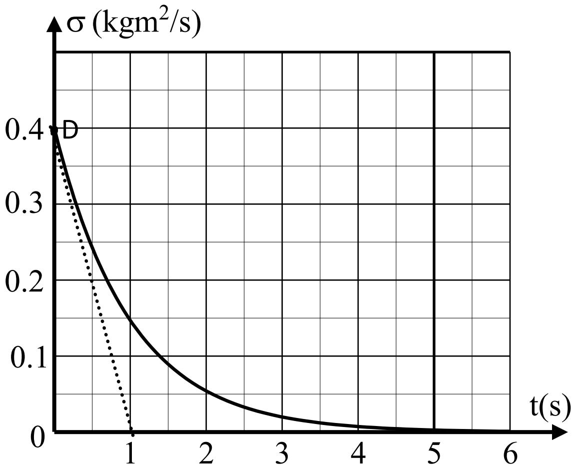


Fig.3

5) Verify that $\sigma = \sigma_0 e^{-\frac{h}{I}t}$ is a solution of the differential equation [σ_0 is the angular momentum of (P′), about (Δ), at the instant $t_0 = 0$].
6) The variation of σ as a function of time, is represented by the curve of figure 3. On this figure, we draw the tangent to the curve at point D at the instant $t_0 = 0$.
a) The curve of figure 3 is in agreement with the solution of the differential equation. Why?
b) Determine the value of h.

<u>Second exercise</u>: (6.5 points) **Charging and discharging of a capacitor**

We set up the circuit whose diagram is represented in figure 1, G is a generator of constant e.m.f E = 10 V and of negligible internal resistance, (C) is a capacitor, initially uncharged, of capacitance C = 1 F, (D) is a resistor of resistance R= 10 Ω, K is a switch and M is an electric motor whose axis is wrapped by a string of negligible mass and carrying a solid of mass m = 1 kg (Fig. 1). Take g = 10 m/s^2.

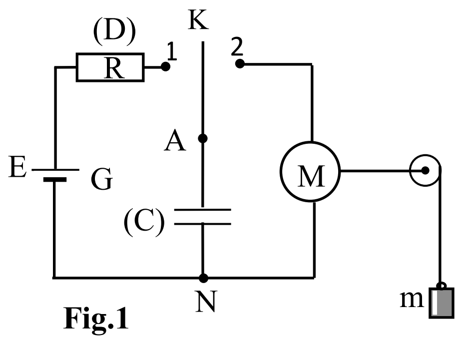


Fig.1

A – Charging of the capacitor
K is in position 1 at the instant t_0= 0.
1) Determine the differential equation that describes the variation of the voltage $u_{AN} = u_C$ across the capacitor.
2) The solution of the differential equation is of the form:
$u_C = A + B\ e^{-\frac{t}{\tau}}$ where A, B and τ are constants.
Determine the expressions of A, B and τ in terms of E, R and C.
3) At the end of charging:
a) deduce the value of the voltage u_C ;
b) calculate, in J, the energy stored in the capacitor.

B – Discharging of the capacitor through the motor
The capacitor being totally charged, we turn the switch K to the position 2 at an instant taken as a new origin of time. During a time t_1, the solid is raised by height h = 1.5 m. At the instant t_1, the voltage across the capacitor is $u_C = u_1$.
The variation of the voltage u_C across the capacitor during discharging through the motor between the instants 0 and t_1 is represented by the curve of figure 2.

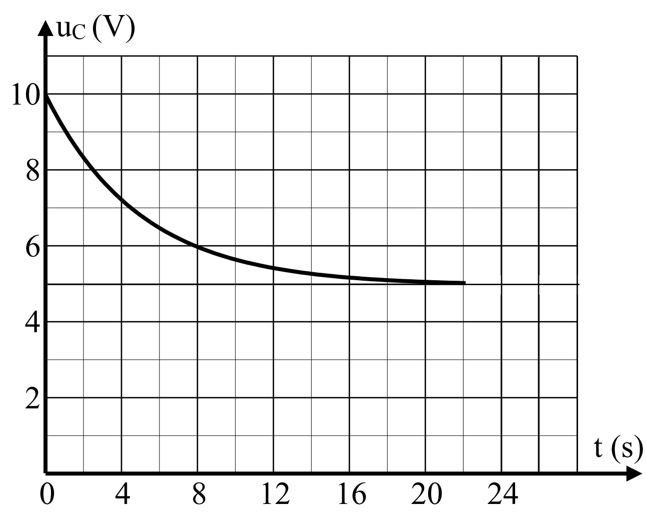


Fig.2

1) Referring to figure 2:

a) give the value of t_1, at which the voltage u_C attains the minimum value u_1;
b) give the value of the voltage u_1.

2) At the instant t_1, the capacitor still stores energy W_1.
   a) Tell why.
   b) Calculate the value of W_1 .
3) Assume that the energy yielded by the capacitor is received by the motor.
   a) Calculate the value of the energy W_2 yielded by the capacitor between the instants 0 and t_1.
   b) To what forms of energy is W_2 transformed?
   c) Determine the efficiency of the motor.

<u>Third exercise</u>: (8 points) **Electromagnetic oscillations**

An electric circuit is formed of a generator of constant e.m.f. E = 10 V and of negligible internal resistance, a capacitor, initially uncharged and of capacitance $C = 10^{-3}$F, a coil of inductance L = 0.1 H and of negligible resistance and a rheostat of variable resistance R.
In order to study the effect of R on the electric oscillations of an (R, L, C) circuit, we connect the circuit represented in figure (1).

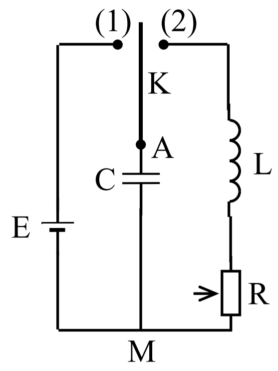


Fig.1

A – The switch is in position (1).

1) Give the name of the physical phenomenon that takes place in the electric circuit.
2) After closing the circuit for a sufficient time, specify the value of:
   a) the current;
   b) the voltage $u_{AM} = u_C$ across the capacitor;
   c) the electric energy W_{ele} stored in the capacitor.

B – The capacitor being totally charged, we turn the switch to position (2) at an instant $t_0 = 0$ taken as an origin of time.

I – The resistance of the rheostat is regulated at a value R = 0.

1) Derive the differential equation of the variation of $u_C = u_{AM}$ as a function of time.
2) The solution of the differential equation is of the form $u_C = E\cos(\frac{2\pi}{T_0}t)$.
   a) Determine, in terms of L and C, the expression of the proper period T_0 of the free electric oscillations that take place in the circuit.
   b) Calculate the value of T_0.
3) Express, as a function of time, the electric energy W_{ele} stored in the capacitor.
4) The electric energy W_{ele} is a periodic function of period T′. Write the relation between T′and T_0.
5) Calculate the electric energy stored in the capacitor at the instant $t_0 = 0$.
6) Trace the shape of the graph of W_{ele} as a function of time.

II – The rheostat is regulated at a small resistance R.
The variation of the electric energy W_{ele} as a function of time is represented in figure (2).
Referring to this figure:

1) give the name of the type of the electric oscillations;
2) determine the value of the pseudo-period T of the electric oscillations;
3) justify that at the instants: 0 ; 31.5 ms ; 63 ms ; t_2 = 94.5 ms ; 126 ms, the total energy stored in the circuit is electric;

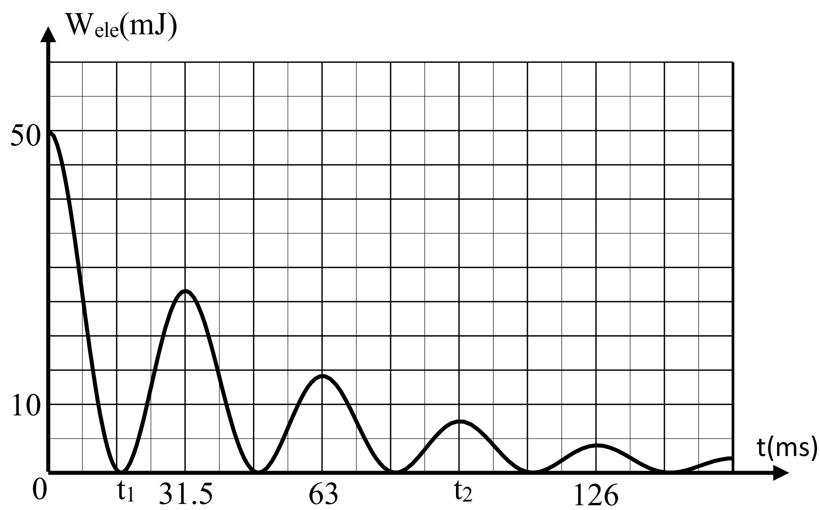


Fig.2

4) specify the form of the energy in the circuit at the instant t_1;
5) specify, between the instants $t_0 = 0$ and t = 31.5 ms, the time interval during which the:

– coil provides energy to the circuit;

– capacitor provides energy to the circuit;

6) calculate the energy dissipated in the rheostat between the instants $t_0 = 0$ and t_2.

III – What will happen if the resistance of the rheostat is very large?

<u>Fourth exercise</u>: (7.5 points) Spectrum of the hydrogen atom

Rydberg found in 1885 an empirical formula that gives the wavelengths of the lines of Balmer series; other series are discovered after that date.
An atom in an excited state n, passes to a lower energy state m, emits electromagnetic rays of wavelength λ , such that:

$$\frac{1}{\lambda} = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right),\ \lambda \text{ in meter and } R = 1.097\times10^{7}\text{m}^{-1}.$$

Given: Speed of light in vacuum $c = 2.998\times10^{8}$m/s;

Planck′s constant $h = 6.626\times10^{-34}$ J.s;
1 ev = 1.60×10^{-19}J.

1) Show that the energy E_n of the hydrogen atom, corresponding to an energy level n, can be expressed as $E_n = -\frac{hcR}{n^2}$.
2) Deduce that the energy E_n , expressed in eV, may be written in the form $E_n = -\frac{13.6}{n^2}$.
3) Calculate the value of the:
- **a)** maximum energy of the hydrogen atom;
- **b)** minimum energy of the hydrogen atom ;
- **c)** energy of the hydrogen atom in the first excited state E_2 ;
- **d)** energy of the atom in the second excited state E_3 .

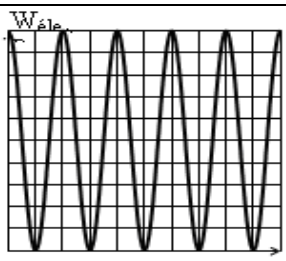
4) Deduce that the energy of the atom is quantized.
5) Give three characteristics of a photon.
6) **a)** Define the ionization energy W_i of the hydrogen atom, found in the ground state.
b) Calculate the value of W_i.
c) Calculate the value of the wavelength of the radiation capable of producing this ionization.
7) The Lyman series corresponds to the lines emitted by the excited hydrogen atom in a downward transition to the fundamental state.
- **a)** Determine the shortest and the longest wavelengths of this series.
- **b)** To what domain (visible, infrared, ultraviolet) does it belong?

8) **a)** Calculate the frequencies $\nu_{3\to1}$, $\nu_{2\to1}$, and $\nu_{3\to2}$ of the emitted photons corresponding respectively to the transitions $E_3 \to E_1$, $E_2 \to E_1$ and $E_3 \to E_2$ of the hydrogen atom.
b) Verify Ritz relation: $\nu_{3\to1} = \nu_{3\to2} + \nu_{2\to1}$.

First exercise : Oscillation and rotation of a mechanical system		**8**
Question	**Answer**	
A–1	$2ma = m\frac{L}{2} - m\frac{L}{4} = m\frac{L}{4} \Rightarrow a = \frac{L}{8}$.	½
A–2	$I_0 = m(\frac{L}{2})^2 + m(\frac{L}{4})^2 = \frac{5mL^2}{16}$.	½
A–3	$ME = KE + PE_g = ½ I_0\theta'^2 - 2mga\cos\theta$	¾
A–4	$\frac{dME}{dt} = 0 = I_0\theta'\theta'' + 2mga\theta'\sin\theta \Rightarrow I_0\theta'' + 2mga\,\theta = 0 \Rightarrow \theta'' + \frac{2mga}{I_0}\theta = 0.$	¾
A–5	The proper pulsation of the pendulum $\omega = \sqrt{\frac{2mga}{I_0}} \Rightarrow$ The period is $T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{I_0}{2mga}} = 2\pi\sqrt{\frac{5mL^2 \times 8}{16 \times 2mg \times L}} = 2\pi\sqrt{\frac{5L}{4g}} =$ $2\pi\sqrt{\frac{5 \times 2}{4 \times 9.8}} = 3.17s$.	1
A – 6	g(Moon) < g(Earth) $\Rightarrow$ T(Moon) > T(Earth).	½
B–1	The weight, the reaction of the axis and the couple of forces of friction.	¼
B – 2	The weight and the reaction of the axis meet the axis, their moment is zero, the resultant moment is: $\Sigma M = M_{couple} = -h\theta'$. $\Rightarrow \Sigma M = M = -h\theta'$.	½
B – 3	$I = 2\,m(\frac{L}{2})^2 = m\frac{L^2}{2} = \frac{0.1 \times 4}{2} = 0.2$ kgm^2.	½
B – 4	$\frac{d\sigma}{dt} = \Sigma M_{ext} = M = -h\theta'$, and $\sigma = I\theta' \Rightarrow \frac{d\sigma}{dt} = -\frac{h}{I}\sigma$ $\Rightarrow \frac{d\sigma}{dt} + \frac{h}{I}\sigma = 0$.	¾
B – 5	$\frac{d\sigma}{dt} = -\frac{h}{I}\sigma_0 e^{-\frac{h}{I}t} \Rightarrow -\frac{h}{I}\sigma_0 e^{-\frac{h}{I}t} + \frac{h}{I}\sigma_0 e^{-\frac{h}{I}t} = 0.$	½
B – 6 – a	Because at $t = 0$, $\sigma_0 = I \times \theta'_0 = 0.2 \times 2 = 0.4$ kgm^2/s. decreasing curve and as $t \rightarrow 5s$, $\sigma \rightarrow 0$.	½
B – 6 – b	$\frac{d\sigma}{dt} = -\frac{h}{I}\sigma_0 e^{-\frac{h}{I}t}$, at $t = 0$, $\frac{d\sigma}{dt} = -\frac{h}{I}\sigma_0 = -\frac{0.4}{1} \Rightarrow h = \frac{0.4 \times 0.2}{0.4} = 0.2$ S.I.	1

Second exercise : Charging and discharging of a capacitor		6 ½
Question	**Answer**	
A–1	$E = Ri + u_C = RC\frac{du_C}{dt} + u_C$	½
A–2	$\frac{du_C}{dt} = -\frac{B}{\tau}\ e^{-\frac{t}{\tau}} \Rightarrow E = RC(-\frac{B}{\tau}\ e^{-\frac{t}{\tau}}) + A + B\,e^{-\frac{t}{\tau}} \Rightarrow$ A= E and $RC(-\frac{B}{\tau})+B = 0$ $\Rightarrow \tau = RC$. for t = 0, $u_C = 0 = A + B \Rightarrow B = -A = -E$	1 ½
A–3–a	$u_C = E\,(1 - e^{-\frac{t}{RC}})$, for $t \to \infty$, $u_C \to E = 10$ V.	½
A–3–b	$W = ½\,C\,E^2 = ½\,(1)\,(100) = 50$ J.	½
B–1–a	$t_1 = 22$ s.	¼
B–1–b	$u_1 = 5$ V.	¼
B–2–a	because $u_C = u_1 = 5\ V \neq 0$.	¾
B–2–b	$W_1 = ½\,C(u_C)^2 = ½\,(1)\,(5)^2 = 12.5$ J.	½
B–3–a	$W_2 = W - W_1 = 50 - 12.5 = 37.5$ J.	½
B–3–b	Thermal and mechanical (kinetic)	¼
B–3–c	$r = \frac{mgh}{W_2} = \frac{1 \times 10 \times 1.5}{37.5} = 40$ %.	1

Third exercise : Electromagnetic Oscillations		8
Question	**Answer**	
A–1	Charging of the capacitor	¼

A–2–a–b–c	$i = 0$; $u_C = E = 10V$; $W_{ele} = ½CE^2 = ½(10^{-3})(100) = 0.05$ J.	¾
B–I–1	$u_C = u_{AM} = L\frac{di}{dt}$, $i = -C(u_C)' \Rightarrow \frac{di}{dt} = -C(u_C)'' \Rightarrow (u_C)'' + \frac{1}{LC}u_C = 0$	1
B–I–2–a	$(u_C)' = -\frac{2\pi}{T_0}E\sin\frac{2\pi}{T_0}t$, $(u_C)'' = -(\frac{2\pi}{T_0})^2 E\cos\frac{2\pi}{T_0}t$, replace in the differential equation we get : $-(\frac{2\pi}{T_0})^2 E\cos\frac{2\pi}{T_0}t + \frac{1}{LC}\mathrm{E}\cos\frac{2\pi}{\mathrm{T}_0} = 0 \Rightarrow (\frac{2\pi}{T_0})^2 = \frac{1}{LC} \Rightarrow T_0 = 2\pi\sqrt{LC}$	1
B–I–2–b	$T_0 = 2\pi\sqrt{10^{-4}} = 0.0628$ s = 62.8 ms.	¼
B–I–3	$W_{ele} = ½ C(u_C)^2 = ½ CE^2\cos^2(\frac{2\pi}{T_0}t) = 0.05\cos^2(100t)$.	½
B–I–4	$T' = T_0/2$.	¼
B–I–5	At $t_0 = 0$, $W_{ele} = 0.05$ J.	¼
B-I–6		½
B–II–1	free-damped electric oscillations.	¼
B –II–2	2T = 126 ms ; T = 63 ms.	½
B –II–3	At the instants :0 ; 31.5 ms ; 63 ms ; 94.5 ms ; 126 ms ; the electric energy is maximum $\Rightarrow$ u_C is max. $\Rightarrow i = C(u_C)' = 0 \Rightarrow$ magnetic energy $E_{mag} = ½ L(i)^2$ is zero $\Rightarrow$ E_{total} is electric.	3/4
B – II –4	Magnetic energy	¼
B –II –5	$0 < t < t_1$: W_{ele} decreases $\Rightarrow$ the capacitor gives energy to the circuit. $t_1 < t < 31.5$ ms : W_{ele} increases $\Rightarrow$ the coil gives energy to the circuit.	½
B –II –6	W(dissipated) = 50 – 7.5 = 42.5 mJ.	½
B – III	The electric energy is lost quickly in the resistor and the mode is not oscillatory	½

Fourth exercise : Spectrum of the hydrogen atom		**7 ½**
Question	**Answer**	
1	$E_n - E_m = \frac{hc}{\lambda} = hc \times R(\frac{1}{m^2} - \frac{1}{n^2}) \Rightarrow E_n = -\frac{hcR}{n^2}$	¾
2	$hcR = 6.626\times10^{-34} \times 2.998\times10^{8} \times 1.097\times10^{7}$ (in J) $= 21.79\times10^{-19}$ J = 13.6 eV $\Rightarrow$ $E_n = -\frac{13.6}{n^2}$ eV.	¾

3–a	as $n \to \infty$, $E_{max} \to 0$.	¼
3–b	as $n \to 1$; $E_{min} = - 13.6$ ev	¼
3–c	$E_2 = -\frac{13.6}{2^2} = -3.4\text{eV}$	¼
3–d	E_3 for n = 3 $\Rightarrow E_3 = -1.51$ eV.	¼
4	Only certain values of E_n (–13.6; –3.4; –1.51; –0.85 ……) are allowed	¼
5	The photon: no mass, no charge, speed in vacuum is c, of energy hν.	¾
6–a	The ionization energy is the energy needed for the atom to absorb for it to release its electron without speed.	½
6–b	$W_i + (-13.6) = 0$; $W_i = 13.6$ eV.	½
6–c	$\frac{1}{\lambda} = R(\frac{1}{m^2} - \frac{1}{n^2})$ for $n \to \infty$ and m = 1, $\frac{1}{\lambda} = R = 1.097 \times 10^7 \Rightarrow \lambda = 0.911 \times 10^{-7}$ m.	½
7–a	$\frac{1}{\lambda} = R(\frac{1}{m^2} - \frac{1}{n^2})$; for m =1 and n = 2, we obtain $\lambda_{max} = 0.121 \times 10^{-6}$m for m=1 and $n \to \infty$, we obtain $\lambda_{min} = 0.091 \times 10^{-6}$m.	½
7–b	ultra-violet.	¼
8–a	$\frac{1}{\lambda} = R(\frac{1}{m^2} - \frac{1}{n^2})$. for m=1 and n=3, $\frac{1}{\lambda} = R(\frac{1}{1^2} - \frac{1}{3^2}) = \frac{8}{9}R = 0.975 \times 10^7$ $\nu = \frac{c}{\lambda} \Rightarrow$ $\nu_{3\to1} = 2.92 \times 10^{15}$ Hz. for m=1 and n=2 on a $\frac{1}{\lambda} = R(\frac{1}{1^2} - \frac{1}{2^2}) = \frac{3}{4}R = 0.82275 \times 10^7 \Rightarrow \nu_{2\to1} = 2.47 \times 10^{15}$ Hz. for m =2 and n=3 on a $\frac{1}{\lambda} = R(\frac{1}{2^2} - \frac{1}{3^2}) = \frac{5}{36}R = 0.15236 \times 10^7 \Rightarrow$ $\nu_{3\to2} = 0.46 \times 10^{15}$ Hz.	1 ¼
8–b	$\nu_{3\to1} = \nu_{3\to2} + \nu_{2\to1}$ is verified	½

الدورة الإستثنائية للعام 2012	امتحانات الشهادة الثانوية العامة الفرع : علوم عامة	وزارة التربية والتعليم العالي المديرية العامة للتربية دائرة الامتحانات
الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	

This exam is formed of four exercises in four pages numbered from 1 to 4.
The use of a non-programmable calculator is recommended.

First exercise: (7 ½ points)

Mechanical oscillator

A metallic rigid rod MN, of mass m = 0.25 kg, can slide without friction, on two parallel and horizontal metallic rails PP' and QQ'. During sliding, the rod remains perpendicular to the rails. These two rails, separated by a distance ℓ , are connected by a resistor of resistance R (Fig.1).
Neglect the resistance of the rod and of the rails.

A – Electromagnetic induction

The whole setup is placed in an upward, uniform and vertical magnetic field $\vec{B}$ of value B. The position of G, the center of inertia of the rod, is defined by its abscissa x on the horizontal axis (O, $\vec{i}$) with O corresponding to the position of G at $t_0 = 0$. Let O'O = d.

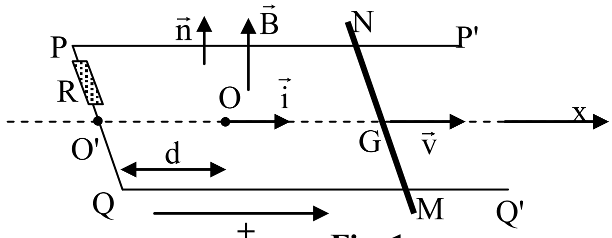


Fig. 1

At an instant t, G has an abscissa $\overline{OG}$ = x and a velocity $\vec{v}$ of algebraic value v (Fig. 1).

1) Show that, taking into consideration the arbitrary positive direction chosen in figure 1, the expression of the magnetic flux crossing the surface limited by the circuit MNPQ is given by: $\varphi = B(d+x)\ell$.
2) a) Derive the expression of the induced e.m.f. "e" across the terminals of the rod MN in terms of B, ℓ and v.
   b) i) Derive the expression of the induced current i in the circuit in terms of R, ℓ, B and v.
      ii) Deduce the direction of the induced current.
3) Show that the expression of the electromagnetic force $\vec{F}$ acting on the rod can be written as:
$$\vec{F} = \frac{-B^2\ell^2}{R}\vec{v}.$$

B – Free un-damped oscillations

We remove the magnetic field $\vec{B}$.
The center of inertia G of the rod is attached to a horizontal massless spring, of un-stretched length L_0 = O'O = d and stiffness k = 50 N/m. Thus at equilibrium the abscissa of G is x = 0.
The rod, is displaced by a distance X_m = 10 cm in the positive direction, and is then released without initial velocity at the instant $t_0 = 0$; the rod thus oscillates around its equilibrium position. At an instant t, G has an abscissa x and a velocity $\vec{v}$ of algebraic value v (Fig. 2).

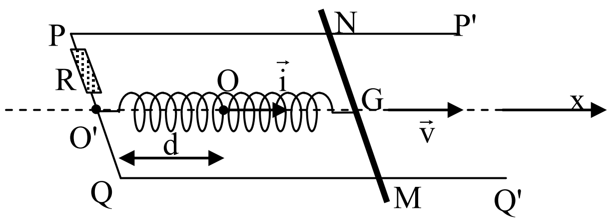


Fig. 2

1) Write, in terms of m, v, k and x, the expression of the mechanical energy of the system (rod, spring, Earth). Take the horizontal plane through G as a gravitational potential energy reference.
2) Derive the differential equation of the second order in x, which describes the motion of G.
3) The solution of this differential equation is of the form: x = A cos (ωt + ϕ). Determine the values of the constants ω, A and ϕ (A > 0).

C – Free damped oscillations

The setup of figure 2 is placed now in the magnetic field $\vec{B}$. The rod is displaced again by $X_m = 10$ cm in the positive direction, and is then released without initial velocity at the instant $t_0 = 0$; the rod thus oscillates around its equilibrium position. At an instant t, G has an abscissa x and a velocity $\vec{v}$ of algebraic value v (Fig. 3).

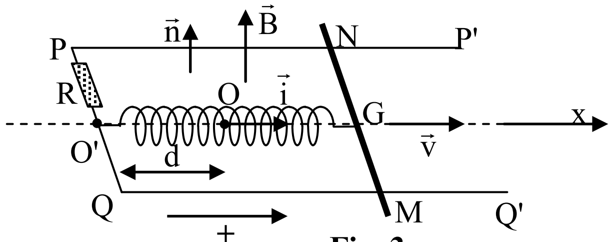


Fig. 3

1) Calculate, at the instant $t_0 = 0$, the mechanical energy of the system (rod, spring, Earth). Take the horizontal plane through G as a gravitational potential energy reference.
2) During its motion, the oscillator loses mechanical energy.
   a) Show that the power of the electromagnetic force $\vec{F}$, exerted on the rod, is given by: $P = \frac{-B^2\ell^2v^2}{R}$.
   b) Determine the expression of the power lost due to Joule's effect in the resistor in terms of B , ℓ, v and R.
   c) Deduce in what form the energy of the oscillator is dissipated.
3) After a few oscillations, the rod stops. Give , in J, the value of the total energy dissipated by the oscillator during its motion.

Second exercise: (7 ½ points)

Determination of the characteristics of a coil

In order to determine the inductance L and the resistance r of a coil, we connect the coil in series with a capacitor of capacitance C = 160 μF across the terminals of a low frequency generator (LFG) delivering an alternating sinusoidal voltage: $u_g = u_{AD} = 20\sin(100\pi t)$; (u_g in V , t in s).
The circuit thus carries an alternating sinusoidal current i.
An oscilloscope is connected so as to display the voltage $u_g = u_{AD}$ on the channel Y_A and the voltage $u_C = u_{BD}$ on the channel Y_B (Fig. 1).
On the screen of the oscilloscope we observe a display of the waveforms represented in figure 2. Take $\pi = \frac{1}{0.32}$.

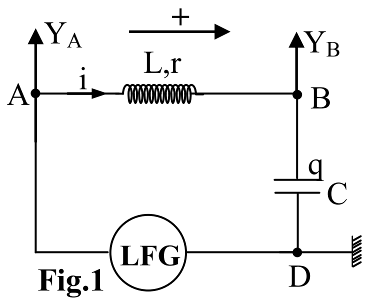


Fig.1

1) Knowing that the vertical sensitivity S_V is the same on both channels, calculate its value.
2) Calculate the phase difference between u_g and u_C. Which of them lags behind the other?
3) Deduce the expression of the voltage u_C across the terminals of the capacitor as a function of time.
4) Using the relation between the current i and the voltage u_C, determine the expression of i as a function of time.
5) Applying the law of addition of voltages, and by giving the time t two particular values, determine r and L.
6) In order to verify the preceding calculated values of L and r, we proceed as follows:
   - ❖ we measure the average power consumed in the circuit for ω =100π rad/s and we obtain 8.66 W.
   - ❖ we keep the maximum value of u_g constant but we vary its frequency f; for f = 71 Hz the effective value of the current in the circuit is maximum .

   Determine the values of r and L.

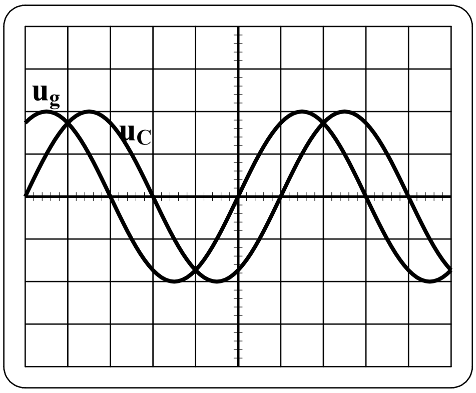


Fig. 2

Third exercise: (7 ½ points)

Diffraction and interference of light

A laser source emits a monochromatic cylindrical beam of light of wavelength λ = 640 nm in air.

A – Diffraction

This beam falls normally on a vertical screen (P) having a horizontal slit F_1 of width a. The phenomenon of diffraction is observed on a screen (E) parallel to (P) and situated at a distance D = 4 m from (P).

Consider on (E) a point M so that M coincides with the second dark fringe counted from O, the center of the central bright fringe. OIM = θ (θ is very small) is the angle of diffraction corresponding to the second dark fringe (Fig. 1).

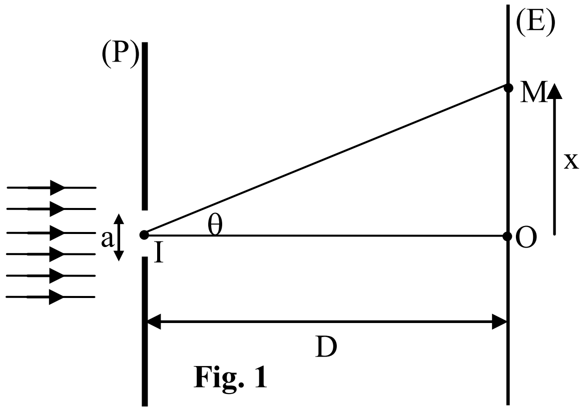


Fig. 1

1) Write the expression of θ in terms of a and λ.
2) Determine the expression of OM = x in terms of a, D and λ.
3) Determine the value of a if OM = 1.28 cm.
4) We replace the slit F_1 by another slit F_1' of width 100 times larger than that of F_1. What do we observe on the screen (E)?

B – Interference

We cut in (P) another slit F_2 identical and parallel to F_1 so that the distance F_1F_2 = a' = 1 mm. The laser beam falls normally on the two slits F_1 and F_2. We observe on (E) a system of interference fringes. O' is the orthogonal projection of the midpoint I' of F_1F_2 on (E) (Fig. 2).

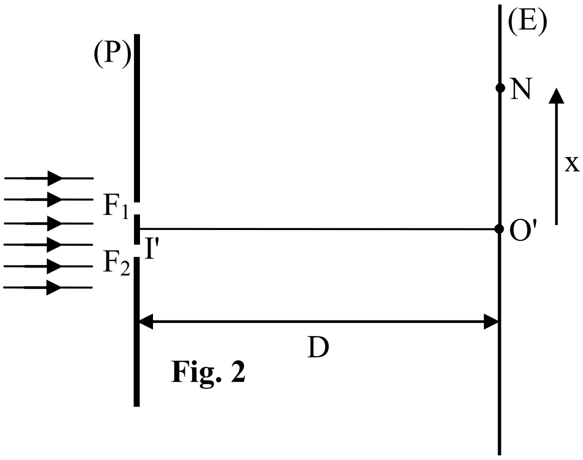


Fig. 2

1) **a)** Due to what is the phenomenon of interference?
   b) Describe the fringes observed on (E).
2) Consider a point N on (E) so that O'N = x.
   a) Write the expression of the optical path difference $\delta = F_2N - F_1N$ in terms of a', x and D.
   b) If N is the center of a dark fringe of order k, write the expression of the optical path difference δ at N in terms of λ and k.
   c) Deduce the expression of x in terms of a', D, k and λ.
   d) Knowing that the interfringe distance i is the distance between the centers of two consecutive dark fringes, deduce then the expression of i in terms of λ, D and a'.
3) The whole set up of figure 2 is immersed in water of index of refraction n.
   a) **i)** The interfringe distance i varies and becomes i'. Why?
   ii) Show that $i' = \frac{i}{n}$.
   b) We move (E) parallel to (P) and away from it by a distance $d = \frac{4}{3}$ m. We notice that the interfringe distance takes again the initial value i.
   Deduce then the value of n.

Fourth exercise: (7 ½ points)

Nuclear reactor

Given:

- Atomic mass unit 1u = 931.5 MeV/c^2 = 1.66×10^{-27} kg;
- 1 MeV = 1.6×10^{-13} J;
- Mass of particles (in u): antineutrino ${}^{0}_{0}\bar{\nu} \approx 0$; electron ${}^{0}_{-1}e$: 5.5×10^{-4} ; neutron ${}^{1}_{0}n$: 1.0087.

Element	Molybdenum		Technetium		Tellurium
Nuclide	${}^{101}_{42}Mo$	${}^{102}_{42}Mo$	${}^{101}_{43}Tc$	${}^{102}_{43}Tc$	${}^{135}_{52}Te$
Mass (in u)	100.9073	101.9103	100.9073	101.9092	134.9167

Element	Uranium		Neptunium	Plutonium
Nuclide	${}^{235}_{92}U$	${}^{238}_{92}U$	${}^{239}_{93}Np$	${}^{239}_{94}Pu$
Mass (in u)	235.0439	238.0508	239.0533	239.0530

Read carefully the following text about fast neutrons, and answer the questions that follow.

" …the basic substance used to obtain nuclear energy is the natural uranium which is mainly formed of the two isotopes: uranium 235 and uranium 238…

… The fast-neutron nuclear reactors (breeder reactors), use uranium 235 or plutonium 239 (or the two at the same time) as fuel. In each reactor we put around the core which is constituted of uranium 235 (${}^{235}_{92}U$), a cover made essentially of fertile uranium 238 (${}^{238}_{92}U$). This cover can trap fast neutrons issued from the fission reactions of uranium 235.

These reactors transform more uranium 238 atoms into plutonium 239.

Finally, in the very well studied fast neutrons reactors, the quantity of fissionable matter that is created, exceeds notably the consumed quantity. For this reason, these reactors are called breeder reactors…"

Questions

1) **a)** What is meant by isotopes of an element?

b) Give the composition of each of uranium 235 and uranium 238 nuclei.

2) In the reactor, the uranium 238 reacts with the fast neutrons according to the reaction:

$${}^{238}_{92}U + {}^{1}_{0}n \rightarrow X \quad \text{(reaction 1)}$$

The obtained nucleus X is radioactive and after two successive β^- emissions , it is transformed into plutonium:

$$X \rightarrow {}^{0}_{-1}e + Y + {}^{0}_{0}\bar{\nu} \quad \text{(reaction 2)}$$

$$Y \rightarrow {}^{0}_{-1}e + {}_{94}Pu + {}^{0}_{0}\bar{\nu} \quad \text{(reaction 3)}$$

a) Identify X and Y.

b) Deduce the nuclear reaction that occurs between a ${}^{238}_{92}U$ nucleus and a fast neutron that leads to the formation of a plutonium 239 (reaction 4).

3) The plutonium 239 (${}^{239}_{94}Pu$) is fissile and can react with neutrons according to the reaction :

$${}^{239}_{94}Pu + {}^{1}_{0}n \rightarrow B + {}^{135}_{52}Te + 3\,{}^{1}_{0}n \quad \text{(reaction 5)}$$

a) Identify B.

b) Calculate, in MeV/c^2, the mass defect Δm in reaction 5.

c) Deduce, in Mev, the energy E liberated during the fission of a plutonium nucleus.

d) Find, in joules, the energy liberated by the fission of one kilogram of plutonium.

4) From reactions 4 and 5, justify the definition of a breeder reactor given in the text.

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First exercise: Mechanical oscillator		**7 ½**
Part of the Q	**Answer**	**Mark**
A.1	The flux $\varphi = S\vec{B}.\vec{n} = BS\cos(\theta) = B(d+x)\ell$. $[\theta = 0]$	½
A.2.a	The induced emf "e" : $e = -\frac{d\varphi}{dt} = -B\ell v$;	½
A.2.b.i	The value i of the induced electric current: $i = \frac{e}{R} = -\frac{B\ell v}{R}$	½
A.2.b.ii	$i < 0$, then the direction of i is opposite to the chosen positive direction, it is directed from N to M in the rod.	¼
A.3	The direction of Laplace's force is opposite to that of the motion (From Lenz's law: since the electromagnetic effect of the induced current opposes the causes of it). $F = i\ell B, = (\frac{-B\ell v}{R}).B\ell = \frac{-B^2\ell^2 v}{R} \Rightarrow \vec{F} = \frac{-B^2\ell^2}{R}\vec{v}$.	1
B.1	$ME = ½ mv^2 + ½ kx^2$.	½
B.2	No friction, conservation of mechanical energy, ME = constant. Derive ME with respect to time: $\frac{dME}{dt} = 0$; $mvv' + kxx' = 0 \Rightarrow mx'' + kx = 0$ ($v = x'$ and $v' = x''$) $\Rightarrow x'' + \frac{k}{m}x = 0$.	¾
B.3	$x' = -\omega A\sin(\omega t + \varphi)$ and $x'' = -\omega_0^2 A\cos(\omega t + \varphi)$. By replacing in the differential equation: $\Rightarrow \omega^2 = \frac{k}{m} \Rightarrow \omega = \sqrt{\frac{k}{m}} = 14.1$ rd/s For $t_0 = 0$, $x' = 0 = \omega A\sin(\varphi) = 0 \Rightarrow \varphi = 0$ or π. Also: for $t_0 = 0$, $x = X_m = A\cos(\varphi) > 0$ and $A > 0$, then $\varphi = 0$ and $A = 10$ cm.	1 ½
C.1	The initial mechanical energy is: $ME_o = ½ k x_m^2 = ½ \times 50 \times 0.01 = 0.25$ J.	½
C.2.a	The power of the force $\vec{F}$ is : $\vec{F}\cdot\vec{v} = P = \frac{-B^2\ell^2 v^2}{R}$.	¼
C.2.b	The power lost by Joule's effect is: $Ri^2 = R\times(\left(\frac{B\ell v}{R}\right)^2 = \frac{B^2\ell^2 v^2}{R}$	½
C.2.c	Since $\lvert P_{electromagnetic}\rvert = \lvert P_{thermal}\rvert$ therefore the mechanical energy is totally transformed into thermal energy in the resistor.	½
C.3	The total dissipated energy: $= ME_o = 0.25$ J.	¼

Second exercise: Determination of the characteristics of a coil		7 ½
Part of the Q	**Answer**	**Mark**
1	The maximum voltage across the terminals of the generator corresponds to 2 div $\Rightarrow$ $S_V = \frac{20}{2} = 10V/div$	½
2	The phase difference extends over 1 div and the period over 6 div $\varphi = \lvert\varphi\rvert = \frac{1\times 2\pi}{6} = \frac{\pi}{3}$ rad ; u_C lags u_g	1
3	$U_C)_{max} = 20V$, $\omega = 100\pi$ and u_C lags u_g $\Rightarrow u_C = 20\sin(100\pi t - \frac{\pi}{3})$	1
4	$i = C\frac{du_c}{dt}$; $\frac{du_C}{dt} = 2\times 10^3\pi\cos(100\pi t - \frac{\pi}{3})$ $\Rightarrow i = 160\times 10^{-6}\times 2\times 10^3\pi\times\cos(100\pi t - \frac{\pi}{3}) = \cos(100\pi t - \frac{\pi}{3})$	1 ½
5	$u_{AD} = u_{AB} + u_{BD}$. $20\sin(100\pi t) = ri + L\frac{di}{dt} + u_C$ $20\sin(100\pi t) = r\cos(100\pi t - \frac{\pi}{3}) - 100\pi L\sin(100\pi t - \frac{\pi}{3}) + 20\sin(100\pi t - \frac{\pi}{3})$ * For $100\pi t = \frac{\pi}{3}$ we obtaim : $20\frac{\sqrt{3}}{2} = r \Rightarrow r = 10\sqrt{3}\,\Omega$ * For t = 0 we obtain : $L = \frac{1}{10\pi} = 0.032H$	2
6	The electric power is consumed only in the resistor of the coil : $P = r(I_{eff})^2 = 8.66 = \left(\frac{1}{\sqrt{2}}\right)^2 r \Rightarrow r = 17.3\Omega$ The observed phenomenon is the current resonance. In this case we have : $f = \frac{1}{2\pi\sqrt{Lc}} = 71 \Rightarrow L = 0.03$ H.	1 ½

Third exercise: Diffraction and interference of light		7 ½
Part of the Q	**Answer**	**Mark**
A.1	M is a dark fringe if $\sin\theta = n\dfrac{\lambda}{a} = \theta$, the second fringe: n =2 then $\theta = 2\dfrac{\lambda}{a}$	**1**
A.2	$\tan\theta = \theta = \dfrac{OM}{D} = \dfrac{x}{D}$ then **x** $= OM = D\times\theta = \dfrac{2D\lambda}{a}$	¾
A.3	$a = \dfrac{2\lambda D}{x} = 0.4mm$	¾
A.4	We observe a spot of light.	½
B.1.a	It is due to the superposition of 2 luminous radiations.	½
B.1.b	bright and dark fringes. parallel , rectilinear and equidistant	½
B.2.a	$\delta = \dfrac{a'x}{D}$	¼
B.2.b	$\delta = (2k+1)\dfrac{\lambda}{2}$	¼
B.2.c	$x = (2k+1)\ \dfrac{\lambda D}{2a'}$	½
B.2.d	$i = x_{k+1} - x_k = \dfrac{\lambda D}{a'}$	½
B.3.a.i	$i = \dfrac{\lambda D}{a}$ and λ varies because the speed of light varies, ⇒ i varies.	½
B.3.a.ii	$\lambda' = \dfrac{v}{\nu}$ and $v = \dfrac{c}{n} \Rightarrow \lambda' = \dfrac{\lambda}{n}$; $i' = \dfrac{\lambda' D}{a'} = \dfrac{\lambda D}{na'} = \dfrac{i}{n}$	¾
B.3.b	$D' = D + d$; $i = \dfrac{\lambda(D+d)}{na'} = \dfrac{\lambda D}{a'} \Rightarrow \dfrac{(D+d)}{n} = D \Rightarrow n = \dfrac{D+d}{D} = 1.33$	¾

Fourth exercise: Nuclear reactor		7 ½
Part of the Q	**Answer**	**Mark**
1.a	We call isotopes the nuclei that have the same atomic number Z and of different mass numbers A.	½
1.b	Uranium nuclei have 92 protons and 143 neutrons for ${}^{235}_{92}U$, 146 neutrons for ${}^{238}_{92}U$.	½
2.a	${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{92}X$ (reaction 1); ${}^{239}_{92}X$ is an isotope of uranium. ${}^{239}_{92}U \rightarrow {}^{0}_{-1}e + {}^{239}_{93}Y + {}^{0}_{0}\bar{\nu}$ (reaction 2); ${}^{239}_{93}Y$ is a nucleus of neptunium ${}^{239}_{93}Np$. ${}^{239}_{93}Np \rightarrow {}^{0}_{-1}e + {}^{239}_{94}Pu + {}^{0}_{0}\bar{\nu}$ (reaction 3)	1 ½
2.b	The addition of (1) + (2) + (3) gives the nuclear reaction leading to the formation of plutonium : ${}^{238}_{92}U + {}^{1}_{0}n \rightarrow {}^{239}_{94}Pu + 2\,{}^{0}_{-1}e + 2\,{}^{0}_{0}\bar{\nu}$. (reaction 4)	1
3.a	${}^{239}_{94}Pu + {}^{1}_{0}n \rightarrow {}^{102}_{42}B + {}^{135}_{52}Te + 3\,{}^{1}_{0}n$ (reaction 5) ${}^{102}_{42}B$ is a nucleus of molybdenum ${}^{102}_{42}Mo$	½
3.b	$\Delta m = 239.053 + 1.0087 - (101.9103 + 134.9167 + 3\times1.0087)$ $= 0.2086\ u = 0.2086 \times 931.5\ MeV/c^2 = 194.3\ MeV/c^2$.	1
3.c	$E = \Delta m \times c^2 = 194.3$ MeV	½
3.d	The number of plutonium nuclei in 1 kg is: $N = \dfrac{1}{1.66\times10^{-27}\times239.053} = 2.52\times10^{24}$ nuclei $E' = 2.52\times10^{24}\times194.3\times1.6\times10^{-13} = 7.83\times10^{13}$ J.	1 ½
4	Under the action of an incident neutron, a plutonium nucleus reacts according to the equation (5) and liberates three neutrons during its fission. For these three neutrons: ❖ one is used to sustain the fission reaction of plutonium; ❖ the two others are available to react with the uranium 238 to create two new plutonium atoms. For one fissile plutonium nucleus consumed, two fissile plutonium nuclei are created. This justifies the appelation of breeder reactor giving to such reactor.	½

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This exam is formed of four exercises in four pages numbered from 1 to 4
The use of non-programmable calculator is recommended

First exercise: (7 ½ points)

Verification of Newton's Second Law

Consider an inclined plane that makes an angle $\alpha = 30^o$ with the horizontal plane.
An object (S), supposed as a particle, of mass $m = 0.5$ kg is launched from the bottom O of the inclined plane, at the instant $t_0 = 0$, with a velocity $\vec{V}_0 = V_0\,\vec{i}$ along the line of the greatest slope (OB).
Let A be a point of OB such that OA = 5 m (fig.1).
The position of (S), at the instant t, is given by $\overrightarrow{OM} = x\vec{i}$ where x = f(t).

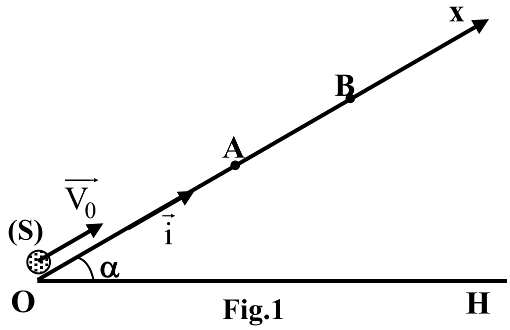

Fig.1

The variation of the mechanical energy of the system [(S), Earth], as a function of x, is represented by the graph of figure 2.
Take:

- The horizontal plane passing through OH as a gravitational potential energy reference;
- $g = 10\ ms^{-2}$.

Fig.2

1) Using the graph of figure 2:
   a) show that (S) is submitted to a force of friction between the points of abscissas $x_0 = 0$ and $x_A = 5$ m;
   b) i) calculate the variation of the mechanical energy of the system [(S), Earth] between the instants of the passage of (S) through the points O and A;
   ii) deduce the magnitude of the force of friction, supposed constant, between O and A;
   c) determine, for $0 \le x \le 5$ m, the expression of the mechanical energy of the system [(S),Earth] as function of x;
   d) Determine the speed of (S) at the point of abscissa x = 6 m.
2) Let v be the speed of (S) when it passes through the point M of abscissa x so that $0 \le x \le 5$ m.
   a) Determine the relation between v and x.
   b) Deduce that the algebraic value of the acceleration of (S) is $a = -9\ ms^{-2}$.
3) a) Determine the values of the speed of (S) at O and at A.
   b) Calculate the duration $\Delta t = t_A - t_0 = t$ of the displacement of (S) from O to A, knowing that the algebraic value of the velocity of (S) is given by: $v = at + v_0$.
   c) Determine the linear momentums $\vec{P}_O$ and $\vec{P}_A$ of (S), at O and at A respectively.
4) Determine the resultant of the external forces $\sum \overrightarrow{F_{ext}}$ acting on (S).
5) Verify, using the previous results, Newton's second law knowing that $\frac{\Delta \vec{P}}{\Delta t} = \frac{d\vec{P}}{dt}$.

<u>Second exercise</u>: (7 ½ points)

Torsion Pendulum

The aim of this exercise is to study the motion of a torsion pendulum in three different situations.

Consider a torsion pendulum that is constituted of a homogenous disk (D), of negligible thickness, suspended from its center of gravity O by a vertical torsion wire connected at its upper extremity to a fixed point O' (fig. 1).

Given :

- torsion constant of the wire : C = 0.16 m.N/rad ;
- moment of inertia of the disk with respect to the axis OO': $I = 25 \times 10^{-4}$ kg·m^2.

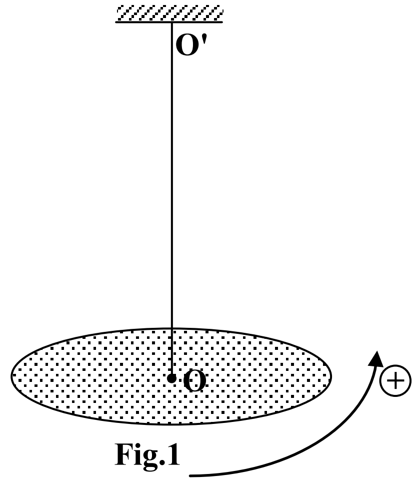

Fig.1

A – Free un-damped oscillations

The disk is in its equilibrium position. It is rotated around OO', in a direction considered positive, by an angle $\theta_m = 0.1$ rad (fig.1). The disk is then released without initial velocity at the instant $t_0 = 0$.

Take the horizontal plane passing through O as a gravitational potential energy reference.

At the instant t, the angular abscissa of the disk is θ and its angular velocity is $\theta' = \frac{d\theta}{dt}$.

1) Write the expression of the mechanical energy M.E of the system (pendulum, Earth) in terms of I, θ, C and θ'.

2) Suppose that the forces of friction are negligible.

a) Derive the differential equation, in θ, that describes the motion of the disk.

b) The time equation of the motion of the disk has the form: $\theta = \theta_m \sin(\omega_0 t + \phi)$. Determine ω_0 and ϕ.

c) Determine the angular velocity of the disk when it passes through its equilibrium position for the first time.

B – Free damped oscillations

In reality, the disk is subjected to a force of friction whose moment with respect to OO': $\mathcal{M} = -h\theta'$ where h is a positive constant.

1) Applying the theorem of angular momentum on the disk, show that the differential equation , in θ, describing its motion is written as: $\theta'' + \frac{h}{I}\theta' + \frac{C}{I}\theta = 0$.

2) Determine, in terms of h and θ', the expression $\frac{dM.E}{dt}$ (the derivative, with respect to time, of the mechanical energy M.E of the system [pendulum, Earth]). Deduce the sense of the variation of M.E.

C – Forced oscillations

The pendulum is at rest and at its equilibrium position. An exciter (E), coupled to the disk, provides it with periodic excitations of adjustable pulsation ω_e .

When we vary ω_e of (E), the amplitude θ_m of motion of the disk takes a maximum value of 0.25 rad for $\omega_e = \omega_r$.

1) Name the physical phenomenon that takes place.

2) Indicate the approximate value of ω_r.

3) Sketch the shape of the curve that represents the variation of the amplitude θ_m as a function of ω_e .

Third exercise: (7 ½ points)

Determination of the characteristics of an unknown component

An electric component (D), of unknown nature, may be a resistor of resistance R', or a coil of inductance L and of resistance r or a capacitor of capacitance C.
To determine its nature and its characteristics, we connect it in series with a resistor of resistance $R = 10\ \Omega$ across a generator G as shown in figure 1.
An oscilloscope is connected so as to display the voltage $u_g = u_{AM}$ across the generator and the voltage $u_R = u_{BM}$ across the resistor.

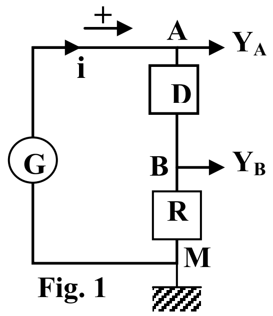

Fig. 1

A – Case of a DC voltage

The generator G delivers a constant voltage U_0. On the screen of the oscilloscope we observe the oscillograms of figure 2.

1) Prove that the voltage $U_0 = 12$ V.

2) **a)** Determine, in the steady state, the value I of the current in the circuit.
b) Deduce that (D) is not a capacitor.
c) Determine the resistance of the component (D).

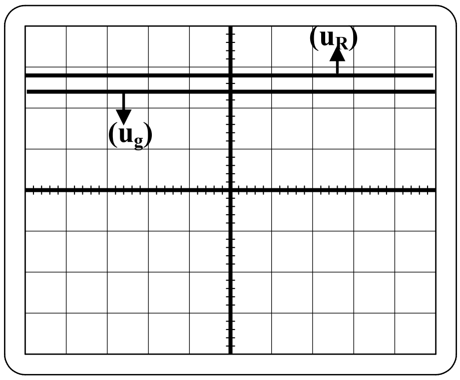

Fig.2 **Channel A: S_V = 5 V/div**
Channel B: S_V = 2 V/div

B – Case of an AC voltage

The generator G delivers now an alternating sinusoidal voltage. On the screen of the oscilloscope we observe the waveforms of figure 3.

1) Referring to the waveforms of figure 3, show that:
a) (D) is a coil;
b) the waveform (2) represents the variation of the voltage u_R across the resistor.

2) The voltage across the generator is given by: $u_g = U_m \sin(\omega t)$. Determine U_m and ω.

3) Determine the expression of i as a function of time.

4) Applying the law of addition of voltages and giving t two particular values, determine the inductance L and the resistance r of (D).

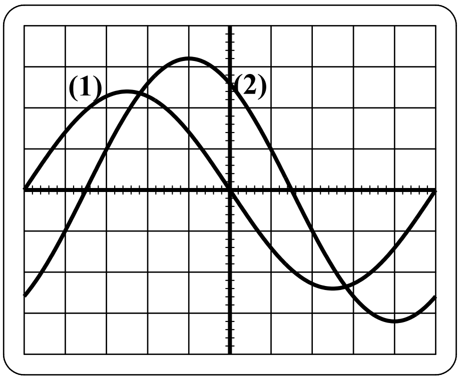

Fig.3 **Channel A: S_V = 5 V/div**
Channel B: S_V = 1 V/div
Time base: S_h = 2 ms/div

5) To verify the values of L and r of (D), we add a capacitor of adjustable capacitance C in series to the previous circuit.
For $C = 10^{-4}$ F, we obtain the waveforms of figure 4.
a) Name the observed phenomenon.
b) Verify, using the waveforms of figure 4, the values of L and r.

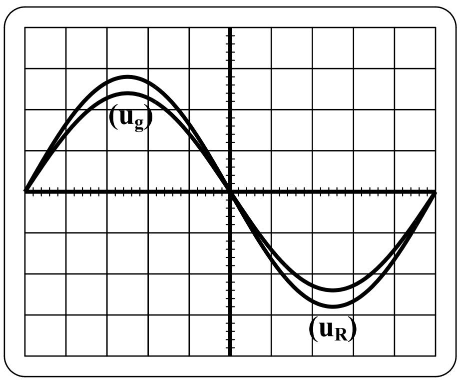

Fig.4 **Channel A: S_V = 5 V/div**
Channel B: S_V = 2 V/div
Time base: S_h = 2 ms/div

Fourth exercise: (7 ½ points)

Nuclear Fission

The nuclear chain fission reaction, conveniently controlled in a nuclear power plant, can be a source of a huge amount of energy able to generate electric power.

Given:

Masses of nuclei: ${}^{235}_{92}U = 234.9934$ u; ${}^{138}_{x}Ba = 137.8742$ u; ${}^{y}_{36}Kr = 94.8871$ u;

molar mass of ${}^{235}U = 235$ g mol^{-1}; Avogadro's number $N_A = 6.02\times10^{23}$ mol^{-1};

$m({}^{1}_{0}n) = 1.0087$ u; 1 u = 931.5 MeV/c^2; 1 eV = 1.6×10^{-19} J.

A – Efficiency of a nuclear power plant

In the reactor of a nuclear power plant, we use natural uranium enriched with uranium 235. The nucleus of a uranium 235 captures a thermal neutron and is transformed into a nucleus of uranium 236 in an excited state. The decay of this nucleus is accompanied by the emission of a photon γ of energy equal to 20 MeV.

1) **a)** Complete the following reaction: ${}^{236}_{92}U^{*} \rightarrow \; ..... \; + \; \gamma$

b) Indicate the value of the excess of energy possessed by a uranium 236 nucleus in the excited state.

2) The obtained uranium nucleus, breaks instantaneously, producing two nuclides called fission fragments with the emission of some neutrons and γ photon, so the overall equation is:

$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{138}_{x}Ba + {}^{y}_{36}Kr + 3\,{}^{1}_{0}n + \gamma$$

Determine:

a) x and y;

b) in MeV, the energy liberated by the fission of a uranium 235 nucleus;

c) the energy liberated by the fission of 1 g of uranium 235;

d) the efficiency of the nuclear power plant, knowing that it provides an electric power of 800 MW and consumes 2.8 kg of uranium 235 per day.

B – Chain Reaction

The kinetic energy of a neutron that may produce the fission of uranium 235 nucleus should be of the order of 0.04 eV.

We suppose that all the neutrons emitted by the fission reactions have the same kinetic energy.

1) The sum of the kinetic energies of the two fragments (Kr and Ba) is equal to 174 MeV and the energy of the emitted γ photon is $E_\gamma = 20$ MeV.

a) Show, using the conservation of the total energy, that the kinetic energy of a neutron emitted by this fission is 2 MeV.

b) Deduce that the emitted neutrons cannot produce fission reactions of uranium 235.

2) To produce a fission by an emitted neutron, it is necessary to slow it down by collisions with carbon 12 atoms in graphite rods. We suppose that each collision between a neutron and one carbon 12 atom is perfectly elastic and that the velocities before and after collision are collinear.

Take: $m({}^{1}_{0}n) = 1$ u and $m({}^{12}C) = 12$ u.

a) Let $\overrightarrow{V_0}$ be the velocity of one emitted neutron just before collision and $\overrightarrow{V_1}$ its velocity just after its first collision with a carbon 12 atom supposed initially at rest. Show that: $\left|\frac{V_1}{V_0}\right| = k = \frac{11}{13}$.

b) **i)** Show that the ratio of the kinetic energies just after and just before the first collision of the emitted neutron is: $\frac{K.E_1}{K.E_0} = k^2$.

ii) Determine the number of collisions needed for an emitted neutron with carbon 12 atoms, to slow down so that its kinetic energy is reduced to 0.04 eV.

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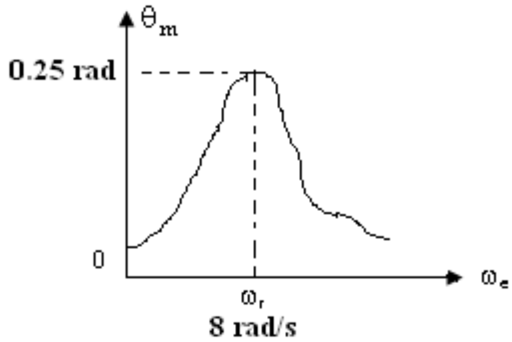
First exercise: (7 ½ points)

Part of the Q	Answer	Mark
1.a	Since the mechanical energy decreases along this part	0.25
1.b.i	$\Delta ME = ME_f - ME_i = 15 - 25 = -10$ J.	0.50
1.b.ii	$\Delta ME = W(\vec{f}) = -f\,x \Rightarrow f = \frac{10}{5} = 2$ N.	0.75
1.c	ME = ax + b; For x = 0 $\Rightarrow$ M.E = 25 J $\Rightarrow$ b = 25 And $a = \frac{\Delta ME}{\Delta x} = \frac{-10}{5} = -2$ J/m $\Rightarrow$ M.E = – 2x + 25.(ME in J; x in m)	0.75
1.d	$ME = mgh + \frac{1}{2}mV^2 = mgx\sin\alpha + \frac{1}{2}mV^2 = 0.5\times10\times6\times0.5 + \frac{1}{2}mV^2$ then $15 = 15 + \frac{1}{2}mV^2 \Rightarrow V = 0$.	0.75
2.a	$ME = \frac{1}{2}mV^2 + mgx\sin\alpha = -2x + 25 \Rightarrow 0.25\,V^2 + 4.5x - 25 = 0$.	0.5
2.b	Derive with respect to time : $\Rightarrow 0.5Va + 4.5V = 0 \Rightarrow a = -9\ ms^{-2}$.	0.50
3.a	Speed at O: $(PE_g)_O = 0$; $M.E = 25 = \frac{1}{2}mV_0^2 \Rightarrow V_0 = 10\ ms^{-1}$. Speed at A: $ME = \frac{1}{2}mV_A^2 + mgx_A\sin\alpha = 15$ $\Rightarrow V_A = \sqrt{10} = 3.16\ ms^{-1}$.	1.00
3.b	$\vec{P}_0 = m\vec{V}_0 \Rightarrow P_0 = 0.5\times10 = 5$ kg·ms^{-1}. $\vec{P}_A = m\vec{V}_A \Rightarrow P_A = 0.5\times3.16 = 1.58$ kg·ms^{-1}	0.50
3.c	$v = at + v_0 \Rightarrow t = \frac{3.16 - 10}{-9} = 0.76$ s.	0.50
4	$\sum\vec{F}_{ext.} = \vec{N} + m\vec{g} + \vec{f}$ project along the direction of its motion Then $\sum\vec{F}_{ext} = (-mg\sin\alpha - f)\,\vec{i} = -4.5\,\vec{i}$.	0.75
5	$\frac{\Delta\vec{P}}{\Delta t} = \frac{1.58 - 5}{0.76} = -4.5\,\vec{i}$. thus $\frac{\Delta\vec{P}}{\Delta t} = \sum\vec{F}_{ext}$.	0.75

Second exercise: (7 ½ points)

Part	solution	Note
A-1	ME = $PE_e + kE + PE_g = ½\,I\,\theta'^2 + ½\,C\,\theta^2 + 0$	**0.75**
A-2.a	$\frac{dME}{dt} = 0 = I\,\theta'\theta'' + C\,\theta\theta' \Rightarrow \theta'' + \frac{C}{I}\theta = 0$.	**0.75**
A-2.b	$\theta = \theta_m \sin(\omega_0 t + \varphi)$; $\theta' = \omega_0\theta_m \cos(\omega_0 t + \varphi)$; $\theta'' = -\omega_0^2\theta_m \sin(\omega_0 t + \varphi)$ $\theta'' + \frac{C}{I}\theta = 0$ replacing θ" and θ in the differential equation then $\omega_0 = \sqrt{\frac{C}{I}} = 8$ rad/s for $t_0 = 0$, $\theta = \theta m \sin\varphi = \theta_m \Rightarrow \sin\varphi = 1 \Rightarrow \varphi = \frac{\pi}{2}$ rad.	**2**
A-2.c	When the disk passes $\theta = 0 \Rightarrow \sin(\omega_0 t + \varphi) = 0 \Rightarrow \cos(\omega_0 t + \varphi) = \pm 1 \Rightarrow$ $\theta' = \pm\,\omega_0\theta_m$ it passes for the first time in the negative sense $\Rightarrow \theta'_0 = -\,\omega_0\,\theta_m = -\,0.8$ rad/s	**1**
B-1	$\frac{d\sigma}{dt} = \sum M \Rightarrow I\theta'' = -\,C\,\theta - h\theta' + \cancelto{0}{\overrightarrow{M}_{mg} + M_T} \Rightarrow \theta'' + \frac{h}{I}\theta' + \frac{C}{I}\theta = 0$.	**0.75**
B-2	$\frac{dME}{dt} = I\theta'\theta'' + C\theta\theta'$; by replacing θ" we obtain : $\frac{dME}{dt} = I\theta'(-\frac{h}{I}\theta' - \frac{C}{I}\theta) + C\theta\theta' = -\,h\theta'^2$. $\frac{dME}{dt} < 0 \Rightarrow E_m$ decreases with time	**1.25**
C-1	Amplitude resonance	**0.25**
C-2	For $\omega_e = \omega_r = \omega_0 = 8$ rad/s.	**0.25**
C-3		**0.5**

Third exercise: (7 ½ points)

Part of the Q	Answer	Mark
A.1	The voltage U_0 = 5 V/div×2.4 div = 12 V.	0.50
A.2.a	$u_R = RI$, u_R = 2 V/div×2.8 div = 5.6 V $\Rightarrow I = \frac{5.6}{10}$ = 0.56 A.	0.50
A.2.b	This result allows us to eliminate the capacitor since there is passage of a current in the circuit in the steady state.($I \neq 0$)	0.50
A.2.c	Under a DC voltage, a coil behaves in the steady state as a resistor ($L\frac{di}{dt} = 0$), thus if (D) is a coil or a resistor, we can determine the resistance x of (D). $U_g = (R+x)I \Rightarrow R + x = 12/0.56 = 21.43\ \Omega$. Thus x = 21.43 – 10 = 11.43 Ω.	0.75
B.1.a	(D) cannot be a resistor, it is a coil because there is a phase difference between u_g and u_R. ($\phi \neq 0$)	0.25
B.1.b	Since (D) is a coil, the current i will be in lag of phase with u_g and then u_R lags u_g. The waveform (2) represents then the variations of the voltage u_R across the resistor.	0.50
B.2	U_m = 5V/div×2.4 div = 12 V, and $\omega = \frac{2\pi}{T}$; $T = S_h \times x$ = 2ms/div×10 div = 20 ms $\Rightarrow \omega = 100\pi$ rd/s or 314.16 rd/s $u_g = 12\sin(100\pi\tau\ t)$.	0.75
B.3	$I_m = \frac{U_m(R)}{R} = \frac{1\times3.2}{10} = 0.32$ A and $\varphi = \frac{2\pi\times1.5}{10}$; $\varphi = 0.3\pi = 0.94$ rd. $i = 0.32\sin(\omega t - 0.94)$.	0.75
B.4	$u_{coil} = L\frac{di}{dt} + ri$ $u_{coil} = L\times100\pi\times0.32\cos(\omega t - 0.3\pi) + 0.32r\sin(\omega t - 0.3\pi)$. $u_g = 12\sin(\omega t) = L\times100.5\cos(\omega t - 0.3\pi) + (R+r)0.32\sin(\omega t - 0.3\pi)$. **For $\omega t = 0$** $\Rightarrow 0 = 100.5\,L\cos(0.3\pi) - (R+r)0.32\sin(0.3\pi)$ $\Rightarrow L = 0.0044\,(R+r)$ **For $\omega t = \frac{\pi}{2}$** $\Rightarrow 12 = 100.5L\sin(0.2\pi)+0.32(R+r)\cos(0.2\pi)$ $12 = 81.30L + 0.188(R+r) = (0.358 + 0.188)(R+r) = 0.546\,(R+r)$ $\Rightarrow R+r = 21.97\ \Omega \Rightarrow r = 11.\ 97\ \Omega$. $L = 0.0044\times21.97 = 0.097$ H.	2.00
B.5.a	We observe the phenomenon of resonance.	0.25
B.5.b	At the resonance, $T = T_0 = 2\pi\sqrt{LC}$ = 20 ms = 2×10^{-2} s $\Rightarrow 10^{-4} = \pi^2 LC = \pi^2 L\times10^{-4}$ $\Rightarrow L = 0.1$ H At the resonance: $U_m(G) = 12\text{ V} = (R+r)I_m$, $U_m(R)$ = 2V/div×2.8 = 5.6 V = $RI_m \Rightarrow I_m = 0.56$ A So, $R+r = \frac{12}{0.56} = 21.43\ \Omega \Rightarrow r = 11.43\ \Omega$.	0.75

<u>Fourth exercise</u>: (7 ½ points)

Part of the Q	Answer	Mark
A.1.a	${}^{236}_{92}U^{*} \rightarrow {}^{236}_{92}U + \gamma$	0.25
A.1.b	The excess of energy is 20 MeV	0.25
A.2.a	Conservation of mass number: 1 + 235 = 138 + y + 3 $\Rightarrow$ y = 95. Conservation of charge number: 92 = x + 36 $\Rightarrow$ x = 56	0.75
A.2.b	$\Delta m = 1.0087 + 234.9934 - 137.8742 - 94.8871 - 3\times1.0087 = 0.2147$ u $E = \Delta m\, c^2$ Then $E = 0.2147\times931.5\ \text{MeV}/c^2\times c^2 = 199.99 \approx 200$ MeV	1.00
A.2.c	Number of nuclei contained in 1 g of uranium 235 : $n = \frac{m}{M}N_A = \frac{1}{235}6.02\times10^{23} = 2.56\times10^{21}$ nuclei. The nuclear energy liberated by 1 g: $2.56\times10^{21}\times200\times1.6\times10^{-13} = 8.19\times10^{10}$ J.	1.25
A.2.d	The nuclear energy liberated each day: $2800\times8.19\times10^{10} = 2.29\times10^{14}$ J. The electric energy provided each day: $8\times10^{8}\times24\times3600 = 6.91\times10^{13}$ J Efficiency of the plant: $\frac{6.91\times10^{13}}{2.29\times10^{14}} = 0.30$ or 30%.	0.75
B.1	$m({}^1_0n)\cdot c^2 + KE({}^1_0n) + m({}^{235}U) + KE({}^{235}U)$ $= m(B_a).c^2 + KE(B_a) + m(K_r)\cdot c^2 + KE(K_r) + 3m({}^1_0n)\cdot c^2 + KE({}^1_0n)_{emitted} + E(\gamma)$ $\Rightarrow E_{liberated} = KE(Ba) + KE(K_r) + 3KE({}^1_0n)_{emitted} + E(\gamma) - KE_C({}^1_0n)_{incident}$ $\Rightarrow E_C({}^1_0n)_{emitted} = 1$ MeV.	1.00
B.2.a	Conservation of linear momentum: $m_1\vec{V}_0 = m_1\vec{V}_1 + m_2\vec{V}_2$; collinear $\Rightarrow m_1(V_0 - V_1) = m_2V_2$ (1) The collision is elastic, thus $\frac{1}{2}m_1V_0^2 = \frac{1}{2}m_1V_1^2 + \frac{1}{2}m_2V_2^2$; $\Rightarrow m_1(V_0^2 - V_1^2) = m_2V_2^2$ (2) $\frac{(2)}{(1)} \Rightarrow V_0 + V_1 = V_2$ (3) ; (1) and (3) $\Rightarrow V_1 = \frac{m_1 - m_2}{m_1 + m_2}V_0$; $\Rightarrow \left\lvert\frac{V_1}{V_0}\right\rvert = \left\lvert\frac{m_1 - m_2}{m_1 + m_2}\right\rvert = \frac{11}{13} = k$	1.25
B.2.b	$\frac{K.E_1}{K.E_0} = \frac{V_1^2}{V_0^2} = k^2$, after the first collision, also $\frac{KE_2}{KE_1} = k^2$ after the second collision $\Rightarrow \frac{KE_2}{KE_0} = \left(k^2\right)^2 = k^4$, we demonstrate by recurrence that: $\frac{KE_n}{E_0} = k^{2n} \Rightarrow \frac{0.04}{2\times10^6} = k^{2n} \Rightarrow n = \frac{1}{2}\left(\frac{\ln 2.\ 10^{-8}}{\ln\frac{11}{13}}\right) = 53$ collisions	1.00

امتحانات الشهادة الثانوية العامة
الفرع : علوم عامة

دورة العام 2013 الاستثنائية
الخميس 22 اب 2013

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

This exam is formed of four exercises in four pages numbered from 1 to 4.
The use of non-programmable calculator is recommended.

First exercise: (7.5 points)

Horizontal mechanical oscillator

A horizontal mechanical oscillator is formed of a puck (S), of mass m = 510 g, attached to two identical springs of un-jointed loops whose other extremities A and B are connected to two fixed supports. Each spring is of negligible mass, natural length ℓ_0 and stiffness k = 10 Nm^{-1}. (S) may slide along a horizontal air table and its center of inertia G can then move along a horizontal axis x'Ox.

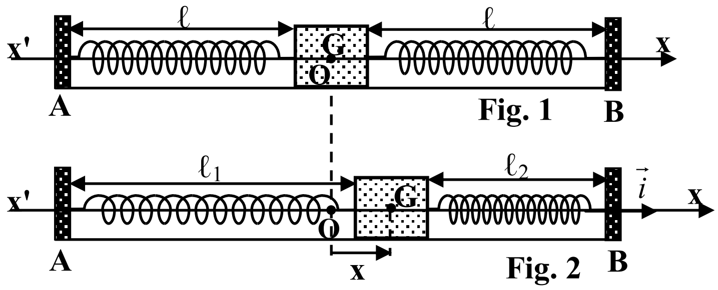


Fig. 1
Fig. 2

At equilibrium (Fig. 1):

- G coincides with the origin O of the axis x'x;
- each spring is elongated by $\Delta\ell$ such that its length is $\ell = \ell_0 + \Delta\ell$.

The horizontal plane passing through G is taken as a reference level of gravitational potential energy.

A – Theoretical Study

(S) is supposed to oscillate without friction. At an instant t, the abscissa of G is x = $\overline{OG}$, the algebraic value of its velocity is $v = \frac{dx}{dt}$ and the two springs have lengths ℓ_1 and ℓ_2 (Fig. 2).

1) **a)** Referring to figure 2, express ℓ_1 and ℓ_2 in terms of ℓ and x.

b) Show that, at an instant t, the total elastic potential energy stored in the two springs is given by: $PE_e = k[(\Delta\ell)^2 + x^2]$.

2) Write down, at an instant t, the expression of the mechanical energy of the system (puck, two springs, Earth) in terms of v, m, k, $\Delta\ell$ and x.

3) Derive the second order differential equation in x that describes the motion of G.

4) The solution of the differential equation is of the form: $x = X_m \cos(\omega_0 t + \varphi)$ where X_m, ω_0 and φ are constants.

a) Determine, in terms of k and m, the expression of ω_0.

b) Deduce the value T_0 of the proper period of the oscillations of G.

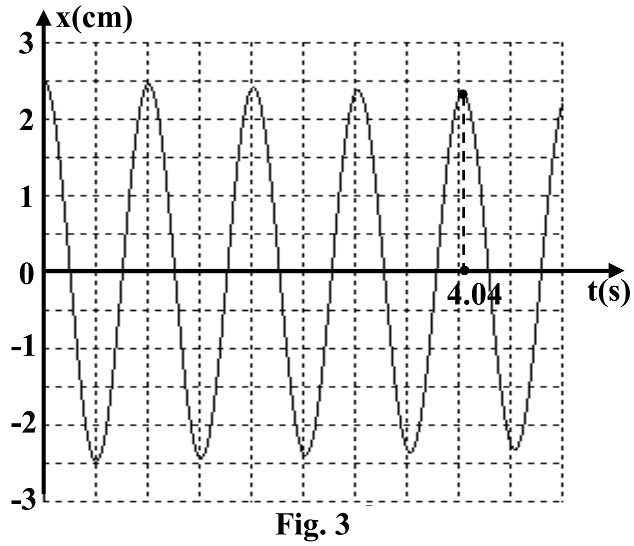


Fig. 3

B – Experimental study

An appropriate apparatus allows the recording of the abscissa x of G as a function of time (Fig. 3)

1) **a)** The experimental value of the period T is slightly different from the theoretical value T_0. Indicate the cause of this difference.

b) Determine, referring to figure 3, the period T of the oscillations of G.

2) At t = 4.04 s, the amplitude of the oscillations is 2.36 cm.

a) Determine the mechanical energy lost by the system (puck, two springs, Earth) between the instants $t_0 = 0$ and t = 4.04 s.

b) Deduce the average power lost in this interval.

3) The extremity A of the left spring is coupled to an exciter (E) of adjustable frequency « f » (Fig. 4). With an appreciable amount of friction, the puck is forced to oscillate on the air table with a frequency equal to that of (E). The variations, as a function of time, of the abscissa x of G is represented for two values of « f » by figures 5 and 6.

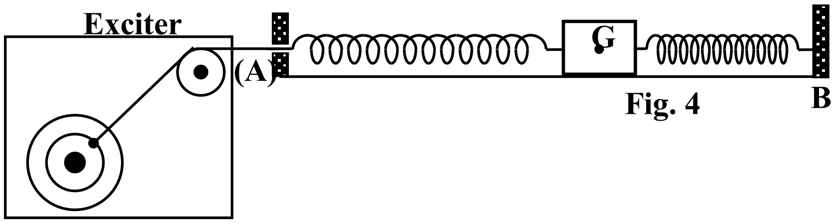


Fig. 4

a) Determine, in each case, the amplitude and the period of the oscillations of G.

b) The amplitude of the oscillations represented in figure 6 is larger than that of the oscillations of figure 5. Interpret this increase.

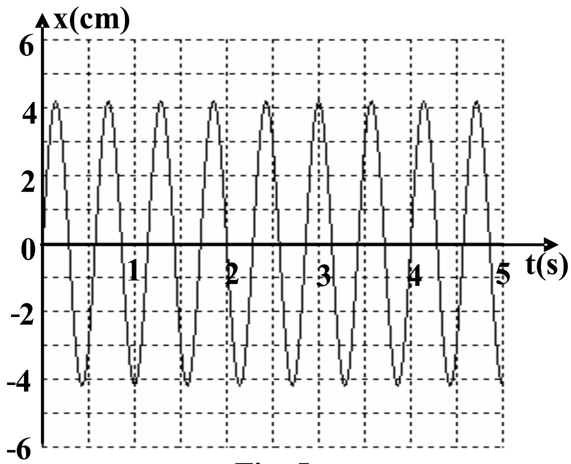


Fig. 5

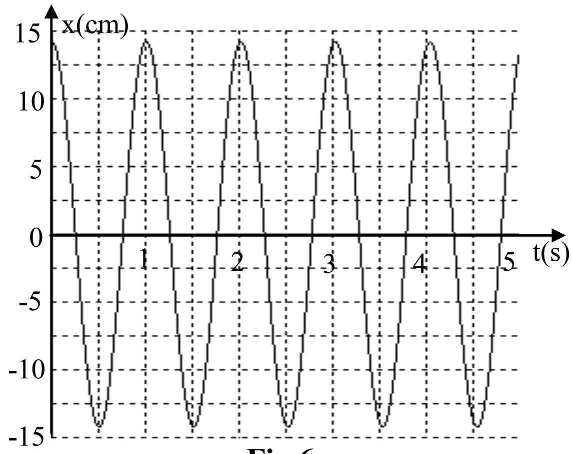


Fig.6

<u>Second exercise</u>: (7.5 points) Determination of the characteristics of a coil

In order to determine the characteristics of a coil, we consider the electric circuit represented in figure1. This circuit is formed of a capacitor of capacitance C, the coil of inductance L and of resistance r, a resistor of resistance R and an ammeter (A) of negligible resistance, all connected in series across an LFG, of adjustable frequency f, that maintains across its terminals an alternating sinusoidal voltage :

$u = u_{AM} = U\sqrt{2}\,\sin(2\pi ft + \varphi)$.

Thus the circuit carries an alternating sinusoidal current: $i = I\sqrt{2}\,\sin(2\pi ft)$ (Fig.1).

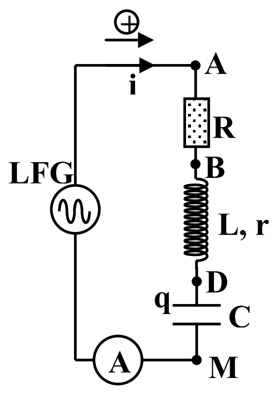


Fig. 1

A – 1) Write the expression of the voltage:

a) u_{AB} across the terminals of the resistor in terms of R, I, f and t;

b) u_{BD} across the terminals of the coil in terms of r, L, I, f and t.

2) Show that the voltage across the terminals of the capacitor is:

$$u_{DM} = -\frac{I\sqrt{2}}{2\pi f\,C}\cos(2\pi ft).$$

B – 1) Applying the law of addition of voltages and giving t two particular values, show that:

a) The effective value of the current is: $I = \dfrac{U}{\sqrt{(R+r)^2 + (2\pi f L - \dfrac{1}{2\pi f C})^2}}$;

b) The phase difference φ between the voltage u_{AM} and the current i is: $\tan\varphi = \dfrac{2\pi f L - \dfrac{1}{2\pi f C}}{R+r}$.

2) U is maintained constant and f is varied; the ammeter indicates a value I for each value of f. An appropriate device allows to plot the curve representing the variation of I as a function of f (Fig. 2).
This curve shows an evidence of a physical phenomenon for $f = f_0 = 110$ Hz.

a) Name this phenomenon.
b) Indicate the value I_0 of I corresponding to the value f_0 of f.
c) For $f = f_0$, show that:
   i) $4\pi^2 f_0^2\ LC = 1$ using the relation given in part (B-1-b);
   ii) the circuit is equivalent to a resistor of resistance $R_t = R + r$ using the relation given in part (B-1-a).
d) Calculate the value of L knowing that $C = 21\mu F$.
e) Calculate the resistance r knowing that U = 8 V and R = 30 Ω.

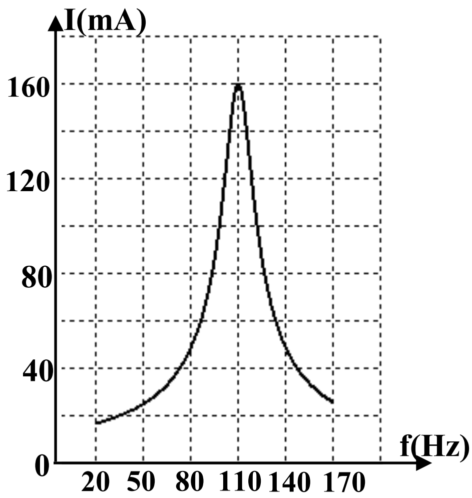


Fig. 2

<u>Third exercise</u>: (7.5 points) **Nuclear submarine**

A nuclear submarine is powered with a nuclear reactor using uranium 235. We intend to determine the efficiency of the reactor of this submarine that consumes 112 g of uranium 235 per day.
Take: $c = 3\times10^8$ m/s; 1 MeV = 1.6×10^{-13} J; mass of 1 atom of uranium 235 = 3.9×10^{-25} kg.

1) One of the nuclear reactions that take place inside the reactor is:

$$ {}_0^1n + {}_{92}^{235}U \longrightarrow {}_{36}^{91}Kr + {}_X^YBa + 3{}_0^1n $$

a) Determine the values of X and Y.
b) Is the previous reaction provoked or spontaneous? Justify.
c) Give the condition satisfied by the projectile neutron for this reaction to take place.

2) The adjacent table gives the binding energy per nucleon $\frac{E_B}{A}$ of the involved nuclei.

Nucleus	${}_{92}^{235}U$	${}_{36}^{91}Kr$	${}_Z^ABa$
$\frac{E_B}{A}$ (MeV/nucleon)	7.59	8.55	8.31

a) Calculate the binding energy E_B of each nucleus.
b) Write the expression of the binding energy E_B of a nucleus ${}_Z^AX$ in terms of A, Z, m_X [mass of the nucleus], m_P [mass of a proton] and m_n [mass of a neutron].
c) Show that the energy liberated by this fission reaction is: $E_{lib} = E_B(Kr) + E_B(Ba) - E_B(U)$.
d) Deduce the value of E_{lib} in MeV and in joule.

3) We suppose that the other nuclear fission reactions, that might take place in the reactor, liberate approximately the same amount of energy as that obtained in part (2-d).
a) Calculate the energy liberated by the fission of 112 g of uranium 235.
b) Determine the efficiency of the reactor of the submarine knowing that it delivers an electric power of 25 MW.

<u>Fourth exercise</u>: (7.5 points) **Photoelectric effect**

Given: $c = 3\times10^8$ m/s ; 1 eV = 1.6×10^{-19} J ; $h = 6.64\times10^{-34}$ Js.

A – Emission of photoelectrons

Let W_0 be the minimum energy needed to extract an electron from the surface of a metal that covers the cathode of a photo cell and ν_0 the threshold frequency of this metal.

1) Define the threshold frequency ν_0.
2) Write the relation between W_0 and ν_0.
3) To determine W_0 and then the nature of the metal, we illuminate the cathode of the photo cell successively and separately each time with radiations of different frequencies and we determine the maximum kinetic energy (KE_{max}) of the emitted photoelectrons for each radiation of frequency ν. We obtain the results shown in table 1.

ν ($\times10^{14}$ Hz)	5.5	6.2	6.9	7.5
KE_{max}(eV)	0.20	0.49	0.79	1.03

Table (1)

a) Trace the curve representing the variations of KE_{max} in terms of ν.
Scale: on the horizontal axis: 1 cm $\rightarrow 10^{14}$ Hz ; on the vertical axis: 1 cm $\rightarrow$ 0.20 eV.

b) i) The obtained graph confirms with Einstein's relation concerning the photoelectric effect. Justify.
ii) Name the physical constant that is represented by the slope of this graph.

c) Using the graph, determine the value of:
i) this physical constant;
ii) the threshold frequency ν_0.

d) Deduce the value of W_0.

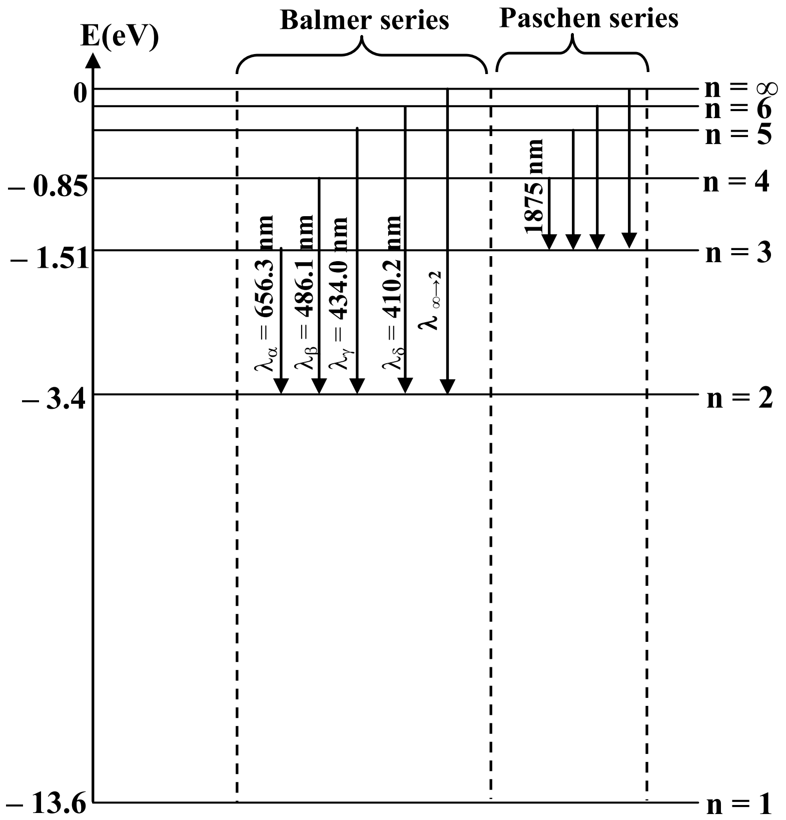
e) Referring to table 2, indicate the nature of the metal used.

metal	cesium	sodium	potassium
W_0 (eV)	2.07	2.28	2.30

Table (2)

B – The hydrogen atom

The spectral lines that constitute the hydrogen spectrum can be classified into many series; each series corresponds to the electronic transitions that lead to the same energy level. The figure below shows two of these series with the wavelengths of some emitted radiations.
The radiations emitted by the hydrogen gas lamp illuminates the cesium cathode of a photo cell.



1) Consider the spectral line having the smallest wavelength of the Paschen series.
a) To which transition does this line correspond?
b) Deduce the energy of the corresponding emitted photon.
c) Can the photons of the Paschen series extract photoelectrons from a cesium surface? Why?

2) Consider the spectral lines corresponding to the emitted radiations of wavelengths λ_α and λ_β of Balmer series.
a) Referring to the above energy diagram, calculate the corresponding frequencies ν_α and ν_β.
b) One of these two radiations can extract photoelectrons from the surface of cesium. Specify this radiation.

First exercise: (7.5 points)

Part of the Q	Answer	Mark
A.1.a	$\ell_1 = \ell + x$ and $\ell_2 = \ell - x$	½
A.1.b	The elastic potential energy stored in the two springs is: $PE_e = \frac{1}{2}k(\Delta\ell + x)^2 + \frac{1}{2}k(\Delta\ell - x)^2 = k(\Delta\ell^2 + x^2)$	1
A.2	The mechanical energy of the system is: $ME = \frac{1}{2}mv^2 + k(\Delta\ell^2 + x^2)$	½
A.3	No Friction $\Rightarrow \frac{dME}{dt} = 0 \Rightarrow mvv' + 2kxx' = 0 \Rightarrow mx'' + 2kx = 0$ $\Rightarrow x'' + \frac{2k}{m}x = 0.$	1
A.4.a	$x' = -\omega_0 X_m \sin(\omega_0 t + \varphi)$ and $x'' = -\omega_0^2 X_m \cos(\omega_0 t + \varphi)$. By replacing in the differential equation: $\omega_0^2 = \frac{2k}{m}$. $\omega_0 = \sqrt{\frac{2k}{m}}$	½
A.4.b	The value of the proper period T_0 is: $T_0 = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{m}{2k}} = 2\pi\sqrt{\frac{0.51}{2\times10}} = 1.003\text{ s} \approx 1\text{ s}$	½
B.1.a	T is slightly greater than T_0 because of friction.	½
B.1.b	$4T = 4.04 \Rightarrow T = 1.01$ s	¼
B.2.a	Variation of the mechanical energy: $ME_0 = k(\Delta\ell^2 + x_0^2)$ at t = 0s $ME_{4T} = k(\Delta\ell^2 + x_4^2)$ at t = 4T $\Rightarrow \Delta ME = k[x_4^2 - x_0^2] = 10[5.57\times10^{-4} - 6.25\times10^{-4}] = -6.8\times10^{-4}$ J. So the loss is 6.8×10^{-4} J.	¾
B.2.b	The lost average power: $\frac{\lvert\Delta ME\rvert}{\Delta t} = \frac{6.8\times10^{-4}}{4.04} = 1.68\times10^{-4}$ W	½
B.3.a	Figure 5 : $X_m = 4.1$ cm and $T = \frac{4}{7} = 0.57$ s. Figure 6 : $X_m = 14$ cm and T = 1.01 s.	1
B.3.b	In the case (figure 5) we are far from the resonance $T < T_0$ and in the case (figure 6) there is a resonance $T = T_0$.	½

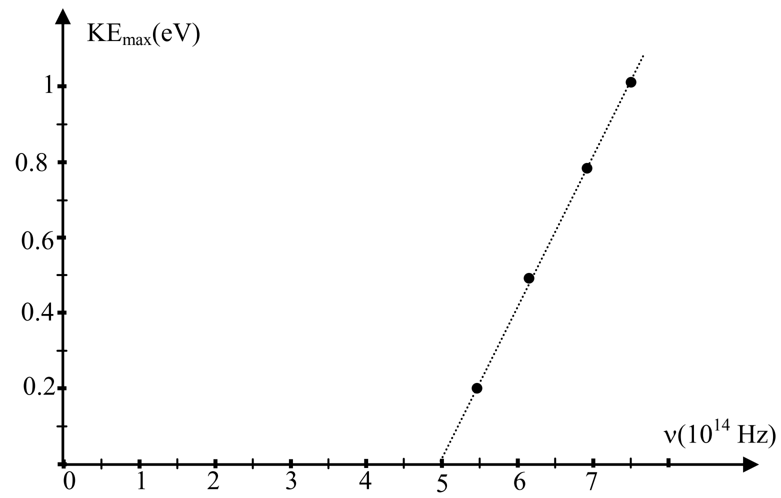
Second exercise: (7.5 points)

Part of the Q	Answer	Mark
A.1.a	$u_{AB} = Ri = RI\sqrt{2}\ \sin(2\pi ft)$	½
A.1.b	$u_{BD} = L\dfrac{di}{dt} + ri = 2\pi fL\ I\sqrt{2}\cos(2\pi ft) + rI\sqrt{2}\ \sin(2\pi ft)$	½
A.2	$u_{DM} = \dfrac{q}{C}$ but $dq = idt = I\sqrt{2}\ \sin(2\pi ft)dt \Rightarrow q = -\dfrac{I\sqrt{2}}{2\pi f}\cos(2\pi ft)$. $\Rightarrow u_{DM} = -\dfrac{I\sqrt{2}}{2\pi f\ C}\cos(2\pi ft)$.	1
B.1.a	$u_{AB} = u_{AB} + u_{BD} + u_{DM}$ $U\sqrt{2}\ \sin(2\pi ft + \varphi) = (\ 2\pi fL - \dfrac{1}{2\pi f C})I\sqrt{2}\cos(2\pi ft) + (R + r)\ I\sqrt{2}\ \sin(2\pi ft)$ For $2\pi ft = 0$ we get: $U\sin\varphi = I\ (2\pi f_0\ L - \dfrac{1}{2\pi f C}\ )$ .... (1) For $2\pi ft = \dfrac{\pi}{2}$ we get: $U\cos\varphi = I(R+r)$ …….. (2) Squaring and adding (1) and (2), we get: $U^2 = \left[(R+r)^2 + (2\pi f L - \dfrac{1}{2\pi f C})^2\right] I^2$ $\Rightarrow I = \dfrac{U}{\sqrt{(R+r)^2 + (2\pi f L - \dfrac{1}{2\pi f C})^2}}$.	2
B.1.b	The ratio $\dfrac{(1)}{(2)}$) gives: $\tan\varphi = \dfrac{2\pi f L - \dfrac{1}{2\pi f C}}{R+r}$.	½
B.2.a	Current resonance	¼
B.2.b	$I = I_0 = 160$ mA.	½
B.2.c.i	According to the relation (B-1-b) , i and u_{AM} are in phase $\Rightarrow \varphi = 0 \Rightarrow \tan\varphi = 0 \Rightarrow 2\pi f_0\ L - \dfrac{1}{2\pi f_0 C} = 0 \Rightarrow 4\pi^2 f_0^2\ LC = 1$	¾
B.2.c.ii	The relation (B-1-a) becomes $U = (R + r\ )I \Rightarrow$ the circuit is equivalent to a resistor of resistance $R_t = R + r$.	½
B.2.d	The relation $4\pi^2 f_0^2\ LC = 1 \Rightarrow\ L = 0.1$ H	½
B.2.e	At resonance the expression $U = (R + r\ )I \Rightarrow (R + r) = 50 \Rightarrow r = 20\ \Omega$	½

Third exercise: (7.5 points)

Part of the Q	Answer	Mark
1.a	Conservation of mass number: $1 + 235 = 91 + Y + 3 \Rightarrow Y = 142$ Conservation of charge number: $0 + 92 = 36 + X + 0 \Rightarrow X = 56$	1
1.b	The nuclear reaction is provoked, because it needs an external intervention : bombarded with a thermal neutron	½
1.c	The neutron must be thermal (low kinetic energy)	½
2.a	Since $E_B(X) = A\frac{E_{B(X)}}{A}$, then: $E_B(U) = 235\times7.59 = 1783.65$ MeV; $E_B(Kr) = 91\times8.55 = 778.05$ MeV; $E_B(Ba) = 142\times8.31 = 1180.02$ MeV.	1
2.b	$E_{B(X)} = [Z\times m_P + (A - Z)m_n - m_X]c^2$	½
2.c	$m_X = [Z\times m_P + (A - Z)m_n] - \frac{E_{B(X)}}{c^2}$ $E_{lib} = \Big\{[m_n + (92\,m_P + (235 - 92)m_n - \frac{E_{B(U)}}{c^2}]$ $- [(36\,m_P + (91 - 36)m_n - \frac{E_{B(Kr)}}{c^2})]$ $- [(56\,m_P + (142 - 56)m_n - \frac{E_{B(Ba)}}{c^2})]$ $- (3m_n)\Big\}c^2$ $E_{lib} = E_B(Kr) + E_B(Ba) - E_B(U)$	1½
2.d	$E_{lib} = 1180.02 + 778.05 - 1783.65 = 174.42$ MeV. $E_{lib} = 174.42\times1.6\times10^{-13} = 2.79\times10^{-11}$ J	¾
3.a	1 fission reaction $\rightarrow 3.9\times10^{-25}$ kg $\rightarrow 2.79\times10^{-11}$ J 0.112 kg $\rightarrow$? The energy liberated by the fission of 112 g is: 8.0123×10^{12} J.	¾
3.b	$P = \frac{E}{t} = \frac{8.0123\times10^{12}}{24\times3600} = 9.2735\times10^{7}$ watt The efficiency of the reactor is : $\xi = \frac{25\times10^{6}}{92.735\times10^{6}} = 0.269 = 26.9\%$	1

Fourth exercise (7.5 points)

Part of the Q	Answer	Mark
A.1	The threshold frequency ν_0 of a metal is the minimum frequency of an electromagnetic wave that can extract an electron when it illuminates the metal.	½
A.2	$W_0 = h\ \nu_0$.	¼
A.3.a		1½
A.3.b.i	$h\nu = W_0 + KE_{max} \Rightarrow KE_{max} = h\nu - h\nu_0$ which is a linear function of the frequency ν.	½
A.3.b.ii	The slope of the graph is h (Planck's constant)	¼
A.3.c.i	$h = \frac{\Delta KE_{max}}{\Delta \nu} \Rightarrow h = \frac{(1.03-0.2)\times 1.6\times 10^{-19}}{(7.5-5.5)\times 10^{14}} = 6.64\times 10^{-34}$ Js	1
A.3.c.ii	$\nu_0 = 5\times 10^{14}$ Hz,	¼
A.3.d	$W_0 = h\nu_0 = 6.64\times 10^{-34}\times 5\times 10^{14} = 3.32\times 10^{-19}$ J ; $W_0 = \frac{3.32\times 10^{-19}}{1.6\times 10^{-19}} = 2.075$ eV	½
A.3.e	The used metal is cesium.	¼
B.1.a	The smallest wavelength in the Paschen series corresponds to the transition from $n = \infty$ to $n = 3$.	½
B.1.b	The energy of the corresponding photon is: $E_\infty - E_3 = 1.51$ eV.	½
B.1.c	No, because the maximum of energy of the emitted photon in Paschen series is 1.51 eV which is less than 2.075 eV	½
B.2.a	We know that $\upsilon = \frac{c}{\lambda}$ $\Rightarrow \nu_\alpha = \frac{3\times 10^8}{656.3\times 10^{-9}} = 4.57\times 10^{14}$ Hz.; $\nu_\beta = \frac{3\times 10^8}{486.10\times 10^{-9}} = 6.17\times 10^{14}$ Hz	½
B.2.b	The radiation of frequency $\nu_\alpha < \nu_0$ does not emit photoelectrons; while$\nu_\beta > \nu_0$ emits photoelectrons.	½

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

This exam is formed of four exercises in four pages numbered from 1 to 4.
The use of non-programmable calculator is recommended.

First exercise: (7 ½ points) Measure of a small displacement

The aim of this exercise is to measure a very small displacement of an apparatus.

In order to do that we attach to the apparatus a monochromatic source (S) of wavelength λ in vacuum.

Given : Planck's constant : $h = 6.62\times10^{-34}$ J.s ; $c = 3\times10^{8}$ m/s ; 1 eV = 1.6×10^{-19} J ; mass of an electron: $m_e = 9.1\times10^{-31}$ kg.

A – Determination of the wavelength λ

The source (S) illuminates the cathode of a photo cell which is covered by cesium whose work function is $W_0 = 1.9$ eV.

1) Calculate the threshold wavelength λ_o of cesium.

2) The maximum speed of an emitted photoelectron from the cathode is 2.37×10^{5} m/s.

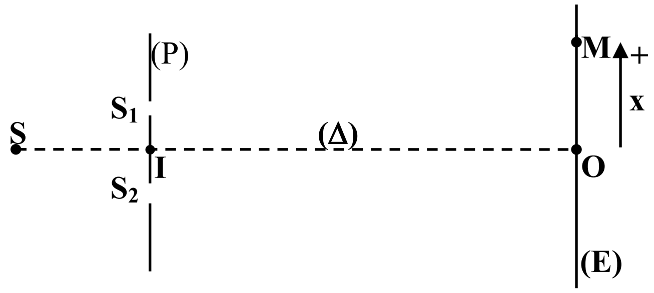
a) Calculate the maximum kinetic energy of the emitted photoelectrons.

b) Deduce that the value of the wavelength of the incident light is $\lambda = 0.602$ µm.

B – Determination of the displacement of an apparatus

The source (S), of wavelength λ, is placed on the axis of symmetry (Δ) of two small and parallel slits S_1 and S_2, separated by a distance a = 0.8 mm and made in an opaque screen (P). A screen (E) is placed parallel to (P) and at distance D = 1.6 m. I and O are the intersection of (P) and (E) with the axis (Δ) respectively (adjacent figure).

(S) illuminates the two slits S_1 and S_2.



1) Redraw the figure and show on it the region of interference.

2) On the screen (E), we observe a set of fringes. Point M is found in the region of interference on the screen (E) and is defined by its abscissa $x = \overline{OM}$.

a) Describe the interference fringes observed on the screen.

b) Express, in terms of x, D and a, the optical path difference $\delta = S_2M - S_1M$.

c) Deduce, in terms of λ, D and a, the expression of the abscissa x of M such that M is the center of:

i. a bright fringe;

ii. a dark fringe.

d) Show that O is the center of the central fringe.

3) **a)** Determine, in terms of λ, D and a, the expression of the interfringe distance i. Calculate its value.

b) Specify the nature and the order of the fringe whose center has an abscissa is x = – 4.2 mm.

4) When we displace (S) towards the two slits and along the axis (Δ). Does the position of the central fringe change? Justify.

5) The source (S) is maintained on the axis (Δ) at a distance d = 8 mm from I. We displace (S) slowly and perpendicularly to (Δ) towards one of the two slits. The optical path difference δ' at M is given by:

$\delta' = \frac{ax}{D} + \frac{ay}{d}$; where "y" is the displacement of (S). Knowing that the new position of the central fringe is the position that was originally occupied by the center of the bright fringe of order + 1 before the displacement of (S), determine "y" and deduce the direction of the displacement of (S).

Second exercise: (7 ½ points) Nuclear power plant

A – Nuclear fission reaction

A nuclear reactor uses enriched uranium constituted of 3% of $^{235}_{92}U$ and 97 % of $^{238}_{92}U$.

1) One of the possible nuclear fission reaction of uranium 235 is:

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{94}_{...}Sr + ^{140}_{54}Xe + ...^{1}_{0}n$ (1)

a) Define the term fissile isotope.

b) Complete the equation of the reaction and specify the used laws.

2) The binding energy per nucleon of the nuclei of reaction (1) are given in the table below:

nucleus	$^{235}_{92}U$	$^{140}_{54}Xe$	$^{94}_{...}Sr$
Binding energy per nucleon $\frac{E_B}{A}$	7.5 MeV	8.2 MeV	8.5 MeV

Calculate the binding energy E_B of each nucleus.

3) **a)** Determine the expression of the mass of a nucleus $^{A}_{Z}X$ in terms of A, Z, m_P (mass of proton), m_n (mass of neutron), E_B and c (speed of light in vacuum).

b) Show that the liberated energy by reaction (1) can be written as: $E_{lib} = E_B\ (Sr) + E_B\ (Xe) - E_B\ (U)$.

c) Calculate this energy in MeV.

4) In the core of the reactor, the fission of one uranium 235 nucleus liberates on average an energy of 200 MeV. 30% of this energy is transformed into electrical energy. A power plant furnishes an electric power of 1350 MW. Determine, in kg, the daily consumption of $^{235}_{92}U$ in this power plant.

Given: 1MeV = 1.6×10^{-13} J; $N_A = 6.02\times10^{23}$ mol^{-1} ; molar mass of ^{235}U = 235g.

B – Danger of radioactivity

Iodine131 is one of the emitted gases from a nuclear reactor. $^{131}_{53}I$ is a β^- emitter of half – life T = 8 days and the daughter nucleus is (Tellurium)Te.

1) **a)** The disintegration of $^{131}_{53}I$ nucleus is usually accompanied with the emission of γ. Write the equation of disintegration of iodine 131.

b) Indicate the cause of the emission of γ .

2) The iodine 131 causes serious problems because it has the ability to be fixed on the thyroid gland. Let A_0 be the activity of a sample of iodine 131 at an instant $t_0 = 0$ and A is its activity at an instant t.

a) Calculate, in day^{-1}, the value of the decay constant λ of iodine 131.

b) Determine the expression of $-\ell n\,(\frac{A}{A_0})$ in terms of λ and t.

c) Trace, between t = 0 and t = 32 days, the curve that represents $-\ell n\,(\frac{A}{A_0})$ as a function of t.

Take the scale: on the abscissa 1 cm ↔ 4 days ; on the ordinate 1 cm ↔ 0.5.

d) we suppose that the effect of iodine on organism becomes approximately negligible when its activity becomes one-tenth of its initial activity. Determine from the traced curve the time at which there is no effect on organisms.

<u>Third exercise</u>: (7 ½ points) **Capacitor and coil**

The aim of this exercise is to determine, by different methods, the characteristics of a capacitor and a coil.

A – RC circuit

Consider a series circuit formed, of a resistor of resistance R = 100 Ω, a neutral capacitor of capacitance C and a switch K, fed by a generator of negligible internal resistance and of emf E (Fig.1).

At the instant $t_0 = 0$, we close the switch K; then a current i flows in the circuit.

1) Derive the differential equation that describes the variation of $u_C = u_{AB}$ as a function of time.

2) The solution of this differential equation is $u_C = E(1 - e^{\frac{-t}{\tau}})$.

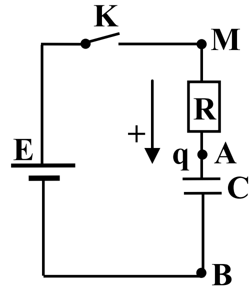


Fig.1

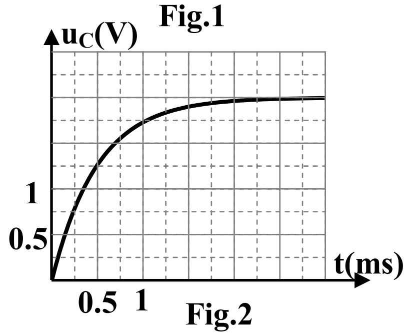


Fig.2

a) Determine the expression of τ in terms of R and C.

b) Show that at the end of duration 5τ, the charging of the capacitor is practically completely charged.

3) An appropriate system registers the variations of the voltage $u_C = u_{AB}$ across the terminals of the capacitor (Fig.2).

a) Referring to figure 2:

i. indicate the value of E;

ii. determine the value of τ;

b) Deduce the value of C.

B – RL circuit

The capacitor is replaced by a coil of inductance L and of resistance r (Fig.3).
At the instant $t_0 = 0$, the switch K is closed. An appropriate system records the variations of the current i in the circuit as a function of time (fig. 4).

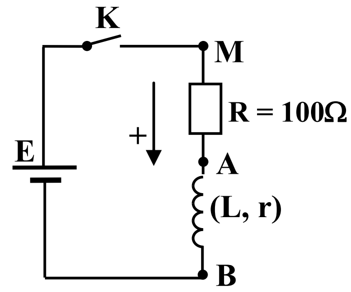


Fig.3

1) Derive the differential equation that describes the variation of i as a function of time.

2) Verify that: $i = \dfrac{E}{(R+r)}(1 - e^{\frac{-t}{\tau}})$ is the solution of the differential equation, where $\tau = \dfrac{L}{R+r}$.

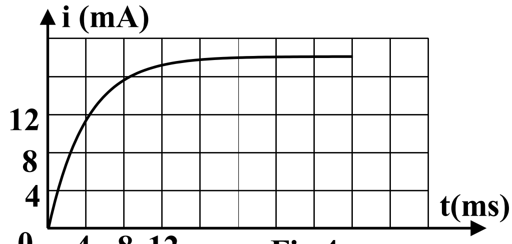


Fig.4

3) Determine, in the steady state, the expression of the current I in terms of E, R and r.

4) Referring to figure 4, indicate the value of I.

5) Determine the values of r and L.

C – RLC circuit

The previous capacitor of capacitance $C = 5\times10^{-6}$ F, initially charged under the voltage E, is connected in series with the coil (L, r = 11Ω), the resistor of resistance R = 100Ω and the switch K as indicated in figure 5.
At $t_0 = 0$, the switch K is closed. The recording of the variations of the voltage $u_C = u_{AB}$ across the capacitor as a function of time is represented in figure 6.

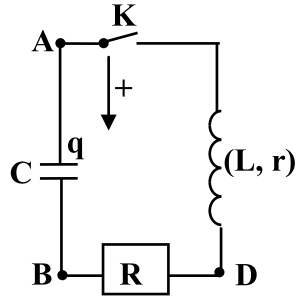


Fig.5

1) Derive the differential equation that describes the variation of u_C as a function of time.

2) The solution of this differential equation is:

$$u_C = 2\, e^{\frac{-(R+r)t}{2L}} \cos(\frac{2\pi}{T}t).$$

Use the graph of figure 6, to determine again the value of the inductance L found in part (B–5).

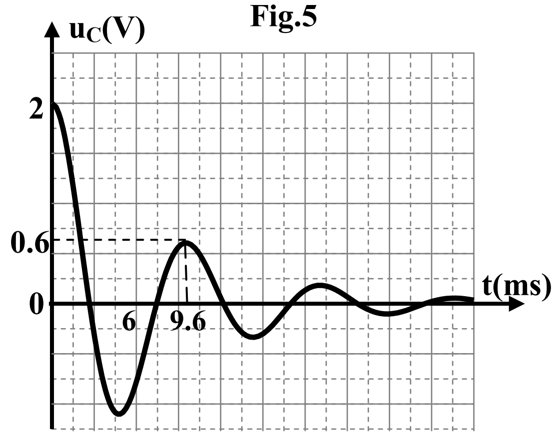


Fig.6

<u>Fourth exercise</u>: (7 ½ points) **Mechanical oscillations**

A simple pendulum consists of a particle of mass m = 100 g, fixed at the free end of a massless rod OA of length $\ell = 0.45$ m.
This pendulum may oscillate in the vertical plane, around a horizontal axis (Δ) passing through the upper extremity O of the rod.
The pendulum is initially at rest in its equilibrium position. At the instant $t_0 = 0$, the particle is launched horizontally in the positive direction as indicated in figure 1, with a velocity $\vec{v}_0$ of magnitude $v_0 = 0.3$ m/s.
At an instant t, the angular abscissa of the pendulum and the algebraic value of the velocity of the particle are θ and v respectively.

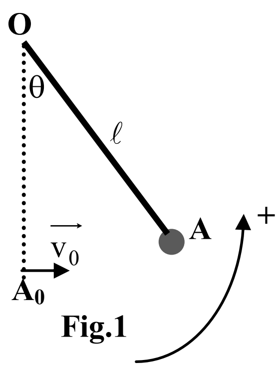


Fig.1

Take:

- The horizontal plane passing through A_0, the position of A at equilibrium, is taken as the reference level for the gravitational potential energy.
- $g = 10\ m/s^2$.
- For small angles: $\cos\theta = 1 - \frac{\theta^2}{2}$ and $\sin\theta \approx \theta$ where θ in rad.

A – The forces of friction are negligible

1) **a)** Show that the mechanical energy of the system (pendulum, Earth) at the instant $t_0 = 0$ is $ME_0 = 4.5$ mJ.

b) Determine, at instant t, the expression of the mechanical energy of the system (pendulum, Earth) in terms of m, v, ℓ, g and θ.

c) Deduce the maximum angle θ_m performed by the pendulum.

2) **a)** Derive the differential equation in θ that describes the motion of the pendulum knowing that $v = \ell\frac{d\theta}{dt}$.

b) Deduce the expression of the proper angular frequency ω_0 and that of the proper period T_0 in terms of ℓ and g.

c) Calculate the values of T_0 and ω_0.

3) The time equation of the motion of the pendulum is of the form: $\theta = \theta_m \sin(\omega_0 t + \varphi)$. Determine φ.

4) Figure (2) shows three curves that represent the kinetic energy KE, the gravitational potential energy PE_g and the mechanical energy ME of the system (pendulum - Earth).

a) Identify each one of the curves a, b and c in the figure.

b) Pick up from figure 2 the value of the period T_E of the variations of the energies.

c) Deduce the relation between T_E and T_0.

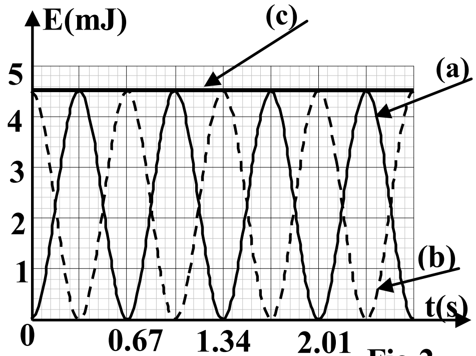


Fig.2

B – In reality, the forces of friction are not negligible. The variations of the angular abscissa θ of the pendulum as a function of time are represented by the graph of figure 3.

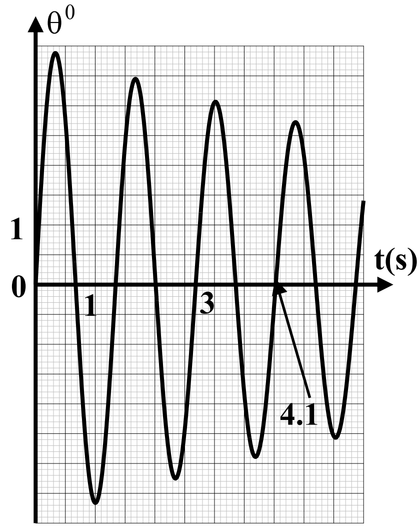


Fig.3

1) Referring to the graph:

a) indicate the type of oscillations performed by the pendulum;

b) determine the duration T of one oscillation. Compare T and T_0.

2) Knowing that the kinetic energy of the pendulum at the instant t = 2T is 2.74 mJ, determine the average power furnished to the pendulum in order to compensate the loss in energy between 0 and 2T.

C – The pendulum undergoes periodic excitations of adjustable angular frequency ω_e.

We record for each value of ω_e the value of the amplitude θ_m of the oscillations of the pendulum, and we trace the graph of $\theta_m = f(\omega_e)$ represented in figure 4.

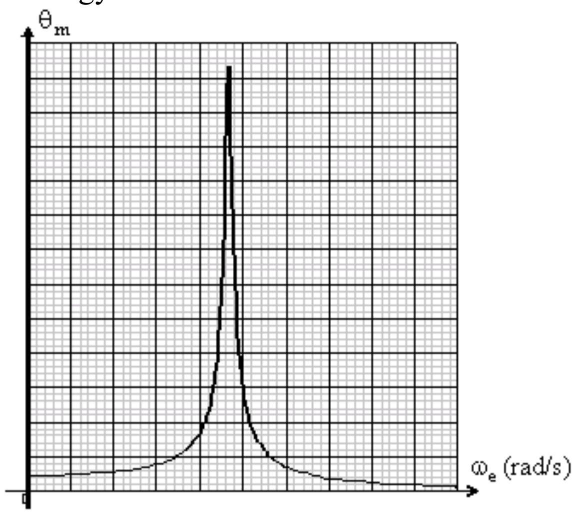
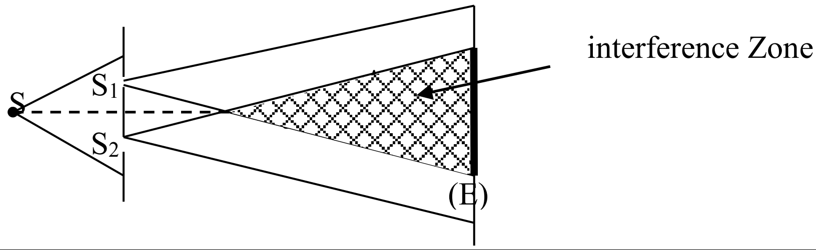


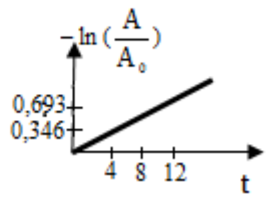
Fig.4

1) **a)** Name the phenomenon that takes place in the graph.

b) Give the value of the angular frequency ω_e so that the amplitude of oscillations is maximum.

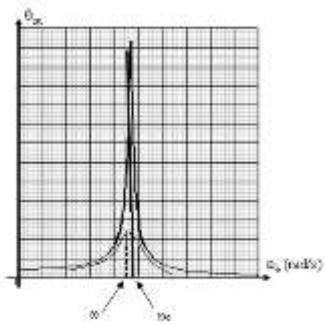
2) An appropriate system may increase slightly the forces of friction. Redraw figure 4 and draw roughly the shape of the curve giving the variations of the amplitude θ_m of oscillations of the pendulum in terms of the angular frequency ω_e of the excitations.

First exercise: Measurement of a small displacement [7.5 pts]		
A.1	$W_0 = 1.9\times1.6\times10^{-19} = \frac{hc}{\lambda_0} \Leftrightarrow \lambda_0 = 6.53 \times 10^{-7}$ m = 0.653 μm.	**0.75**
A.2.a	$KE_{max} = \frac{1}{2} m V_{max}^2 = 2.56\times10^{-20}$ J	**0.5**
A.2.b	$\frac{hc}{\lambda_0} = W_0 + KE_{max} \Leftrightarrow \lambda_0 = 6.02\times10^{-7}$m = 0.602 μm	**0.75**
B.1		**0.5**
B.2.a	We observe on E alternating bright and darks fringes, rectilinear bands, parallel to the slits and equidistant centers.	**0.75**
B.2.b	$\delta = (SS_2 + S_2M) - (SS_1 + S_1M) = d_2 - d_1 = \frac{ax}{D}$	**0.25**
B.2.c.i	$\frac{ax}{D} = k\lambda$ (bright fringe) $\Leftrightarrow x_b = \frac{k\lambda D}{a}$	**0.5**
B.2.c.ii	$\frac{ax}{D} = (2k+1)\frac{\lambda}{2}$ (dark fringe) $\Leftrightarrow x_D = \frac{(2k+1)\lambda D}{2a}$	**0.5**
B.2.d	$\delta = \frac{ax}{D} = d_2 - d_1 = k\lambda$ corresponds to the bright fringes, at O, x = 0 then $\delta = 0 \Leftrightarrow k = 0$ O is the center of the central bright fringe is equidistant from S_1 and S_2.	**0. 5**
B.3.a	$i = x_{K+1} - x_K = \frac{\lambda D}{a}$; $i \approx 1.2\times10^{-3}$m	**0.75**
B.3.b	$x_D = \frac{(2k+1)\lambda D}{2a} \Leftrightarrow k = -4 \Leftrightarrow 4^{th}$ dark	**0.5**
B.4	When (S) is displaced along $\Delta \Leftrightarrow \delta_O = SS_2O - SS_1O = 0$ (unchanged) $\Leftrightarrow \delta_O = d_2 - d_1$ remain 0.	**0.5**
B.5	$\delta' = \frac{ay}{d} + \frac{ax}{D} = 0$ central fringe $\Leftrightarrow y = -\frac{xd}{D}$ the displacement of S is opposite of displacement of the central fringe. $y = -6 \times 10^{-6}$m ; S displaced by 6μm in the opposite direction of x	**0. 5**

Second exercise Nuclear power plant [7.5 pts]		
A.1.a	Fissile leads to fission	0.25
A.1.b	${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{94}_{Z}Sr + {}^{140}_{54}Xe + x\ {}^{1}_{0}n$ Apply the laws of conservation of mass number and charge number $\Rightarrow$ x =2 and Z=38	0.75
A.2	$E_{B\ (U)} = 7.5\times235 = 1762.5$ MeV $E_{B\ (Xe)} = 8.2\times140 = 1148$ MeV $E_{B\ (Sr)} = 8.5\times94 = 799$ MeV	0.25
A.3.a	$E_{B\ (X)} = [Z.m_p + (A-Z).m_n - m_X].\ C^2 \Rightarrow m_X = [Z.m_p + (A-Z).m_n] - E_B/c^2$	0.50
A.3.b	$E_{lib} = [(m_U + m_n) - (m_{Sr} + m_{Xe} + 2m_n)]c^2$; $m_X = Zm_P + (A-Z)m_n - E_B/c^2$ $E_{lib} = [(92m_P+143m_n-E_B(U)/c^2+m_n) - (38m_P+56m_n- E_B(Sr)/c^2+54m_P+86m_n-E_B(Xe)/c^2+2m_n)]c^2$ $E_{lib} = E_B(Sr) + E_B(Xe) - E_l(U)$.	1.25
A.3.c	$E_{lib} = 184.5$ MeV	0.25
A.4	$P_e = 1350$ MW $\Leftrightarrow$ consumption of electric energy in one day : $E_e = P\times t = 1350\times10^{-6} \times 24\times3600 = 1.1664\times10^{14}$J total liberated energy due to fission = $E_t = \frac{E_e}{0.3} = 3.888\times10^{14}$ J $= 2.43\times10^{27}$ MeV 1 nucleus $\longrightarrow$ 200 MeV N $\longrightarrow$ 2.43×10^{27} MeV $N = 1.215\times10^{25}$ nuclei $m = \frac{N\times M}{N_A} = 4743$ g = 4.743 Kg	1.25
B.1.a	${}^{131}_{53}I \longrightarrow {}^{131}_{54}Te + {}^{0}_{-1}e + \bar{\nu} + \gamma$	0.5
B.1.b	The daughter nucleus (**Te**) is in an excited state	0.25
B.2.a	$\lambda = \ln2 / T = 0.693/8 = 0.0866$ day $^{-1}$	0.5
B.2.b	$A = A_0\ e^{-\lambda t} \Rightarrow A/A_0 = e^{-\lambda t} \Rightarrow -\ln(\frac{A}{A_0}) = \lambda t$	0. 5
B.2.c	Straight line passes through the origin  	0.75
B.2.d	$A = A_0/10 \Rightarrow t = 26.58$ days ≈ 27 days	0.5

Third exercise :Capacitor and coil [7.5 pts]		
Part of the Q	**Answer**	**Mark**
A.1	$E = Ri + u_C = RC\dfrac{du_C}{dt} + u_C$	**0.50**
A.2.a	$\dfrac{du_C}{dt} = \dfrac{E}{\tau}e^{\frac{-t}{\tau}} \Rightarrow E = RC\dfrac{E}{\tau}e^{\frac{-t}{\tau}} + E(1 - e^{\frac{-t}{\tau}}) \Rightarrow \dfrac{RC}{\tau} = 1 \Rightarrow \tau = RC.$	**0.75**
A.2.b	If $t = 5\tau \Rightarrow u_C = E(1 - e^{-5}) = 0.99E \approx E$	**0.50**
A.3.a.i	$E = 2$ V	**0.25**
A.3.a.ii	$t = \tau$, $u_C = 0.63\ E = 1.26$ V $\Rightarrow \tau = 0.5$ ms.	**0.25**
A.3.b	$\tau = RC \Rightarrow C = 5\times10^{-6}$ F.	**0.50**
B.1	$E = Ri + ri + L\dfrac{di}{dt} \Rightarrow E = (R+r)i + L\dfrac{di}{dt}$.	**0.50**
B.2	$\dfrac{di}{dt} = \dfrac{E}{L}e^{\frac{-(R+r)t}{L}}$; $(R+r)\dfrac{E}{(R+r)}(1 - e^{\frac{-(R+r)t}{L}}) + L\dfrac{E}{L}e^{\frac{-(R+r)t}{L}} = E$ $\Rightarrow E = E$	**0.75**
B.3	If $t \to \infty \Rightarrow e^{\frac{-(R+r)t}{L}} \to 0 \Rightarrow I = \dfrac{E}{R+r}$ **<u>Or</u>** Steady state $i = I = cte \Rightarrow L\dfrac{di}{dt} = 0 \Rightarrow E = (R+r)I + 0 \Rightarrow I = \dfrac{E}{R+r}$	**0.5**
B.4	$I = 18$ mA in steady state	**0.25**
B.5	$0.018 = \dfrac{2}{100+r} \Rightarrow r = 11\,\Omega$. At $t = \tau$; $i = 0.63\ I = 11.34$ mA $\Rightarrow \tau = 4$ ms. Or $\tau = \dfrac{L}{R+r} \Rightarrow L = 0.44$ H.	**1**
C.1	$u_{AB} + u_{BD} + u_{DA} = 0 \Rightarrow u_C + R.i + L\dfrac{di}{dt} + ri = 0$; $i = \dfrac{dq}{dt} = C\dfrac{du_C}{dt}$ $\Rightarrow u_C + (R+r).C\dfrac{du_C}{dt} + L.C\dfrac{d^2u_C}{dt^2} = 0.$	**0.75**
C.2	$t = 9.6$ ms , $u_C = 0.6$ V , we replace in the solution: $L = 0.44$ H	**0.75**

Fourth exercise :Mechanical oscillations [7.5 pts]

Part of the Q	Answer	Mark
A.1.a	$ME_0 = PE_g + KE = 0 + \frac{1}{2} m(v_0)^2 = 0 + \frac{1}{2}(0.1)(0.3)^2$ $ME_0 = 4.5\times10^{-3}$ J = 4.5 mJ.	**0.50**
A.1.b	$ME = \frac{1}{2} mv^2 + mgh = \frac{1}{2} mv^2 + mg\ell(1-\cos\theta)$	**0.75**
A.1.c	ME (for $\theta = \theta_m$) = ME_0 (no friction) $\Rightarrow\ 0 + mg\ell(1-\cos\theta_m) = 0.1\times10\times0.45(1-\cos\theta_m) = 4.5\times10^{-3}$ J $\Rightarrow\ 1-\cos\theta_m = 0.01 \Rightarrow \cos\theta_m = 0.99 \Rightarrow \theta_m = 8^o$ $\Rightarrow$ the amplitude of oscillations being small	**0.75**
A.2.a	$\frac{dME}{dt} = 0 = mvv' + mg\,\theta'\,\ell\sin\theta$; we have $v = \ell\theta' \Rightarrow v' = \ell\,\theta''$, thus : $\theta'' + \frac{g}{\ell}\sin\theta = 0$, for small angles : $\sin\theta \approx \theta \Rightarrow \theta'' + \frac{g}{\ell}\theta = 0$	**0.75**
A.2.b	$\omega_0 = \sqrt{\frac{g}{\ell}}$ and $T_0 = 2\pi\sqrt{\frac{\ell}{g}}$	**0.50**
A.2.c	$\omega_0 = \sqrt{\frac{g}{\ell}} = \sqrt{\frac{10}{0.45}} = 4.71$ rd/s; $T_0 = 2\pi\sqrt{\frac{\ell}{g}} = 1.34$ s	**0.50**
A.3	$\theta = \theta_m\sin(\omega_0 t + \varphi)$; for t = 0, $\sin\varphi = 0 \Rightarrow \sin\varphi = 0 \Rightarrow \varphi = 0$ or $\varphi = \pi$ $\theta' = \omega_0\theta_m\cos(\omega_0 t + \varphi)$; $\theta'_0 = \omega_0\theta_m\cos\varphi > 0 \Rightarrow \varphi = 0$.	**0.75**
A.4	The curve (**c**) represents ME because it is parallel to t axis (not changed). Curve (**a**) represents PE_g because it passes in the origin at t = 0 (reference) The curve(**b**) represents KE because at $t = 0 \Rightarrow v_0 = v_{max} \Rightarrow KE_{max} = ME$	**0.5**
A.4.b	$T_E = 0.67$ s;	**0.25**
A.4.c	$T_0 = 1.34\text{ s} = 2T_E$.	**0.25**
B.1.a	The pendulum performs free damped oscillations.	**0.25**
B.1.b	$T = \frac{4.1}{3} = 1.37$ s. T is slightly greater than T_0	**0.50**
B.2	$P_{av} = \frac{\lvert\Delta Em\rvert}{\Delta t} = \frac{\lvert ME_{(2T)} - ME_{(0)}\rvert}{2T}$ $ME_{(2T)} = KE_2 + PE_g = 2.74\times10^{-3} + 0 = 2.74\times10^{-3}$ J ; $ME_{(0)} = KE_0 + PE_g = 4.5\times10^{-3} + 0 = 4.5\times10^{-3}$ J ; To maintain the oscillations, it is necessary to provide to the pendulum an Average power: $P_{av} = \frac{1.76\times10^{-3}}{2\times1.37} = 0.64\times10^{-3}$ W	**0.75**
C.1.a	Amplitude Resonance	**0.25**
C.1.b	For $\omega_e = \omega_0 = 4.71$ rad/s	**0.25**
C.2.		**0.25**

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

This exam is formed of four exercises in four pages.
The use of non-programmable calculators is recommended.

First exercise: (7 points)

Mechanical oscillator

The aim of this exercise is to study the free oscillations of a mechanical oscillator. For this aim the oscillator is formed of a puck (A) of mass m = 0.25 kg fixed to one end of a massless spring of unjointed turns and of stiffness k = 10 N/m; the other end of the spring is attached to a fixed support (C) figure 1.
(A) slides on a horizontal rail and its center of inertia G can move on a horizontal axis x'ox.

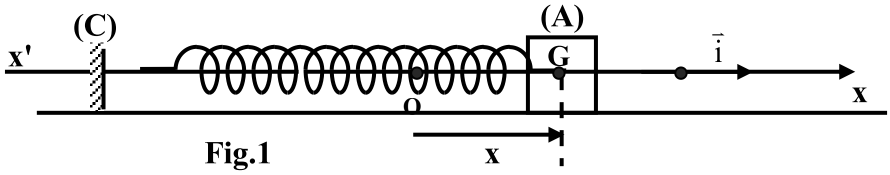


Fig.1

At equilibrium, G coincides with the origin O of the axis x' x.
At an instant t the position of G is defined, on the axis $(O, \vec{i})$, by its abscissa $x = \overline{OG}$; its velocity $\vec{v} = v\,\vec{i}$ where $v = x' = \frac{dx}{dt}$.
The horizontal plane through G is taken as reference level for the gravitational potential energy.

A – Theoretical study

In this part we neglect all forces of friction.

1) a) Write down the expression of the mechanical energy of the system [(A) , spring , Earth] in terms of k , m , x and v .
b) Derive the differential equation in x that describes the motion of G.

2) The solution of this differential equation is of the form: $x = X_m \sin\left(\frac{2\pi}{T_0}t + \varphi\right)$ where X_m and φ are constants and T_0 is the proper period of the oscillator .
a) Determine the expression of T_0 in terms of m and k. Calculate its value.
b) At $t_0 = 0$, G passes through the point of abscissa $x_0 = 2$ cm with a velocity of algebraic value $v_0 = -\,0.2$ m/s, determine the values of X_m and φ .

B – Experimental study

In this part, the frictional force is given by $\vec{f} = -\mu\vec{v}$ where μ is a positive constant. An appropriate setup allow to record the curve giving the variations of x = f(t) (fig 2) and those giving the variations of the kinetic energy KE(t) of G and of the elastic potential energy PEe(t) of the spring (fig 3).

1) Referring to figure 2, give the value of the pseudo-period T of the motion of G .Compare its value to that of the proper period T_0.
2) Referring to figures 2 and 3, specify which curve A or B represents PEe(t).
3) a) Verify that the ratio $\frac{X_m(T)}{X_m(0)} = \frac{X_m(2T)}{X_m(T)} = a$ where a is constant to be determined.
b) Knowing that $a = e^{-\frac{\mu T}{2m}}$, calculate , in SI unit, the value of μ .
4) On figure 3 two particular instants t_1 and t_2 are located.

a) Referring to figure 3 indicate with justification at which instant , t_1 or t_2 , the magnitude of the velocity of the puck is :

  i) maximum;

  ii) equal to zero.

b) What can you conclude about the force of friction at each of the above instants?

c) Deduce around which instant t_1 or t_2, the mechanical energy decreases by a greater amount.

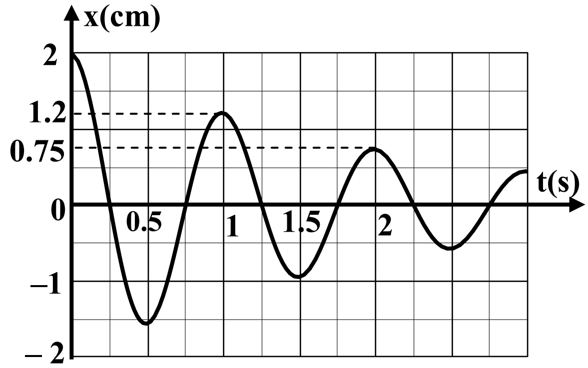


Fig.2

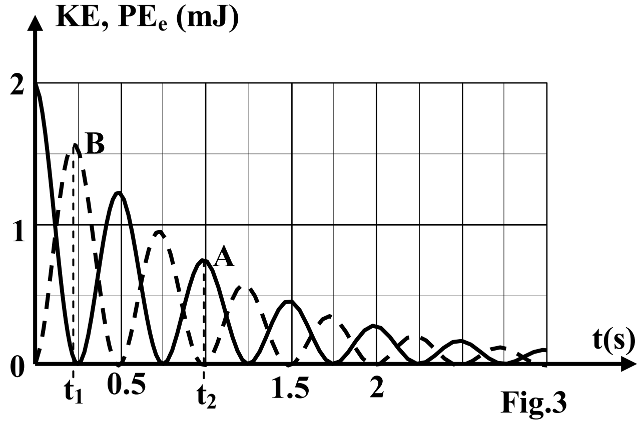


Fig.3

Second exercise: (7 points)

Characteristic of an electric component

In order to determine the characteristic of an electric component (D), we connect up the circuit represented in figure 1.

This series circuit is composed of: the component (D), a resistor of resistance $R = 100\,\Omega$, a coil ($L = 25$ mH; $r = 0$) and an (LFG) of adjustable frequency f maintaining across its terminals a sinusoidal alternating voltage $u = u_{AM}$.

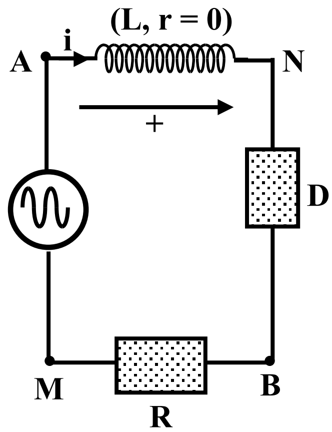


Fig.1

A – First experiment

We connect an oscilloscope so as to display the variation, as a function of time, the voltage u_{AM} across the generator on the channel (Y_1) and the voltage u_{BM} across the resistor on the channel (Y_2).

For a certain value of f , we observe the waveforms of figure 2.

The adjustments of the oscilloscope are:

- ✓ vertical sensitivity: 2 V/div on the channel (Y_1);
  0.5 V/div on the channel (Y_2);
- ✓ horizontal sensitivity: 1 ms/ div.

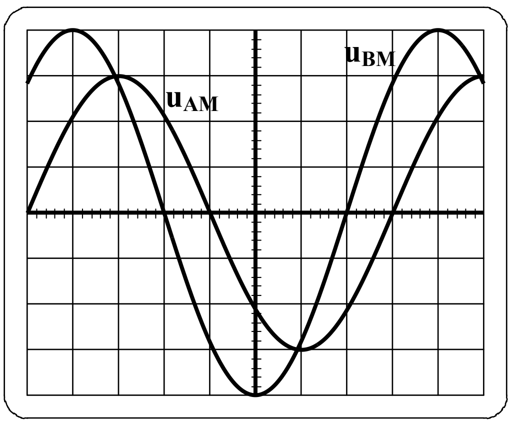


Fig.2

1) Redraw figure 1 and show on it the connections of the oscilloscope.

2) Using figure 2, determine:

a) the value of f and deduce the value of the angular frequency ω of u_{AM};

b) the maximum value U_m of the voltage u_{AM};

c) the maximum value I_m of the current i in the circuit;

d) the phase difference φ between u_{AM} and i. Indicate which one leads the other.

3) (D) is a capacitor of capacitance C. Justify.

4) Given that: $u_{AM} = U_m \sin \omega t$. Write down the expression of i as a function of time.

5) Show that the expression of the voltage across the capacitor is:

$$u_{NB} = -\frac{0.02}{250\pi C}\cos(\omega t + \frac{\pi}{4}) \quad (u_{NB} \text{ in V ; C in F ; t in s})$$

6) Applying the law of addition of voltages and by giving t a particular value, determine the value of C.

B – Second experiment

The effective voltage across the generator is kept constant and we vary the frequency f . We record for each value of f the value of the effective current I.

For a particular value $f = f_0 = \frac{1000}{\pi}$ Hz , we notice that I admits a maximum value.

1) Name the phenomenon that takes place in the circuit for the frequency $f = f_0$.

2) Determine again the value of C.

<u>Third exercise</u>: (6 ½ points)

Electric circuit

A – Study of a (L, C) circuit

The (L,C) circuit of figure 1, composed of a capacitor of capacitance C and of a coil of inductance L and of negligible resistance and a switch k. Initially the armature A of C caries a charge $Q_0 > 0$. The switch is closed at $t_0 = 0$. At an instant t the charge of armature A is q and the current in the circuit is i.

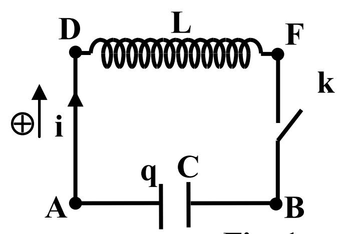


Fig. 1

1) **a)** Indicate the form of the energy in the circuit at $t_0 = 0$.
   b) Deduce that the value of the current at $t_0 = 0$ is 0.

2) Using the principle of the conservation of the electromagnetic energy, show that the differential equation in q has the form of: $q'' + \frac{1}{LC}q = 0$.

3) The solution of this differential equation is of the form $q = Q_m \cos(\omega_0 t + \phi)$; Q_m, ω_0 and ϕ are constants and $Q_m > 0$.
   a) Determine ϕ.
   b) Determine the expression of Q_m in terms of of Q_0 and that of ω_0 in terms of L and C.

4) **a)** Determine the expression of i as a function of time.
   b) Trace the shape of the curve i = f(t).

B – Study of a (L, R) series circuit

We consider the adjacent circuit 2. It is formed of an ideal DC power supply of e.m.f. E, a resistor of resistance R, a switch k and a coil of inductance L and of zero internal resistance.

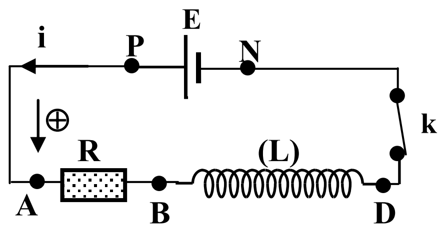


Fig.2

The switch is closed at $t_o = 0$.

1) Apply the law of addition of voltages, establish the differential equation in the current i.

2) Deduce that the value of the current in the steady state is $I = \frac{E}{R}$.

3) The solution of the differential equation is of the form: $i = A + B e^{-\lambda t}$. Determine the expression of the constants A, B and λ in terms of I , R and L.

4) When k is opened we observe a spark on k.
   a) Name the phenomenon responsible of this spark.
   b) To eliminate this spark a neutral capacitor is used. How should it be connected?

Fourth exercise: (7 points)

Nuclear reactions

Given: mass of a proton: $m_p = 1.0073$ u; mass of a neutron: $m_n = 1.0087$ u;

mass of ${}^{235}_{92}U$ nucleus = 235.0439 u; mass of ${}^{90}_{36}Kr$ nucleus = 89.9197 u;

mass of ${}^{142}_{Z}Ba$ nucleus =141.9164 u; molar mass of ${}^{235}_{92}U$ = 235 g/mole;

Avogadro's number: $N_A = 6.022\times10^{23}$ mol^{-1}; 1u = 931.5 MeV/c^2 = 1.66×10^{-27} kg; 1 MeV = 1.6×10^{-13} J.

A – Provoked nuclear reaction

As a result of collision with a thermal neutron, a uranium 235 nucleus undergoes the following reaction:

$${}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{90}_{36}Kr + {}^{142}_{Z}Ba + y\,{}^{1}_{0}n$$

1) **a)** Determine y and z.

b) Indicate the type of this provoked nuclear reaction.

2) Calculate, in MeV, the energy liberated by this reaction.

3) In fact, 7% of this energy appears as a kinetic energy of all the produced neutrons.

a) Determine the speed of each neutron knowing that they have equal kinetic energy.

b) A thermal neutron, that can provoke nuclear fission, must have a speed of few km/s; indicate then the role of the "moderator" in a nuclear reactor.

4) In a nuclear reactor with uranium 235, the average energy liberated by the fission of one nucleus is 170 MeV.

a) Determine, in joules, the average energy liberated by the fission of one kg of uranium ${}^{235}_{92}U$.

b) The nuclear power of such reactor is 100 MW. Calculate the time Δt needed so that the reactor consumes one kg of uranium ${}^{235}_{92}U$.

B – Spontaneous nuclear reaction

1) The nucleus krypton ${}^{90}_{36}Kr$ obtained is radioactive. It disintegrates into zirconium ${}^{90}_{40}Zr$, by a series of β^- disintegrations.

a) Determine the number of β^- disintegrations.

b) Specify, without calculation, which one of the two nuclides ${}^{90}_{36}Kr$ and ${}^{90}_{40}Zr$ is more stable.

2) Uranium ${}^{235}_{92}U$ is an α emitter.

a) Write down the equation of disintegration of uranium ${}^{235}_{92}U$ and identify the nucleus produced.

Given:

Actinium ${}_{89}Ac$	Thorium ${}_{90}Th$	Protactinium ${}_{91}Pa$

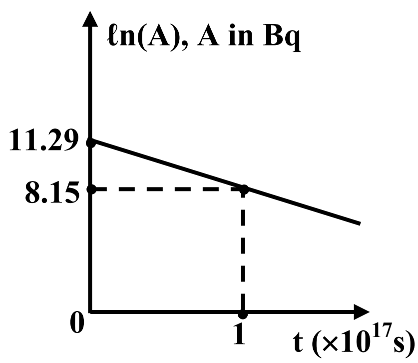
b) The remaining number of nuclei of ${}^{235}_{92}U$ as a function of time is given by: $N = N_0\, e^{-\lambda t}$ where N_0 is the number of the nuclei of ${}^{235}_{92}U$ at $t_0 = 0$ and λ is the decay constant of ${}^{235}_{92}U$.

i) Define the activity A of a radioactive sample.

ii) Write the expression of A in terms of λ, N_0 and time t.

c) Derive the expression of $\ell n(A)$ in terms of the initial activity A_0, λ and t.

d) The adjacent figure represents the variation of $\ell n(A)$ of a sample of ${}^{235}_{92}U$ as a function of time.



i) Show that the shape of the graph, in the adjacent figure, agrees with the expression of $\ell n(A)$.

ii) Using the adjacent figure determine, in s^{-1}, the value of the radioactive constant λ.

iii) Deduce the value of the radioactive period T of ${}^{235}_{92}U$.

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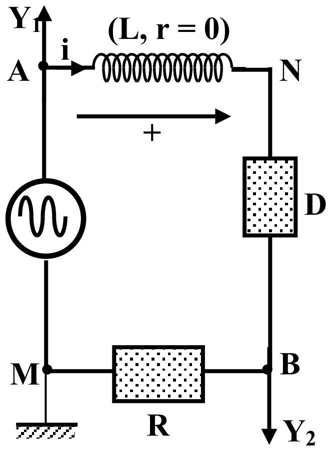
مشروع معيار التصحيح	مسابقة في مادة الفيزياء المدة ثلاث ساعات	الاسم: الرقم:

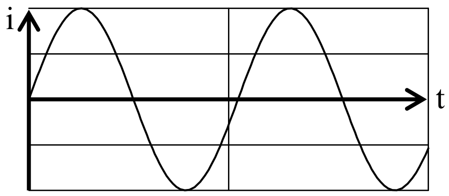
First exercise (7 points)

Part of the Q	Answer	Mark
A.1.a	$ME = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$	½
A.1.b	No frictional forces (No non-conservative forces), ME is conserved $\Rightarrow \frac{dME}{dt} = 0 \Rightarrow x'' + \frac{k}{m}x = 0.$	¾
A.2.a	$x = X_m \sin(\frac{2\pi}{T_o}t + \varphi)$ $x' = X_m \frac{2\pi}{T_o}\cos(\frac{2\pi}{T_o}t + \varphi)$; $x'' = -X_m \frac{4\pi^2}{T_0^2}\sin(\frac{2\pi}{T_o}t + \varphi)$ Sub. in the differential equation : $-X_m \frac{4\pi^2}{T_0^2}\sin(\frac{2\pi}{T_o}t + \varphi) + \frac{k}{m}X_m \sin(\frac{2\pi}{T_o}t + \varphi) = 0$ $\Rightarrow \frac{4\pi^2}{T_0^2} = \frac{k}{m} \Rightarrow T_o = 2\pi\sqrt{\frac{m}{k}} = 2\times 3.14\sqrt{\frac{0.25}{10}} = 0.993\ s \approx 1\ s$	1^+
A.2.b	For t = 0 : x = 2 cm $\Rightarrow 2 = X_m \sin\varphi$ v = – 20 cm/s $\Rightarrow -20 = X_m \times 2\pi\cos\varphi$ The ratio gives : $\tan\varphi = -0.628 \Rightarrow \varphi = -0.56$rd or 2.58 rad For $\varphi = -0.56$rd we get : $X_m = -3.77$ cm < 0 rejected For $\varphi = 2.58$rd we get : $X_m = 3.77$ cm > accepted Therefore $X_m = 3.77$ cm and $\varphi = 2.58$ rad .	1^+
B.1	The graph gives T = 1 s slightly greater than $T_o = 0.993$ s.	½
B.2	On the graph of figure 2 , at $t_0 = 0$, x is maximum therefore $PEe \neq 0$ $\Rightarrow$ curve A represents the variations of PEe.	½
B.3.a	$\frac{X_m(T)}{X_m(0)} = \frac{12.5}{20} = 0.625$; $\frac{X_m(2T)}{X_m(T)} = \frac{7.5}{12.5} = 0.6 \Rightarrow a = 0.6$	½
B.3.b	$a = e^{-\frac{\mu T}{2m}} = 0.6 \Rightarrow \frac{-\mu T}{2m} = \ell n 0.6 \Rightarrow \mu = 0.255$ kg/s.	¾
B.4.a.i	At instant t_1, the KE is maximum therefore v has a maximum value.	+
B.4.a.ii	At instant t_2 , the KE is equal to zero $\Rightarrow$ v has a zero value.	+
B.4.b	At instant t_1, f has large amplitude (v maximum). At instant t_2, f is equal to zero (v = 0) .	½
B.4.c	Around (t_1) the force of friction is maximum $\Rightarrow$ the mechanical energy decreases by greater value.	½

Second exercise (7 points)

Part of the Q	Answer	Mark
A.1		½
A.2.a	$T = 8$ ms $\Rightarrow f = 125$ Hz. $\omega = 2\pi f = 250\pi$ rad/s.	1
A.2.b	$U_m = 3\times 2 = 6$ V.	+
A.2.c	$U_{m(R)} = 0.5\times 4 = 2$ V $\Rightarrow I_m = \dfrac{U_m(R)}{R} = 2\times 10^{-2}$ A	¾
A.2.d	$\lvert\varphi\rvert = \dfrac{2\pi}{8} = \dfrac{\pi}{4}$ rad ; i leads u_{AM}	¾
A.3	i leads u_{AM} $\Rightarrow$ (D) is a capcitor	+
A.4	$i = 2\times 10^{-2}\ \sin(250\pi t + \dfrac{\pi}{4})$ (i in A and t in s)	½
A.5	$i = C\dfrac{du_{BN}}{dt} \Rightarrow u_{NB} = \dfrac{1}{C}\int i\,dt = \dfrac{1}{C}\int 0.02\sin(\omega t + \dfrac{\pi}{4})dt$ $\Rightarrow u_{NB} = -\dfrac{0.02}{250\pi C}\cos(250\pi t + \dfrac{\pi}{4})$	¾
A.6	$U_m\sin(\omega t) = L\omega I_m\cos(\omega t + \dfrac{\pi}{4}) - \dfrac{0.02}{250\pi C}\cos(250\pi t + \dfrac{\pi}{4}) + 2\sin(\omega t + \dfrac{\pi}{4})$ $t = 0 \Rightarrow 0 = L\omega I_m\dfrac{\sqrt{2}}{2} - \dfrac{0.02}{250\pi C}\times\dfrac{\sqrt{2}}{2} + 2\dfrac{\sqrt{2}}{2} \Rightarrow C = 1.06\times 10^{-6}$ F	1.25
B.1	Current resonance	+
B.2	$f_0 = \dfrac{1}{2\pi\sqrt{LC}} \Rightarrow C = 1.06\times 10^{-6}$ F	¾

Third exercise (6 ½ points)

Partie de la Q.	Corrigé	Note
A.1.a	Electric energy	+
A.1.b	$E_{mag} = 0 = ½ Li^2 \Rightarrow i = 0$	½
A.2	At instant t : $E_{total} = E_{elect} + E_{mag} = ½ q^2/C + ½ Li^2 = \text{constant}$ With $i = -\frac{dq}{dt} = - q'$ and $i' = -\frac{d^2q}{dt^2} = - q''$ $\frac{dE}{dt} = 0 \Rightarrow \frac{qq'}{C} + Lii' = 0$ $\Rightarrow \frac{qq'}{C} + L(-q')(-q'') = 0 \Rightarrow q'(\frac{q}{C} + Lq'') = 0$ or $q' \neq 0 \Rightarrow q'' + \frac{1}{LC} q = 0$	¾
A.3.a	$q = Q_m \cos(\omega_0 t + \phi) \Rightarrow \dot{q} = -\omega_0 Q_m \sin(\omega_0 t + \phi)$ $\Rightarrow \ddot{q} = - Q_m(\omega_0)^2 \cos(\omega_0 t + \phi)$; $i = -\frac{dq}{dt} = \omega_0 Q_m \sin(\omega_0 t + \phi)$; for $t = 0$, $i = 0 \Rightarrow 0 = \sin\phi = 0$; $\Rightarrow \phi = 0$ or π rad; for $t= 0$ $q = Q_0 > 0 = Q_m \cos\phi$, with $Q_m > 0 \Rightarrow \cos\phi > 0 \Rightarrow \phi = 0$.	1
A.3.b	$Q_0 = Q_m \cos\phi \Rightarrow Q_m = Q_0$. Replace $q = Q_0 \cos\omega_0 t$ in the differential equation: $- Q_0(\omega_0)^2 \cos(\omega_0 t) + Q_0 \frac{1}{LC} \cos(\omega_0 t) = 0 \Rightarrow \omega_0^2 = \frac{1}{LC} \Rightarrow \omega_0 = \sqrt{\frac{1}{LC}}$	¾
A.4.a	$i = -\frac{dq}{dt} = \omega_0 Q_m \sin(\omega_0 t + \phi) \Rightarrow i = \omega_0 Q_m \sin(\omega_0 t)$	¾
A.4.b		¼
B.1	$u_{AD} = u_{AB} + u_{BD} \Rightarrow E = Ri + L \frac{di}{dt}$,	½
B.2	$E = Ri + L \frac{di}{dt}$, with $u_C = L \frac{di}{dt}$; at steady state, $i = \text{constant} = I$ $\Rightarrow \frac{di}{dt} = 0 \Rightarrow E = RI$ and $I = \frac{E}{R}$.	½
B.3	$i = A + B.e^{-\lambda t}$ At $t_0 = 0 : A + B = i = 0 \Rightarrow A = - B$ $\frac{di}{dt} = -\lambda B e^{-\lambda t} \Rightarrow E = RA - RAe^{-\lambda t} + L\lambda A e^{-\lambda t} \Rightarrow Ae^{-\lambda t}(L\lambda - R) + RA = E$ by identification : $L\lambda - R = 0 \Rightarrow \lambda = \frac{R}{L}$ and $RA = E \Rightarrow A = \frac{E}{R}$ $\Rightarrow B = -A = -\frac{E}{R}$	1
B.4.a	Self - induction	+
B.4.b	Across the switch k	+

Fourth exercise (7 points)

Part of the Q	Answer	Mark
A.1.a	Conservation of charge number: 92 + 0 = 36 + z + 0 thus z = 56 Conservation of mass number: 235 + 1 = 90 + 142 + y thus y = 4	¾
A.1.b	Fission nuclear reaction	¼
A.2	$\Delta m = [m_U + m_n] - [m_{Kr} + m_{Ba} + 4m_n]$ $=235.0439 - [89.9197 + 141.9164 + 3\times1.0087] = 0.1817$ u $E = \Delta mc^2 = [0.1817\times931.5 \text{ Mev}/c^2]\, c^2 = 169.253$ MeV	¾
A.3.a	K.E of each neutron = $\dfrac{169.253\times\frac{7}{100}}{4}$ = 2.96 MeV = $2.96\times1.6\times10^{-13}$ K.E = 4.739×10^{-13} J K.E = ½ mV^2 then V = $\sqrt{\dfrac{2KE}{m}} = \sqrt{\dfrac{2\times4.739\times10^{-13}}{1.0087\times1.66\times10^{-27}}}$ V = 2.379×10^7 m/s = 23790 km/s.	½
A.3.b	A moderator will help in reducing their speed so as to provoke more such reactions	¼
A.4.a	N = $\dfrac{\text{mass}}{\text{molar mass}}\times N_A = \dfrac{1000}{235}\times6.02\times10^{23} = 2.5617\times10^{24}$ nuclei. E = $170\times1.6\times10^{-13}\times2.5617\times10^{24} = 6.97\times10^{13}$ J	½
A.4.b	$E = P\times\Delta t \Rightarrow \Delta t = \dfrac{6.97\times10^{13}}{10^8} = 6.97\times10^5$ s = 8 days	½
B.1.a	${}^{90}_{36}Kr \rightarrow {}^{90}_{40}Zr + a\,{}^{0}_{-1}\beta$ a = 4	¼
B.1.b	A non-stable nucleus decays into a more stable one thus ${}^{90}_{40}Zr$ is more stable	¼
B.2.a	${}^{235}_{92}U \rightarrow {}^{4}_{2}He + {}^{A}_{Z}X$, A = 231 and Z = 90 ⇒X is thorium	½
B.2.b.i	The activity is the number of decays per unit time	¼
B.2.b.ii	$A = \lambda N = \lambda N_0 e^{-\lambda t}$	¼
B.2.c	$\ell n(A) = -\lambda t + \ell n(A_0)$.	½
B.2.d.i	$\ell n(A) = -\lambda t + \ell n(A_0)$ is a straight line of negative slope ⇒ compatible with the graph.	½
B.2.d.ii	λ = – slope of curve = 3.14×10^{-17} s^{-1},	½
B.2.d.iii	$\lambda = \dfrac{\ell n(2)}{T} \Rightarrow T = 22.0747\times10^{15}$s $= 7\times10^8$ years.	½

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مسابقة في مادة الفيزياء المدة ثلاث ساعات	الاسم: الرقم:

<u>This exam is formed of four exercises in four pages.</u>
<u>The use of non-programmable calculator is recommended.</u>

<u>First exercise</u>: (7 points)

The flash of a camera

The electronic flash of a camera is made primarily of a capacitor of capacitance C, a flash lamp and of an electronic circuit which transforms the constant voltage E = 3 V provided by two dry cells into a constant voltage U_0 = 300 V. The aim of this exercise is to show the importance of the electronic circuit in the electronic flash of a camera.

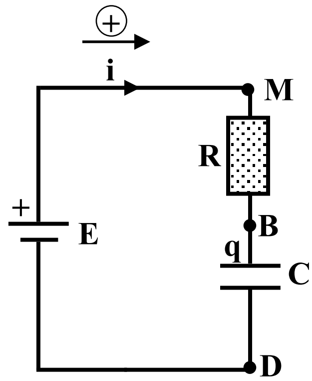


Fig. 1

A – Determination of the value of the capacitance C of the capacitor

To determine the value of the capacitance C of the capacitor, we connect the circuit of figure 1 where the resistor has a large resistance R, the DC generator maintains across its terminals a constant voltage E = 3 V. An appropriate device allows to plot the curve representing the variations of the current i as a function of time. The capacitor, being uncharged, at the instant $t_0 = 0$, we close the circuit. We obtain the graph of figure 2.

1) a) Determine the expression of the current i in terms of C and the voltage $u_C = u_{BD}$ across the terminals of the capacitor.

b) By applying the law of addition of voltages, determine the differential equation of the voltage u_C.

2) The solution of this differential equation is given by:

$u_C = E(1 - e^{-\frac{t}{\tau}})$ where $\tau = RC$.

a) Determine, as a function of time t, the expression of the current i.

b) Deduce, at the instant $t_0 = 0$, the expression of the current I_0 in terms of E and R.

c) Using figure 2:

i) calculate the value of the resistance R of the resistor;

ii) determine the value of the time-constant τ of the circuit.

d) Deduce that $C \approx 641\ \mu F$.

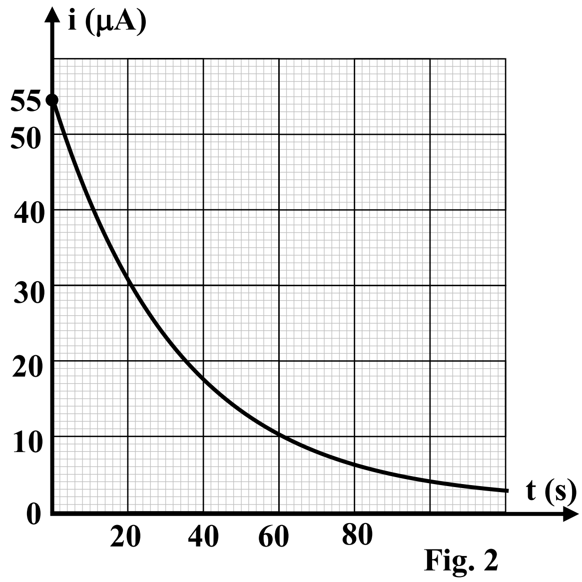


Fig. 2

B – Energetic Study

1) Show that the electric energy stored in the capacitor, when it is completely charged under the voltage E is $W \approx 2.9 \times 10^{-3}$ J.

2) The capacitor, being totally charged, is disconnected from the circuit and discharges through a resistor of same resistance R. Calculate:

a) the duration at the end of which the capacitor can be practically completely discharged ;

b) the average power given by the capacitor during the discharging process.

C – The flash of the camera

The discharge in the flash lamp causes a flash of duration approximately one millisecond .

1) Determine the value of the average electric power P_e consumed by this flash if the capacitor is charged under the voltage:
   a) $E = 3$ V ;
   b) $U_0 = 300$ V.
2) Explain why it is necessary to raise the voltage before applying it across the terminals of the capacitor.

Second exercise: (7 points)

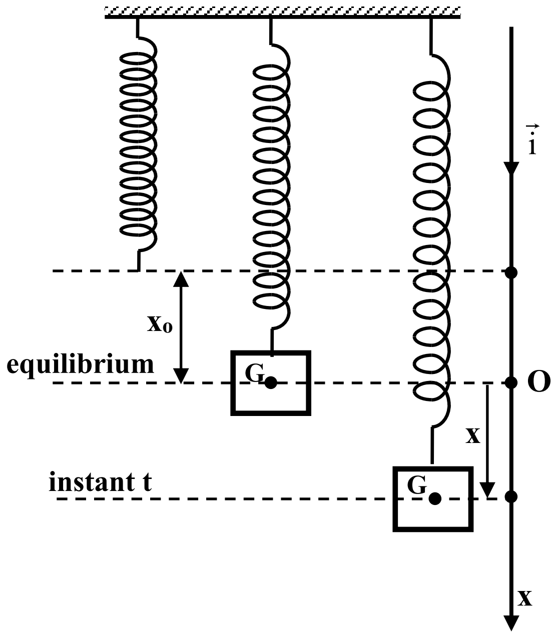
Measurement of the gravitational acceleration

In order to measure the gravitational acceleration, we consider a spring of stiffness k and of negligible mass, connected from its upper end to a fixed support while its other end carries a solid (S) of mass m. At equilibrium the center of mass G of (S) coincides with a point O and the spring elongates by $\Delta\ell_o = x_o$ (adjacent figure).

We denote by g the gravitational acceleration.

The spring is stretched by pulling (S) vertically downwards from its equilibrium position, then releasing it without initial velocity at instant $t_o = 0$. G oscillates around its equilibrium position O. At an instant t, G is defined by its abscissa $x = \overline{OG}$ and the algebraic value of its velocity is $v = \frac{dx}{dt}$.

The horizontal plane passing through O is taken as a reference of gravitational potential energy.



A – Static study

1) Name the external forces acting on (S) at the equilibrium position.
2) Determine a relation among m, g, k and x_o.

B – Energetic study

1) Write, at an instant t, the expression of the :
   a) kinetic energy of (S) in terms of m and v;
   b) elastic potential energy of the spring in terms of k , x and x_o ;
   c) gravitational potential energy of the system [(S), Earth] in terms of m, g and x.
2) Show that the expression of the mechanical energy of the system [(S), spring, Earth] is given by:
   $ME = \frac{1}{2}mv^2 + \frac{1}{2}k(x + x_o)^2 - mgx$.
3) a) Applying the principle of the conservation of the mechanical energy, show that the differential equation in x that describes the motion of G has the form of : $x'' + \frac{k}{m}x = 0$.
   b) Deduce the expression of the proper period T_o of the oscillator in terms of m and k.
   c) Show that the expression of T_o is given by: $T_o = 2\pi\sqrt{\frac{x_0}{g}}$.

C – Experimental study

For different solids of different masses suspended to the same spring, we measure using a stop watch the corresponding values of T_o . The results are collected in the following table:

m (g)	20	40	60	80	100
x_o (cm)	4	8	12	16	20
T_o (s)	0.4	0.567	0.693	0.8	0.894
T_o^2 (s^2)	0.16		0.48	0.64	

1) Complete the table.

2) Plot the curve giving the variations of x_o as a function of T_o^2.

Scale : on the abscissa-axis: 1cm represents 0.16 s^2

on the ordinate –axis: 1cm represents 4 cm.

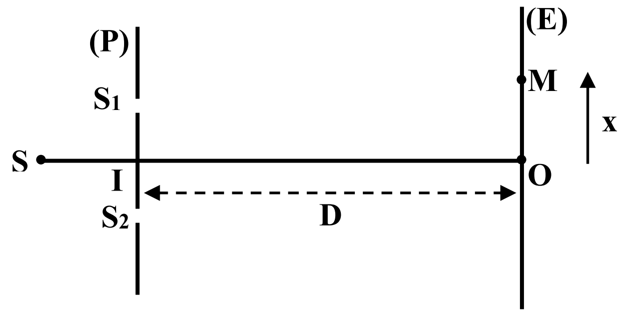
3) Determine the slope of this curve and, using the expression $T_o = 2\pi\sqrt{\frac{x_0}{g}}$, deduce the value of the gravitational acceleration.

<u>Third exercise</u>: (6 points)

Interference of light

Consider Young's double slit apparatus that is represented in the adjacent figure. S_1 and S_2 are separated by a distance a = 1 mm.

The planes (P) and (E) are at a distance D = 2 m. I is the midpoint of [S_1S_2] and O is the orthogonal projection of I on (E). On the perpendicular to IO at point O and parallel to S_1S_2, a point M is defined by its abscissa OM = x.



The optical path difference δ at M ($\overline{OM}$ = x), located in the interference region on the screen of observation is: $\delta = SS_2M - SS_1M = \frac{ax}{D}$.

A – The source S emits a monochromatic light of wavelength λ in air.

1) The phenomenon of interference of light shows evidence of an aspect of light. Name this aspect.

2) Indicate the conditions for obtaining the phenomenon of interference of light.

3) Describe the interference fringes that observed on (E).

4) Determine the expression giving the abscissa of the centers of the bright fringes and that of the centers of the dark fringes.

5) Deduce the expression of the interfringe distance in terms of λ, D and a.

B – The source S emits white light which contains all the visible radiations of wavelengths λ in vacuum or in air where: 400 nm (violet) ≤ λ ≤ 800 nm (red).

1) The obtained central fringe is white. Justify.

2) Compare the positions of the centers of the first bright fringes corresponding to red and violet colors on the same side of O.

3) The point M has an abscissa x = 4 mm.

a) Show that the wavelengths of the radiations that reach M in phase are given by: λ (in nm) = $\frac{2000}{k}$, k being a non- zero positive integer.

b) Determine the wavelengths of these radiations.

C – The source S emits two radiations of wavelengths λ_1 = 450 nm and λ_2 = 750 nm.

Determine the abscissa x of the nearest point to O, where two dark fringes coincide.

Fourth exercise: (7.5 points)

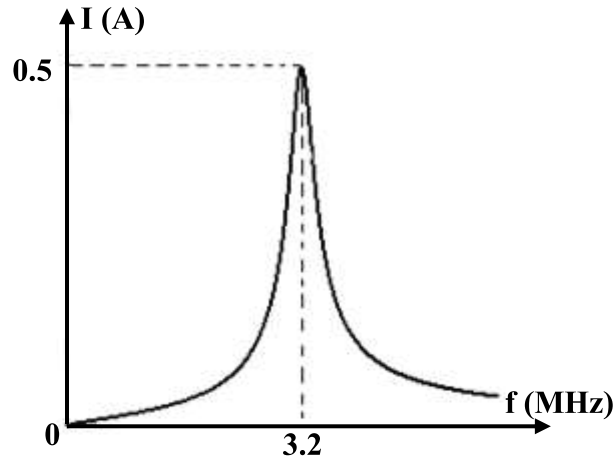
Electric resonance: danger and utilization

The aim of this exercise is to show evidence of the danger that may appear as a result of current resonance in an electric circuit and the application of this phenomenon in the radio receiver.
Consider an electric component (D) that is formed of a series connection of a coil of negligible resistance and of inductance L, a capacitor of capacitance $C = 5 \times 10^{-10}$ F and a resistor of resistance R.
A low frequency generator of adjustable frequency f feeds the component (D) with a sinusoidal alternating voltage $u = 5\sqrt{2}\sin(2\pi f t)$, (u in V; t in s).
Thus the circuit carries a sinusoidal alternating current i of the same frequency f.

Take: $\pi = \frac{1}{0.32}$; 1 MHz = 10^6 Hz.

1) Name the type of electric oscillations that takes place in the circuit.

2) We vary the frequency f of the voltage delivered by the generator and we measure, for each value of f, the effective value I of the current i in the circuit.
The obtained measurements allow us to plot the curve represented in the adjacent figure.



a) Using the figure, give:

i) the maximum value I_o of I;

ii) the frequency f_o for which we get current resonance;

iii) the range of the frequencies of the generator, so that the current i leads the voltage across the generator.

b) Current resonance takes place in the component (D).

i) Name the exciter and the resonator.

ii) Give the value of the phase difference between u and i.

iii) The average power consumed by the component (D) is maximum. Justify.

iv) Calculate the value of this power.

v) Prove that $R = 10\ \Omega$ and $L = 5 \times 10^{-6}$ H.

3) When a student operates with an electric circuit, he must respect the elementary rules of safety.
There is a risk of electrocution with a voltage greater than 24 V.
Current resonance takes place in the component (D).

a) **i)** Write the expression of the current i in the circuit as a function of time.

ii) Deduce the expression of the voltage across the terminals of the capacitor.

b) If the effective voltage across the capacitor is clearly greater than the effective voltage U across the component (D); we say there is an over voltage across the terminals of the capacitor.

i) Calculate the effective voltage across the terminals of the capacitor.

ii) Show that there will be an over voltage across the terminals of the capacitor during resonance.

iii) A student adjusts a voltage of effective value 5 volts across the component (D). Specify the risk that the student may face.

4) We want to capture, with the radio receiver, the emission of a station (S) of wavelength $\lambda = 94$ m.
Receiving is best when the frequency of the wave of the chosen station is close to the proper frequency of the (L, C) receiver. The component (D) constitutes the circuit of reception of the considered radio receiver. Can the radio receiver capture the emission of the station (S)? Justify your answer knowing that the radio waves travel in air with the speed $c = 3 \times 10^8$ m/s.

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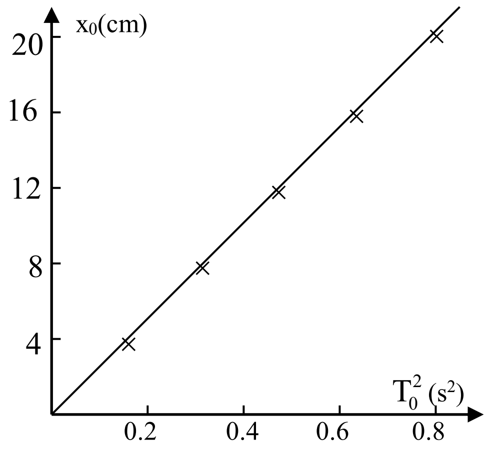
مشروع معيار التصحيح	مسابقة في مادة الفيزياء المدة ثلاث ساعات	الاسم: الرقم:

First exercise (7 points)

Part of the Q	Answer	Mark
A.1.a	The expression of i: $i = \frac{dq}{dt} = C\frac{du_C}{dt}$	0.5
A.1.b	$u_{MD} = u_{MB} + u_{BD} \Rightarrow E = Ri + u_C \Rightarrow E = RC\frac{du_C}{dt} + u_C$	0.5
A.2.a	$i = C\frac{du_C}{dt} = C\frac{E}{RC}e^{-\frac{t}{\tau}}, \Rightarrow\ i = \frac{E}{R}e^{-\frac{t}{\tau}}.$	0.5
A.2.b	At the instant $t_0 = 0$, $I_0 = \frac{E}{R}$.	0.25
A.2.c.i	At the instant $t_0 = 0$, $I_0 = 55\ \mu A \Rightarrow R = 54545.45\ \Omega$.	0.5
A.2.c.ii	For $i = 0.37\ I_0 = 20.35 \approx 20\ \mu A$, $t = \tau = 35$ s.	0.75
A.2.d	$\tau = RC \Rightarrow C = 641\ \mu F$.	0.5
B.1	Electric energy $W = ½\ CE^2 = ½ \times 641\times 10^{-6}\times 9 = 2,9\times 10^{-3}$J	0.5
B.2.a	The duration: $\Delta\tau = 5\tau = 175$ s.	0.5
B.2.b	The average power of the discharge : $\frac{W}{\Delta t} = \frac{2.9\times 10^{-3}}{175} = 1.65\times 10^{-5}$ W	0.75
C.1.a	$W_1 = ½\ CE^2 = 2.9\times 10^{-3}J \Rightarrow P_1 = \frac{W_1}{t} = 2.9$ W.	0.5
C.1.b	$W_2 = ½\ C U_0^2 = 28.845J \Rightarrow P_2 = \frac{W_2}{t} = 28845$ W	0.75
C.2	To increase the power consumed by the flash lamp during discharge.	0.5

Second exercise (7 points)

Part of the Q	Answer	Mark
A.1	The weight $m\vec{g}$ and the force of tension $\vec{T}$ in the spring	0.5
A.2	At equilibrium, $\vec{T} = -m\vec{g} \Rightarrow T = mg \Rightarrow mg = k\,x_0$.	0.75
B.1.a	$KE = \frac{1}{2}mV^2$	0.25
B.1.b	$PE_{el} = \frac{1}{2}k(x+x_o)^2$	0.25
B.1.c	$PE_g = -\ mgx$	0.25
B.2	$ME = KE + PE_{el} + PE_g$ $ME = \frac{1}{2}mV^2 + \frac{1}{2}k(x+x_o)^2 - mgx$.	0.25
B.3.a	ME is conserved $\Rightarrow \frac{dME}{dt} = 0 \Rightarrow \frac{1}{2}m2vx'' + \frac{1}{2}k2(x + x_o)\,v - mgv = 0$ $\Rightarrow V\,(\,mx'' + kx_o - mg + kx\,) = 0$ But $V \neq 0$ and $mg = kx_o$ therefore $x'' + \frac{k}{m}x = 0$.	1
B.3.b	This differential equation is of the form $x'' + \omega_o^2\,x = 0$ therefore : $\omega_o = \sqrt{\frac{k}{m}}$ and $T_o = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{m}{k}}$	1
B.3.c	$mg = kx_o \Rightarrow \frac{m}{k} = \frac{x_o}{g} \Rightarrow T_o = 2\pi\sqrt{\frac{x_0}{g}}$	0.5
C.1	The missed values are :0.321; 0.799 .	0.5
C.2	See figure  	0.5
C.3	The curve is a straight line passing through the origin. The slope is : $a = \frac{x_0}{T_0^2} = 0.25\ m/s^2$. On the other hand : $T_0^2 = 4\pi^2\frac{x_0}{g}$ and $g = 4\pi^2\frac{x_0}{T_0^2}$ $\Rightarrow g = 9.86\ m/s^2$.	1.25

Third exercise (6 points)

Part of the Q	Answer	Mark
A.1	The wave aspect of light	0.5
A.2	The two sources S_1 and S_2 are synchronized and coherent	0.5
A.3	We observe interference fringes : - alternate bright and dark fringes ; - rectilinear and equidistant - parallel of $S_1$and S_2	0.5
A.4	Bright fringe: $\delta = k\lambda = \frac{ax}{D} \Rightarrow x = \frac{k\lambda D}{a}$. Dark fringe: $\delta = (2k+1) = \frac{ax}{D} \Rightarrow x = \frac{(2k+1)\lambda D}{2a}$	1
A.5	$i = x_{k+1} - x_K = (k+1)\frac{\lambda D}{a} - \frac{k\lambda D}{a} = \frac{\lambda D}{a}$	0.5
B.1	each radiation of the white light gives out at O a bright fringe; the superposition of all radiation at O gives the white color	0.5
B.2	$x_V = k\frac{\lambda_v D}{a}$ et $x_R = k\frac{\lambda_R D}{a} \Rightarrow \lambda_R > \lambda_v \Rightarrow x_R > x_v$	0.5
B.3.a	$x = \frac{k\lambda D}{a} \Rightarrow 4\times10^6 \text{(in nm)} = \frac{k\lambda\times2\times10^9}{1\times10^6} \Rightarrow \lambda \text{ (in nm)} = \frac{2000}{k}$	0.5
B.3.b	$400 \le \lambda = \frac{2000}{k} \le 800 \Rightarrow$ $2.5 \le k \le 5 \Rightarrow k = 3, 4$ and 5 $\Rightarrow \lambda_1 = \frac{2000}{3} = 667$ nm ; $\lambda_2 = \frac{2000}{4} = 500$ nm; $\lambda 3_2 = \frac{2000}{5} = 400$ nm .	0.75
C	The abscissa of points on the screen where the radiations arrive in opposition of phase is: $x = \frac{(2k+1)\lambda D}{2a} \Rightarrow$ $\frac{(2k_1+1)\lambda_1 D}{2a} = \frac{(2k_2+1)\lambda_2 D}{2a} \Rightarrow \frac{(2k_1+1)}{(2k_1+1)} = \frac{\lambda_2}{\lambda_1} = \frac{5}{3}$ $(2k_1+1)\lambda_1 = (2k_2+1)\lambda_2$; $\Rightarrow (2k_1+1)\times450 = (2k_2+1)\times750$; $\lambda_1 < \lambda_2$ $\Rightarrow k_1 > k_2$; $900k_1 + 450 = 1500k_2 + 750 \Rightarrow 3k_1 - 5k_2 = 1$. This equation is verified for $k_1 = 2$ and $k_2 = 1$ (first solution) $x \text{ (in mm)} = \frac{(4+1)450\times10^{-6}\times2\times10^3}{2\times1} = 2.25$ mm.	0.75

Fourth exercise (7.5 points)

Part of the Q	Answer	Mark
1	Forced electric oscillations	0.5
2.a.i	$I_0 = 0.5A$	0.25
2.a.ii	$f_0 = 3.2\times10^6 HZ$	0.25
2.a.iii	$0 < f < 3.2$ MHz	0.5
2.b.i	The exciter is the generator; the resonator is (L, C).	0.5
2.b.ii	$\phi = 0$.	0.25
2.b.iii	$P = UICos\,\phi$; at resonance $I = I_{max} = I_0$ and $Cos\,\phi = 1$ is max. since U = cte , P is max .	0.5
2.b.iv	$P_{max} = 5\times0.5\times1 = 2.5W.$	0.5
2.b.v	$P = R\times I_0^2 \Rightarrow R = \frac{2.5}{0.25} = 10\Omega$. At resonance $f_0 = \frac{1}{2\pi\sqrt{LC}} \Rightarrow L = 5\times10^{-6}H$.	1
3.a.i	$i = I_0\sqrt{2}\sin(2\pi f_0 t)$	0.25
3.a.ii	$i = \frac{dq}{dt} = C\frac{du_c}{dt} \Rightarrow u_c = \frac{1}{C}\text{Primitive of } i = -\frac{I_0\sqrt{2}}{2\pi f_0 C}\cos(2\pi f_0 t)$	0.5
3.b.i	$U_c = \frac{I_0}{2\pi f_0 C} = \frac{0.5}{2\pi\times3.2\times10^6\times5\times10^{-10}} = 50V$	0.5
3.b.ii	$U_c = 50V > U = 5V$ $\Rightarrow$ At resonance, there will be over voltage across the capacitor.	0.25
3.b.iii	possibility of electrocution since $U_C > 24V$	0.5
4	$\lambda = \frac{c}{f}$ (f being the frequency of the wave emitted by the station) $\Rightarrow f = \frac{3\times10^8}{94} = 3.19\times10^6 Hz$; f being so close to the proper frequency $\frac{1}{2\pi\sqrt{LC}} = 3.2\times10^6 Hz$ of the component (D), we expect then to have resonance and (S) will capture the emission	1.25

الاسم:	مسابقة في مادة الفيزياء
الرقم:	المدة ثلاث ساعات

This exam is formed of four exercises in four pages numbered from 1 to 4.
The use of non-programmable calculator is recommended,

First exercise: (7.5 points) Variation of the kinetic energy of a system

The aim of this exercise is to verify the theorem of kinetic energy of a system.
The skier (S) of mass M = 80 kg, moves down from O to A, with a constant velocity $\vec{v} = v\vec{i}$, where v = 30m/s along the line of greatest slope of a track inclined by an angle $\alpha = 30^\circ$ with the horizontal. The track exerts on the skier a constant force of friction $\vec{f} = -f\vec{i}$.
The motion of the skier is represented by the motion of its center of mass G on $\overrightarrow{x'x}$ where $\vec{i}$ is a unit vector along this axis (figure 1).
Neglect the air resistance on the skier.
Take:

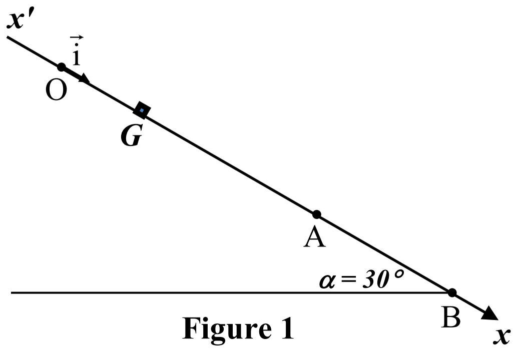


Figure 1

- the horizontal plane through B as a gravitational potential energy reference for the system (skier, Earth).
- $g = 10\ m/s^2$.

1) Name and represent the external forces acting on G along the path OA.

2) **a)** Show that the linear momentum $\vec{P}$ of the skier is constant.
b) Apply Newton's second law on the skier, between the points O and A, deduce the magnitude of $\vec{f}$.

3) The skier, upon reaching A, starts exerting a constant braking force $\vec{f_1} = -f_1\vec{i}$ to stop at B. The skier covers the distance AB during a time interval $\Delta t = 3$ s.
a) Determine the magnitude of $\vec{f_1}$, assuming that $\frac{\Delta\vec{P}}{\Delta t} \approx \frac{d\vec{P}}{dt}$.
b) The mechanical energy of the system (skier, Earth) decreases from A to B. Name the forces that are responsible of this decrease.
c) Determine the distance AB covered by the skier during the time interval Δt.

4) **a)** Determine between A and B :
i. the variation of the gravitational potential energy ΔPE_g of the system (skier, Earth) ;
ii. the work done by the weight $W_{m\vec{g}}$.
b) Compare ΔPE_g and $W_{m\vec{g}}$.

5) ΔKE and $\sum W_{\vec{F}_{ext}}$ are respectively the variation of the kinetic energy of the skier and the algebraic sum of the work done by the external forces between A and B.
Verify, between A and B, the work-energy theorem: $\Delta KE = \sum W_{\vec{F}_{ext}}$.

<u>Second exercise</u>: (7.5 points) The characteristics of RLC series circuit

Consider:

- a generator G delivering an alternating sinusoidal voltage : $u_{AM} = u_G = u = U\sqrt{2}\cos\omega t$ (u in V and t in s), where U = 5 V and $\omega = 2\pi f$ with adjustable frequency f;
- a coil of inductance L and of negligible resistance;
- a capacitor of capacitance C;
- a resistor of resistance R = 150 Ω;
- an oscilloscope;
- a milli-ammeter of negligible resistance;
- a switch K and connecting wires.

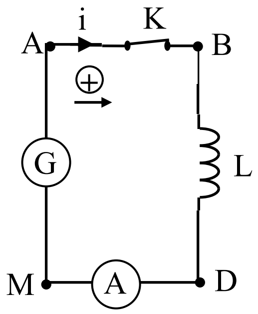


Figure 1

In order to determine L and C, we perform the following experiments:

A- First experiment

We perform successively the setup of figure 1 and of figure 2.

For f = 500 Hz, the effective current I, indicated by the milli-ammeter, has the same value I= 50mA in both setups. Take $\frac{1}{\pi} = 0.32$.

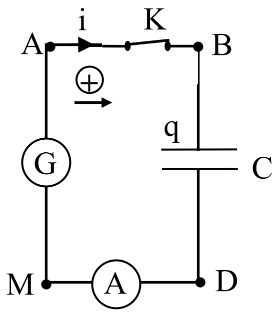


Figure 2

1) The coil is connected across the terminals of G (figure 1). The circuit carries a current i of expression $I = I\sqrt{2}\cos(\omega t - \frac{\pi}{2})$. (i in A and t in s)

- **a)** Determine the expression of the voltage $u_{BD} = u_{coil}$ in terms of L, ω, I and t.
- **b)** Deduce the value of L.

2) The capacitor is connected across the terminals of G (figure 2). The circuit carries a current i of expression $i = I\sqrt{2}\cos(\omega t + \frac{\pi}{2})$.

- **a)** Determine the expression of the voltage $u_{BD} = u_C$ in terms of C, ω, I and t.
- **b)** Deduce the value of C.

B- Second experiment

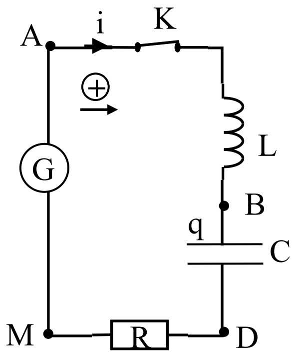


Figure 3

To verify the values obtained for L and C in the first experiment, we perform the setup of the circuit shown in Figure 3. This circuit contains the generator, the coil, the capacitor, and the resistor of resistance R = 150 Ω. The oscilloscope, displays on channel (1), the voltage u_{AM} across the generator, and on channel (2), the voltage u_{DM} across the resistor. Figure (4) shows the waveforms representing u_{AM} and u_{DM}.

The circuit carries a current $i = I\sqrt{2}\cos(\omega t + \varphi)$.

1) Redraw figure 3 and indicate the connections of the oscilloscope.

2) Apply the law of addition of voltages and give t a particular value, show that: $\tan\varphi = \dfrac{\frac{1}{C\omega} - L\omega}{R}$.

3) Referring to the waveform of Figure 4 observed on the screen of the oscilloscope, determine:

- **a)** the frequency f;
- **b)** the phase difference φ between u and i.

4) The effective voltage U being kept constant and we vary f. We observe that u_{AM} and u_{DM} become in phase when f takes the value f_0 = 500 Hz.

- **a)** Name the phenomenon that takes place.
- **b)** Give the relation giving ω_0 in terms of L and C.

5) Determine L and C.

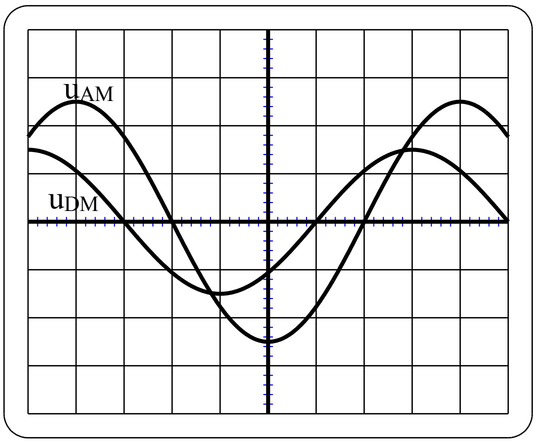


Figure 4
Horizontal Sensitivity : 0.5 ms/div

Third exercise: (7.5 points) Corpuscular aspect of light

The aim of this exercise is to study the emission spectrum of the hydrogen atom and use the emitted light to produce photoelectric effect.

Given:

- Planck's constant: $h = 6.62 \times 10^{-34}$ J.s ;
- Speed of light in vacuum: $c = 3 \times 10^{8}$ m/s ;
- 1 eV = 1.602×10^{-19} J ;
- Elementary charge: $e = 1.602 \times 10^{-19}$ C ;
- 1 nm = 10^{-9} m.

A. Hydrogen atom

The emission spectrum of the hydrogen atom constituted in its visible part of four radiations denoted by H_α, H_β, H_γ and H_δ of respective wavelengths, in vacuum, 656.27nm, 486.13nm, 435.05nm and 410.17nm.

I. In 1885, Balmer noticed that the wavelengths λ of these four radiations verify the empirical formula $\lambda = \lambda_0 \dfrac{n^2}{n^2 - 4}$ where λ_0 = 364.6 nm where n is a non-zero positive whole number.

1) The smallest value of n is 3. Justify.
2) Calculate the wavelength corresponding to this radiation.
3) Deduce the values of n corresponding to the wavelengths of the other three visible radiations in the emission spectrum of the hydrogen atom.

II. The quantized energy levels of the hydrogen atom are given by the formula:
$E_n = -\dfrac{13.6}{n^2}$ (in eV) where n is a whole non-zero positive number.
Using the expression of E_n, determine the energy of the atom when it is:
1) in the ground state.
2) in each of the first five excited levels.
3) ionized state.

B. Photoelectric effect

A hydrogen lamp of power P_S = 2W, emits uniformly radiation in all directions in a homogeneous and non- absorbing medium. This lamp illuminates a potassium cathode C of a photoelectric cell of work function W_0 = 2.20 eV and of a surface area s = 2cm^2 placed at a distance D = 1.25m from the lamp (figure1).

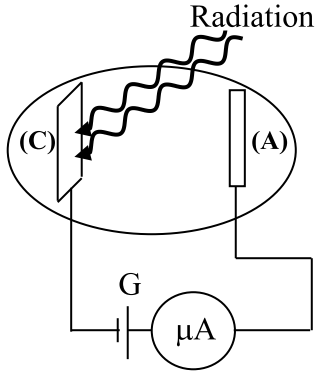


Figure 1

1) Calculate the threshold wavelength of the potassium cathode.
2) Among the rays of Balmer series, specify the radiation that can produce photoelectric emission.
3) Using a filter we illuminate the cell by a blue light H_β of wavelength λ = 486.13nm. The generator G is adjusted so that the anode (A) captures all the emitted electrons by the cathode of quantum efficiency r = 0.875%.
   a) Show that the received power of the radiation P_0 of the cell is 2.04×10^{-5}W.
   b) Determine the number N_0 of the incident photons received by the cathode C in one second.
   c) Determine the current in the circuit.

Fourth exercise: (7.5 points) Compound Pendulum

The aim of this exercise is to study the motion of a compound pendulum.

Consider a compound pendulum (P) consists:

- of a straight and homogeneous rod (R) of length AB = ℓ and of mass m ;
- of a solid (S), taken as a particle of mass m_1, free to slide along the part OB of the rod, O being the midpoint of the rod.

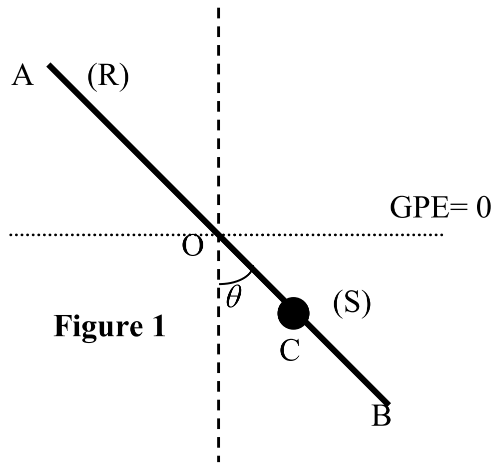


Figure 1

We fix (S) at a point C such that $\overline{OC} = x$ (x > 0).

(P) can oscillate, in a vertical plane, around a horizontal axis (Δ) perpendicular to the rod at O (figure 1).

(P) is shifted from its equilibrium position by a small angle θ_m then released without initial velocity at the instant $t_0 = 0$, the pendulum oscillate then, without friction, around its equilibrium position.

At the instant t, the angular elongation of the pendulum is θ and its angular velocity is $\theta' = \frac{d\theta}{dt}$.

Given: moment of inertia of the rod about the axis of rotation (Δ): $I_0 = \frac{1}{12} m \ell^2$, $m = 3m_1$,

$\ell = 0.5$ m, g = 10 m/s^2 and $\pi^2 = 10$.

For small θ: $\cos\theta \approx 1 - \frac{\theta^2}{2}$ and $\sin\theta \approx \theta$ (θ in rd).

G is the center of inertia of the pendulum and the horizontal plane passing through O is taken as reference level of the gravitational potential energy.

1) Show that:

a) $\overline{OG} = \frac{x}{4}$;

b) The expression of the moment of inertia of the pendulum is: $I = \frac{m}{12}(\ell^2 + 4x^2)$.

2) Determine the expression the mechanical energy of the system (pendulum, Earth) in terms of θ, θ', m ,x and ℓ.

3) **a)** Establish the second order differential equation in θ which governs the oscillations of the pendulum.

b) Deduce that the expression of the proper period of the pendulum is: $T_0 = \sqrt{\frac{4x^2 + \ell^2}{x}}$.

4) **a)** Determine the value of x for which T_0 is minimum.

b) Deduce that $T_{0(min)} = 1.41$ s.

5) Using a coupling device, the pendulum (P) plays the role of an exciter for a simple pendulum (P_1) of length $\ell_1 = 65$ cm. The oscillations of (P) and (P_1) are slightly damped.

a) Knowing that the proper period of the simple pendulum, for small oscillation, is $T = 2\pi\sqrt{\frac{\ell}{g}}$,

Calculate the value of the proper period T_{01} of (P_1).

b) **i)** (P) oscillates now with its minimum period. It is noticed that (P_1) does not enter in amplitude resonance with (P). Justify.

ii) We move (S) between O and B. For a value x_0 of x, we notice that (P_1) oscillates with large amplitude. Calculate the value of x_0.

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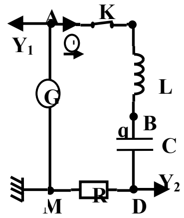
الاسم: الرقم:	مسابقة في مادة الفيزياء المدة ثلاث ساعات	مشروع معيار التصحيح

First exercise (7.5 points)

Part of the Q	Answer	Mark
1	The forces acting on the skier : • Normal reaction $\vec{N}$; • Weight $m\vec{g}$; • The frictional force $\vec{f}$ Diagram.	3/4
2.a	$\vec{P} = M\vec{V}$ since $\vec{V} = \overrightarrow{Cte} \Rightarrow \vec{P} = \overrightarrow{Cte}$.	3/4
2.b	$\frac{d\vec{P}}{dt} = \overrightarrow{Mg} + \vec{N} + \vec{f} = \vec{0}$ project along x'x: Mgsinα – f = 0 $\Rightarrow$ f = Mgsinα = 400 N.	1
3.a	$\frac{d\vec{P}}{dt} = \overrightarrow{Mg} + \vec{f} + \vec{N} + \vec{f_1} = \frac{\Delta\vec{P}}{\Delta t}$ Project along x'x $\Rightarrow -f_1 = \frac{MV_B - MV_A}{\Delta t} = -\frac{MV_A}{\Delta t} \Rightarrow f_1$= 800 N. **Or :** $\frac{\Delta\vec{P}}{\Delta t} = \sum\vec{F}_{ext} \Rightarrow \frac{\vec{P}_O - \vec{P}_A}{\Delta t} = \sum\vec{F}_{ext}$ Project along x'x : $\frac{0 - MV_A}{\Delta t} = Mg\sin\alpha - f - f_1 = 0 - f_1 = -f_1 \Rightarrow f_1 = 800N$	1
3.b	Because friction and braking forces	1/2
3.c	ΔM.E = W($\vec{f}$) + W ($\vec{f_1}$) $\Rightarrow$ M.E$_B$ –M.E$_A$ = W($\vec{f}$) + W ($\vec{f_1}$) $\Rightarrow$ -1/2 MV^2 –Mg AB sinα = - f .AB – f$_1$. AB $\Rightarrow$ (40×900) + (400 × AB) = 1200 × AB $\Rightarrow$ AB = 45 m.	1
4.a.i	ΔGPE = $GPE_B - GPE_A = 0 - Mg\ AB\sin\alpha$ = - Mg AB sinα = - 1800 J	3/4
4.a.ii	W($M\vec{g}$) = Mgh = Mg AB sinα = 1800 J	1/2
4.b	Δ(GPE) = - W ($M\vec{g}$).	1/4
5	ΔM.E = ΔK.E + ΔGP.E = W($\vec{f}$) + W ($\vec{f_1}$) $\Rightarrow\Delta$K.E = W($M\vec{g}$)+ W($\vec{f}$) + W($\vec{f_1}$) since W($\vec{N}$) =0 $\Rightarrow$ ΔK.E = $\sum W_{\vec{F}_{ext}}$ **Or :** ΔM.E = ΔK.E + ΔGP.E = W($\vec{f}$) + W ($\vec{f_1}$) $\Rightarrow\Delta$K.E. = W($\vec{f}$) + W($\vec{f_1}$) – ΔGP.E = W($\vec{f}$) + W($\vec{f_1}$) + W($M\vec{g}$) Or W($\vec{N}$) =0 $\Rightarrow$ Δ K.E. = $\sum W_{\vec{F}_{ext}}$	1

Second exercise (7.5 points)

Part of the Q	Answer	Mark
A.1.a	$u_{BD} = u_L = L\dfrac{di}{dt} = -LI\omega\sqrt{2}\sin(\omega t - \dfrac{\pi}{2})$	¾
A.1.b	$u_{AM} = u_{BD} \Rightarrow -LI\omega\sqrt{2}\sin(\omega t - \dfrac{\pi}{2}) = U\sqrt{2}\cos\omega t \Rightarrow LI\omega\sqrt{2}\cos(\dfrac{\pi}{2} + \omega t - \dfrac{\pi}{2}) = U\sqrt{2}\cos\omega t$ By comparison: $U\sqrt{2} = LI\omega\sqrt{2} \Rightarrow L = 0.032$ H = 32 mH. **Or**: $-LI\omega\sqrt{2}\sin(\omega t - \dfrac{\pi}{2}) = U\sqrt{2}\cos\omega t$ For t = 0: $U\sqrt{2} = LI\omega\sqrt{2} \Rightarrow L = 0.032$ H = 32 mH.	¾
A.2.a	$i = C\dfrac{du_C}{dt} \Rightarrow u_C = \dfrac{1}{C}\int i\,dt = \dfrac{I\sqrt{2}}{C\omega}\sin(\omega t + \varphi)$	¾
A.2.b	$u_{AM} = u_{BD} \Rightarrow U\sqrt{2}\cos\omega t = \dfrac{I\sqrt{2}}{C\omega}\sin(\omega t + \dfrac{\pi}{2}) \Rightarrow U\sqrt{2}\cos\omega t = \dfrac{I\sqrt{2}}{C\omega}\cos(\dfrac{\pi}{2} - \omega t - \dfrac{\pi}{2})$ By comparison : $U\sqrt{2} = \dfrac{I\sqrt{2}}{C\omega} \Rightarrow C = 3.2\times10^{-6}$ F = 3.2 μF **Or** : $u_{AM} = u_{BD} \Rightarrow U\sqrt{2}\cos\omega t = \dfrac{I\sqrt{2}}{C\omega}\sin(\omega t + \dfrac{\pi}{2})$ For t = 0 : $U\sqrt{2} = \dfrac{I\sqrt{2}}{C\omega}\sin(\dfrac{\pi}{2}) \Rightarrow C = 3.2\times10^{-6}$ F = 3.2 μF	¾
B.1	Connections of the oscilloscope  	¼
B.2	$u_{AM} = u_{AB} + u_{BD} + u_{DM} \Rightarrow$ $U\sqrt{2}\cos\omega t = -LI\omega\sqrt{2}\sin(\omega t + \varphi) + \dfrac{I\sqrt{2}}{C\omega}\sin(\omega t + \varphi) + RI\sqrt{2}\cos(\omega t + \varphi)$ For $\omega t = \dfrac{\pi}{2} \Rightarrow 0 = -LI\sqrt{2}\cos\varphi + \dfrac{I\sqrt{2}}{C\omega}\cos\varphi - RI\sqrt{2}\sin\varphi \Rightarrow \tan\varphi = \dfrac{\frac{1}{C\omega} - L\omega}{R}$	1
B.3.a	$T = 4$ ms $\Rightarrow f = \dfrac{1}{T} = 250$ Hz .	½
B.3.b	$\lvert\varphi\rvert = \dfrac{2\pi}{8} = \dfrac{\pi}{4}$ rad.	½
B.4.a	Current resonance	¼
B.4.b	$\varphi = 0 \Rightarrow \tan\varphi = 0 \Rightarrow \dfrac{1}{C\omega_0} = L\omega_0 \Rightarrow LC = \dfrac{1}{\omega_0^2}$.	½
B.5	$\varphi = \dfrac{\pi}{4} \Rightarrow 1 = \dfrac{\frac{1}{C\omega} - L\omega}{R} \Rightarrow C = \dfrac{1 - LC\omega^2}{R\omega} = 3.2\times10^{-6}$ F = 3.2 μF $\Rightarrow LC = \dfrac{1}{\omega_0^2} \Rightarrow L = \dfrac{1}{C\omega_0^2} = 32$ mH	1 ½

Third exercise (7.5 points)

Part of the Q	Answer	Mark
A.I.1	λ , λ_0 and n^2 are positive $\Rightarrow n^2 - 4 > 0 \Rightarrow n > 2 \Rightarrow$ the smallest value is $n = 3$.	½
A.I.2	$\lambda = \lambda_0 \dfrac{n^2}{n^2 - 4} \Rightarrow \lambda = 656.46$ nm.	½
A.I.3	In these conditions: $n = 4$ gives $\lambda = 486.13$ nm $n = 5$ gives $\lambda = 435.05$ nm $n = 6$ gives $\lambda = 410.17$ nm	¾
A.II.1	Ground state $n = 1$: $E_1 = -13.6$ eV.	½
A.II.2	1st energy level (excited): $n = 2$: $E_2 = -\dfrac{13.6}{2^2} = -3.4$eV $E_3 = -1.51$ eV; $E_4 = -0.85$ eV; $E_5 = -0.54$ eV and $E_6 = -0.38$ eV	**1 ¼**
A.II.3	The atom is ionized when $n \to \infty \Rightarrow E_\infty = 0$	½
B.1	$W_0 = \dfrac{hc}{\lambda_0} \Rightarrow \lambda_0 = \dfrac{hc}{W_0} = 5.65\times10^{-7}$m $= 565$nm	¾
B.2	The radiations of Balmer series that can produce photoelectric emission verifies the relation $\lambda \langle \lambda_0$; H_β, H_γ and H_δ produce this emission because $\lambda \langle \lambda_0$	½
B.3.a	$P_0 = \dfrac{P_S \times s}{4\pi D^2} = 2.04\times10^{-5}$ W	¾
B.3.b	$N_{0/s} = \dfrac{P_0}{E_{photon}} = \dfrac{P_0 \times \lambda_\beta}{h \times c} = 4.99\times10^{13}$ photons / s	¾
B.3.b	The number of effective photons = number of emitted electrons N_e $\Rightarrow N_e = r \times N_0 = 4.37\times10^{11}$ electrons/s $I_0 = \dfrac{q}{t} = \dfrac{N_e e}{t} = 6.99\times10^{-8}$ A	¾

Fourth exercise (7.5 points)

Part of the Q	Answer	Mark
1.a	$(m + m_1)\overrightarrow{OG} = m\,\overrightarrow{OO} + m_1\overrightarrow{OM} \Rightarrow \overline{OG} = \frac{x}{4}$	½
1.b	$I_{(sys)} = I_{(rod)} + I_{(S)} \Rightarrow I = \frac{1}{12}m\ell^2 + \frac{m}{3}x^2 = \frac{m}{12}(4x^2 + \ell^2)$	½
2	$ME = \frac{1}{2}I\theta'^2 - (m+m_1)gOG\cos\theta = \frac{m}{24}(4x^2+\ell^2)\theta'^2 - \frac{m}{3}gx\cos\theta$	¾
3.a	$ME = Cte \Rightarrow \frac{dME}{dt} = 0 \Rightarrow \frac{m}{12}(4x^2+\ell^2)\theta'\theta'' + \frac{m}{3}gx\theta'\sin\theta = 0$, $\theta' \neq 0$ For small angle $\sin\theta \approx \theta$ (rd) $\Rightarrow \theta'' + \left(\frac{4gx}{4x^2+\ell^2}\right)\theta = 0$.	¾
3.b	This differential equation has the form: $\theta'' + \omega_0^2\theta = 0 \Rightarrow \omega_0 = \sqrt{\frac{4gx}{4x^2+\ell^2}} \Rightarrow T_0 = \sqrt{\frac{4x^2+\ell^2}{x}}$.	½
4.a	$\frac{dT_0}{dx} = \frac{1}{2}\left(\frac{4x^2-\ell^2}{x^2}\right)\left(\frac{4x^2+\ell^2}{x}\right)^{-\frac{1}{2}}$; T_0 is minimum when $\frac{dT_0}{dx} = 0$ for x $\in \left]0, \frac{\ell}{2}\right] \Rightarrow 4x^2 - \ell^2 = 0$; then T_0 is minimal for $4x^2 = \ell^2 \Rightarrow x = \frac{\ell}{2}$.	1 ½
4.b	$T_0 = \sqrt{\frac{\ell^2+\ell^2}{\frac{\ell}{2}}} = 2\sqrt{\ell} = 1.41$ s	½
5.a	$T_{01} = 2\pi\sqrt{\frac{\ell_1}{g}} = 1.61$ s	½
5.b.i	The phenomenon of amplitude resonance will take place when the proper period of the exciter becomes equal (very close) of that of the resonator. As $T_0 = 1.41$ s of (P) is smaller than $T_{01} = 1.61$ S of (P_1), therefore the phenomenon of resonance does not take place	½
5.b.ii	(P_1) oscillates with large amplitude, therefore it is in resonance of amplitude with (P); and then the proper period of (P) is equal to T_{01}. = 1.61 s. $4x^2 - (1{,}61)^2x + \ell^2 = 0$ $\Rightarrow$ The solution of this quadratic equation gives; $x_1 = 53$ cm (rejected because it is > than $\frac{\ell}{2} = 25$ cm) and $x_2 = 11.75$ cm (accepted)	1 ½

مسابقة في مادة الفيزياء
المدة : ثلاث ساعات

الاسم:
الرقم:

This exam is formed of four exercises in four pages.
The use of non-programmable calculator is recommended.

First exercise: (7.5 points)

Charging and Discharging of a Capacitor

The aim of this exercise is to study the charging and the discharging of a capacitor of capacitance C =1 μF. For that we connect the circuit of figure 1 which is formed of the capacitor, an ideal generator of constant voltage E, a resistor of resistance R and a double switch (K).

Take the direction of the current as a positive direction.

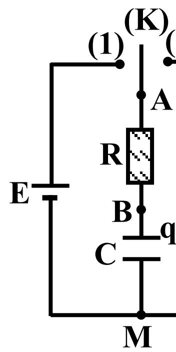


Fig.1

A – Charging of the capacitor

The capacitor is initially neutral and the switch (K) is turned to position (1) at the instant $t_0 = 0$.

A convenient apparatus records the variation of the voltage $u_C = u_{BM}$ across the terminals of the capacitor as a function of time.

1) Derive the differential equation that describes the variation of the voltage u_C as a function of time.

2) The solution of the differential equation is given by:

$u_C = A + B\,e^{-\frac{t}{\tau}}$, where A, B and τ are constants. Determine the expressions of these constants in terms of R, C and E.

3) Figure 2 shows the variation of u_C as a function of time t. The straight line OT represents the tangent to the curve $u_C(t)$ at $t_0 = 0$.

a) Determine the value of τ.

b) Deduce the values of E and R.

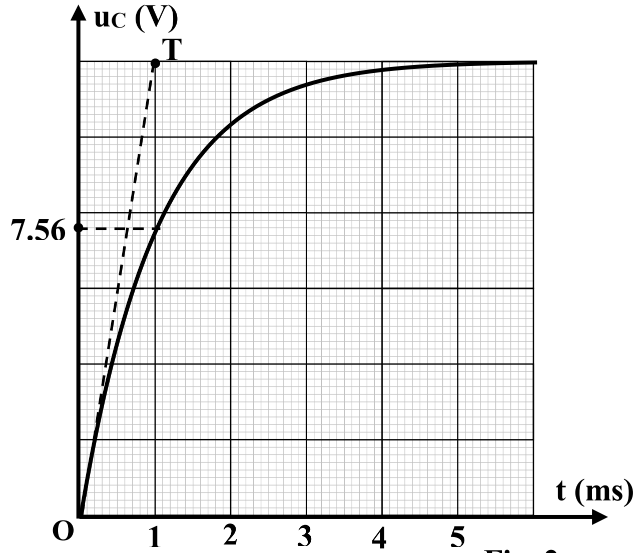


Fig. 2

B – Discharging of the capacitor

The charging of the capacitor being completed, the switch (K) is turned to position (2) at a new origin of time $t_0 = 0$.

At an instant t the circuit carries a current i.

1) Redraw the figure of the discharging circuit and indicate on it the direction of the current i.

2) Show that the differential equation in i has the form:

$i + RC\dfrac{di}{dt} = 0$.

3) Verify that $i = I_0\,e^{-\frac{t}{\tau}}$ is a solution of this differential equation, where $I_0 = \dfrac{E}{R}$.

4) **a)** Calculate the value of i at $t_0 = 0$ and at $t_1 = 2.5\,\tau$.

b) Deduce the value of u_C at $t_1 = 2.5\,\tau$.

5) Determine the electric energy W_e lost by the capacitor between $t_0 = 0$ and $t_1 = 2.5\,\tau$.

6) The energy dissipated due to joule's effect in the resistor between t_0 and t_1, is given by $W_h = \int_{t_0}^{t_1} R\,i^2\,dt$.

a) Determine the value of W_h.

b) Compare W_h and W_e. Conclude.

Second exercise: (7.5 points)

Determination of the inductance of a coil and the capacitance of a capacitor

The aim of this exercise is to determine the inductance L of a coil of negligible resistance and the capacitance C of a capacitor.
For this aim we perform two experiments:

A – First experiment

In this experiment, we set up the circuit represented in figure 1. This series circuit is composed of: a resistor (D_1) of resistance $R_1 = 25\ \Omega$, the coil of inductance L and of negligible resistance and an (LFG) maintaining across its terminals an alternating sinusoidal voltage of expression:

$u_{AB} = U_m \sin \omega t$ (u_{AB} in V , t in s).

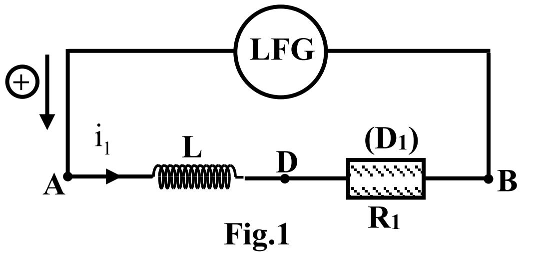


Fig.1

The circuit thus carries an alternating sinusoidal current i_1.

An oscilloscope is used to display the variation, as a function of time, of the voltage u_{AB} on channel (Y_1) and the voltage u_{DB} on channel (Y_2).

The adjustments of the oscilloscope are:

- vertical sensitivity for the both channels: 1 V/div;
- horizontal sensitivity: 1 ms/div.

1) Redraw figure (1) and show on it the connections of the oscilloscope.

2) The obtained waveforms are represented on figure (2).

  a) The waveform (a) represents u_{AB}. Justify.

  b) Using the waveforms of figure (2), determine:

   i) the angular frequency ω of the voltage u_{AB};

   ii) the maximum value U_m and U_{m1} of the voltages u_{AB} and u_{DB} respectively;

   iii) the phase difference between u_{AB} and u_{DB}.

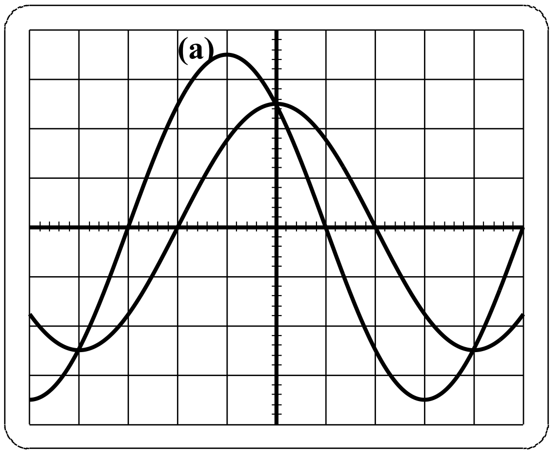


Fig. 2

3) **a)** Write the expression of the voltage u_{DB} as a function of time.

  b) Deduce that $i_1 = 0.1 \sin (\omega t - \frac{\pi}{4})$ (i_1 in A, t in s).

4) Determine the value of L by applying the law of addition of voltages.

B – Second experiment

In this experiment, another series circuit composed of: the capacitor of capacitance C, a resistor (D_2) and an ammeter (A_1) of negligible resistance, is connected between A and B as shown in figure 3. Thus the second branch carries an alternating sinusoidal current i_2.

The oscilloscope is used, in this case, to display the voltage $u_{EB} = u_C$ across the terminals of the capacitor and the voltage u_{DB} across the terminals of (D_1).

U_m and ω of the (LFG) are kept constant. The adjustments of the oscilloscope remain the same.

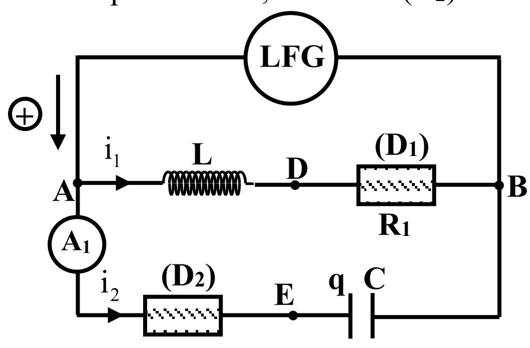


Fig.3

The obtained two waveforms are confounded and represented on figure 4.

Knowing that $i_1 = 0.1 \sin (\omega t - \frac{\pi}{4})$ (i_1 in A, t in s).

1) Write the expression of u_C as a function of time.
2) Determine the expression of i_2 in terms of C and t.
3) The ammeter (A_1) indicates 27.7 mA. Determine the value of C.

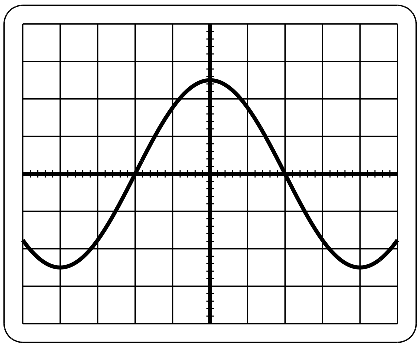


Fig. 4

<u>Third exercise</u>: (7.5 points)

Torsion Pendulum

The aim of this exercise is to study the motion of a torsion pendulum. Consider a torsion pendulum that is constituted of a homogeneous disk (D), of negligible thickness, suspended from its center of inertia O by a vertical torsion wire connected at its upper extremity to a fixed point O' (Fig.1).

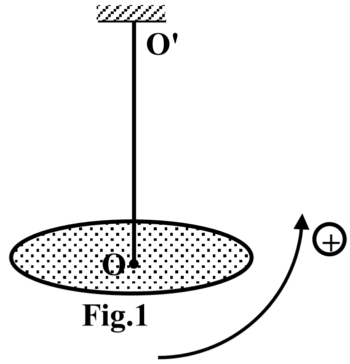


Fig.1

Given:
- the moment of inertia of (D) about the axis (OO'): $I = 3.2\times10^{-6}$ kg.m^2;
- the torsion constant of the wire: $C = 8\times10^{-4}$ m.N/rad;
- the horizontal plane passing through O is taken as a gravitational potential energy reference.

A – Free un-damped oscillations

The forces of friction are supposed negligible.
The disk is in its equilibrium position. It is rotated around (OO'), in the positive direction , by an angle $\theta_m = 0.1$ rad, the disk is then released without initial velocity at the instant $t_0 = 0$.

At the instant t, the angular abscissa of the disk is θ and its angular velocity is $\theta' = \frac{d\theta}{dt}$.

1) Write, at the instant t, the expression of the mechanical energy of the system (pendulum, Earth) in terms of I, C, θ and θ'.
2) Derive the second order differential equation that describes the variation of θ as a function of time.
3) The solution of this differential equation is of the form: $\theta = \theta_m \cos (\frac{2\pi}{T_0} t + \varphi)$.

Determine the constants T_0 and φ.

B – Free damped oscillations

In reality, the forces of friction are no more negligible. (D) thus performs slightly damped oscillations of pseudo period T.

1) At the end of each oscillation, the amplitude of the oscillations decreases by 2.5% of its precedent value.
   a) Calculate the mechanical energy E_0 of the system (pendulum, Earth) at the instant $t_0 = 0$.
   b) Show that the loss in the mechanical energy of the system (pendulum, Earth) by the end of the first oscillation is: $|\Delta E| = 1.97\times10^{-7}$ J.
2) Calculate the value of the average power dissipated by the resistive forces admitting that the value of the pseudo period T is equal to that of T_0.

C – Driven oscillations

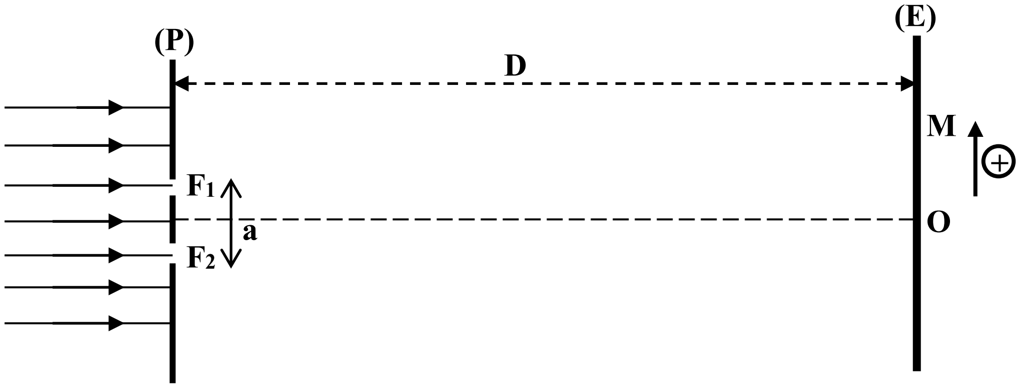
A driving apparatus (M) allows compensating for the loss of energy at the end of each oscillation.
This apparatus stores energy W= 0.8 J. The energy furnished by (M) to drive the oscillations represents 25% of energy stored in it.
Determine, in days, the maximum duration of driving the oscillations.

Fourth exercise: (7.5 points)

Diffraction and interference

Two horizontal slits F_1 and F_2, are illuminated normally with a laser source. Each slit, cut in an opaque screen (P), has a width $a_1 = 0.1$ mm and are situated at a distance $F_1F_2 = a = 1$ mm from each other. The wavelength of the laser light is $\lambda = 600$ nm.

The distance between the plane (P) of the slits and the screen of observation (E) is D = 2 m. (Figure below). O is a point on the screen (E) and belongs to the perpendicular bisector of $[F_1F_2]$.



A – We cover the slit F_1 by an opaque sheet thus light is emitted only from F_2.

1) The phenomenon of diffraction is observed on the screen (E). Justify.

2) Redraw the figure and trace the beam of light leaving the slit F_2.

3) Describe the pattern observed on the screen (E).

4) Write the expression of the angular width α (α is very small) of the central bright fringe in terms of λ and a_1.

5) **a)** Show that the linear width L of the central bright fringe is given by: $L = \frac{2\lambda D}{a_1}$.

b) Calculate L.

6) The opaque sheet is moved to cover the slit F_2. The slit F_1 sends light now on the screen (E). The center of the new central bright fringe is at a distance d from the previous center of the central bright fringe. Specify the value of d.

B – We remove away the opaque sheet and the two slits are now both illuminated with the laser beam.

For a point M on (E), such that $x = \overline{OM}$, the optical path difference in air is given by $\delta = \frac{ax}{D}$.

1) Determine the expression of the abscissa x_k corresponding to the center of the k^{th} dark fringe.

2) Deduce the expression of the interfringe distance i.

3) Calculate i.

4) Consider a point N on the screen (E) having an abscissa $x_N = \overline{ON} = 2.4$ mm. Specify the nature and the order of the fringe at point N.

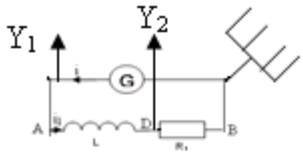
5) We move the screen (E) towards the plane (P) of the slits and parallel to it by a distance of 40 cm. Determine the nature and the order of the new fringe at N.

مشروع معيار التصحيح	مسابقة في مادة الفيزياء المدة ثلاث ساعات

First exercise (7.5 points)

Part of the Q	Answer	Mark
A.1.	$E = u_R + u_C = Ri + u_C$; But $i = \frac{dq}{dt} = C\frac{du_C}{dt}$. $\Rightarrow RC\frac{du_C}{dt} + u_C = E$	0.75
A.2.	$u_C = A + Be^{-\frac{t}{\tau}} \Rightarrow \frac{du_C}{dt} = -\frac{B}{\tau}e^{-\frac{t}{\tau}}$ $E = -\frac{RCB}{\tau}e^{-\frac{t}{\tau}} + A + Be^{-\frac{t}{\tau}} \Rightarrow E = A + (1-\frac{RC}{\tau})Be^{-\frac{t}{\tau}}$ $\Rightarrow E = A, (1-\frac{RC}{\tau})Be^{-\frac{t}{\tau}}=0$ but $B \neq 0 \Rightarrow \tau = RC$ At t=0 ,$u_C = 0 \Rightarrow A + B = 0, \Rightarrow B = -A = -E$ $\Rightarrow u_C = E(1-e^{-\frac{t}{\tau}})$	1
A.3.a	From the graph , τ is the point where line OT intersects the asymptote $\Rightarrow \tau$= 1ms	0.5
A.3.b	At $t = \tau, u_C = 0.63E \Rightarrow E = \frac{7.56}{0.63} = 12V$ $\tau = RC \Rightarrow R = 10^3\Omega$	0.75
B.1.	Figure	0.25
B.2.	$u_{AB} + u_{BM} = 0, \Rightarrow -Ri + u_c = 0 \Rightarrow -Ri + \frac{q}{c} = 0$ Derive w.r.t.time , $-R\frac{di}{dt} + \frac{1}{C}\left(\frac{dq}{dt}\right)$ but $i = -\frac{dq}{dt} \Rightarrow i \;+\; RC\frac{di}{dt} = 0$	0.75
B.3.	$i = I_0e^{-\frac{t}{\tau}} \Rightarrow \frac{di}{dt} = -\frac{I_0}{\tau}e^{-\frac{t}{\tau}} \Rightarrow I_0e^{-\frac{t}{\tau}} - \frac{RC}{\tau}I_0e^{-\frac{t}{\tau}} = 0$, verified	0.5
B.4.a.	$i = I_0e^{-\frac{t}{\tau}}$, at $t_0 = 0, i = I_0e^0 = 0.012A \Rightarrow$ At t =2.5τ, $i = I_0e^{-\frac{t}{\tau}} = 0.082I_0 \Rightarrow i = 9.84\times10^{-4}A$	0.75
B.4.b	$u_C = u_R = Ri = 0.984V$	0.25
B.5.	$W_e = \frac{1}{2}C(E^2 - u^2) = 7.15\times10^{-5}J$	0.75
B.6.a	$W_h = \int_{t_0}^{t_1} R\,i^2\,dt = W_h = \frac{RI_0^2\tau}{2}(e^0 - e^{-5}) = 7.15x10^{-5}J$	0.75
B.6.b	$W_e = W_h$ then the electric energy lost by the capacitor is transformed to heat energy through the resistor	0.5

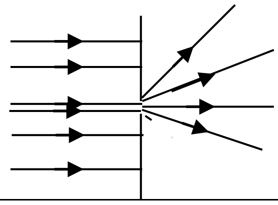
Second exercise (7.5 points)

Part of the Q	Answer	Mark
A.1	Connection 	0.5
A.2.a	In A.C. and in an RL circuit, u_G leads u_{DB} (on i_1). and a leads $\Rightarrow$a gives u_{AB} Or $U_{m1} > U_{m\,(BD)}$ and $Umg > U_{m\,BD}$) $\Rightarrow$a gives u_{AB}	0.5
A.2.b.i	$T = 8\times1 = 8$ ms $= 0.008$ S; $\omega = \frac{2\pi}{T} = 250\ \pi$ rd/s.	1.00
A.2.b.ii	$U_m = 3.5\times1 = 3.5$ V; $U_{m1} = 2.5\times1 = 2.5$ V.	1.00
A.2.b.iii	$\varphi = \frac{2\pi}{8}\times1 = \frac{\pi}{4}$ rad.	0.50
A.3.a.	$u_{R1} = 2.5\sin(250\pi t - \frac{\pi}{4})$.	0.50
A.3.b	$I_{m1} = \frac{U_{m1}}{R_1} = \frac{2.5}{25} = 0.1$ A. $\quad i_1 = 0.1\sin(250\pi t - \frac{\pi}{4})$. Or $i_1 = \frac{u_{R1}}{R} = 0.1\sin(250\pi - \frac{\pi}{4})$	0.50
A.4	$u = u_L + u_{DB}$; with: $u_L = L\frac{di_1}{dt} = 25\pi L\cos(250\pi t - \frac{\pi}{4})$; $u_{DB} = R_1 i_1 = 2.5\sin(250\pi t - \frac{\pi}{4})$. We have then: $3.5\sin(250\pi t) = 25\pi L\cos(250\pi t - \frac{\pi}{4}) + 2.5\sin(250\pi t - \frac{\pi}{4})$. For t = 0, we have: $0 = 25\pi L\frac{\sqrt{2}}{2} - 2.5\frac{\sqrt{2}}{2} \Rightarrow \frac{\sqrt{2}}{2}\times L = \frac{0.1}{\pi} = 0.032$ H.	1.25
B.1	$u_c = u_{R1} = 2.5\sin(250\pi t - \frac{\pi}{4})$.	0.50
B.2.	$i_2 = C\frac{du_C}{dt} = 625\pi C\cos(250\pi t - \frac{\pi}{4})$	0.5
B.3	The ammeter gives $I_{eff} = 0.0277A \Rightarrow I_{2M} = I_{eff}\sqrt{2} = 0.0391A$ But $I_{2m} = 625C \Rightarrow C = \frac{I_{2m}}{625\pi} = 2x10^{-5}F$	0.75

Third exercise (7.5 points)

Part of the Q	Answer	Mark
A.1.	$M.E = \frac{1}{2} I\theta'^2 + \frac{1}{2} C\theta^2$	1.00
A.2.	$M.E = Cte \Rightarrow \frac{dE_m}{dt} = 0 \Rightarrow I\theta'\theta'' + C\theta\theta' = 0 \Rightarrow \theta'' + \frac{C}{I}\theta = 0$	1.00
A.3.	$\theta = \theta_m \cos(\frac{2\pi}{T_0} t + \varphi) \Rightarrow \theta' = -\theta_m \frac{2\pi}{T_0} \sin(\frac{2\pi}{T_0} t + \varphi)$ $\Rightarrow \theta'' = -\theta_m (\frac{2\pi}{T_0})^2 \sin(\frac{2\pi}{T_0} t + \varphi) = -(\frac{2\pi}{T_0})^2 \theta$ Sub. In the differential equation: $\frac{4\pi^2}{T_0^2}\theta + \frac{C}{I}\theta = 0$ $\Rightarrow \omega_0 = \sqrt{\frac{C}{I}} \Rightarrow T_0 = 2\pi\sqrt{\frac{I}{C}} \Rightarrow T_0 \approx 0.4$ s. $\theta = 0.1 rad \Rightarrow \theta_m \cos \varphi = 0.1 \Rightarrow \varphi = 0$	1.5
B.1.a	$M.E_0 = \frac{1}{2} C\, \theta_{0m}^2 = 4\times10^{-6}$ J	0.75
B.1.b	$\theta_{0m} = 0.1 rad \Rightarrow \theta_{1m} = \frac{0.1\times 97.5}{100} = 0.0975$ rad. $\Rightarrow \lvert\Delta E\rvert = \frac{1}{2} C\, (\theta_{0m}^2 - \theta_{1m}^2) = 1.97\times10^{-7}$ J	1.25
B.2	$P_{av} = \frac{\Delta E}{T} = -4.92\times10^{-7}$ W	0.75
C	The energy used for driving is : $\frac{0.8\times25}{100} = 0.2$ J. The duration of driving is : $t = \frac{0.2}{4.92\times10^{-7}} = 406504$ s; $t = \frac{406504}{24\times3600} = 4.7$ day	1.25

Fourth exercise : (7.5 points)

Part of the Q	Answer	Mark
A.1	The width of the slit a_1 is of the order of mm (or λ has to be of the same order of $a_1 (a_1 = 10^3 \lambda)$.	0.50
A.2.	Aspect of the emerging beam. 	0.50
A.3	We observe : • Alternate bright and dark fringes. • The direction of the diffraction pattern is perpendicular to that of the slit. • The width of the central bright fringe is twice as broad as others.	0.75
A.4	$\sin\alpha = \frac{2\lambda}{a_1}$ and in case of small angles $\sin\alpha \approx \alpha_{rd} \Rightarrow \alpha = \frac{2\lambda}{a_1}$	0.50
A.5.a	Figure $\tan\frac{\alpha}{2} = \frac{L}{2D}$ and case of small angles $\tan\alpha \approx \alpha_{rd} \Rightarrow \quad L = \alpha \times D = \frac{2\lambda D}{a_1}$.	0.75
A.5.b	$L = \frac{2\times 0.633\times 10^{-3}\times 2\times 10^{3}}{0.1} \text{mm} = 25 \text{ mm}$.	0.50
A.6.	The displacement of 1 mm is due to the distance a =1 mm between the two slits	0.50
B.1.	$\delta = \frac{ax}{D}$, Dark fringe $\delta=(2k+1)\frac{\lambda}{2} \Rightarrow x = (2k+1)\frac{\lambda D}{2a}$	0.75
B.2.	$i = x_{k+1} - x_k = \frac{[2(k+1)+1]\lambda D}{2a} - \frac{(2k+1)\lambda D}{2a} = \frac{\lambda D}{a}$.	0.75
B.3.	$i = \frac{0.6\times 10^{-3}\times 2\times 10^{3}}{1} = 1.2 \text{ mm}$.	0.50
B.4.	$\frac{x}{i} = \frac{2.4}{1.2} = 2 \Rightarrow x = 2i \Rightarrow$ center of the second bright fringe	0.75
B.5.	$x=(2k+1)\frac{\lambda D}{2a} \Rightarrow 2.4\times 10^{-3} = (2k+1)\frac{600\times 10^{-9}\times 2}{2\times 10^{-3}}$ $\Rightarrow k = 2$ then it corresponds to the center of third dark fringe	0.75

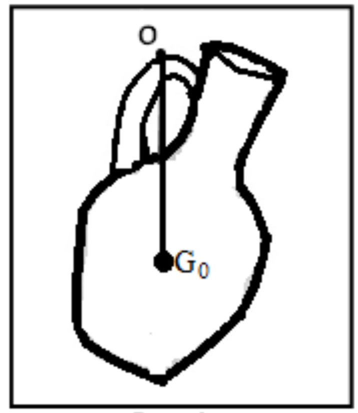
4

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

This exam is formed of four exercises in four pages.
The use of non-programmable calculator is recommended.

Exercise 1 (8 points) Determination of the moment of inertia of a pottery vase

The aim of this exercise is to determine the moment of inertia of a pottery vase about two different axis of rotation. The vase has a mass m = 2 kg and center of mass G.



Doc. 1

1- Moment of inertia of the vase about a horizontal axis

We suspend the vase from a point O, such that the vase is a compound pendulum which can oscillate freely, without friction, about a horizontal axis (Δ) passing through O (Doc 1).

The moment of inertia of the vase about (Δ) is I.

At equilibrium, the center of mass of the vase is in the position G_0, directly below the suspension point O ($OG = OG_0 = a = 24$ cm).

The vase is displaced from its stable equilibrium position by a small angle $\theta_m = 0.16$ rad, and then it is released from rest.

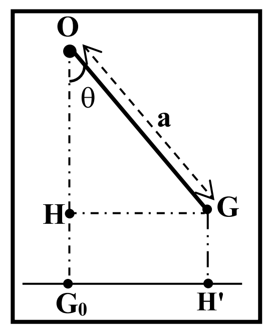
Document 2 is a simplified diagram of the compound pendulum at an instant t.

At the instant t, the angular abscissa of G is $\theta = (\overrightarrow{OG_0}, \overrightarrow{OG})$ and the algebraic value of its angular velocity is $\theta' = \frac{d\theta}{dt}$.

The horizontal plane passing through G_0 is taken as a gravitational potential energy reference.

Neglect air resistance.

Given: $g = 10$ m/s²; for small angles: $\cos\theta = 1 - \frac{\theta^2}{2}$ and $\sin\theta = \theta$ (θ in rad).



Doc. 2

1-1) Determine, at an instant t, the expression of the mechanical energy of the system (pendulum – Earth) in terms of I, a, g, m, θ and θ'.

1-2) Establish the differential equation in θ that describes the motion of the pendulum.

1-3) The solution of the obtained differential equation is: $\theta = \theta_m \sin(\omega_0 t + \varphi)$. θ_m, φ and ω_0 are constants.

1-3-1) Determine the expression of the proper angular frequency ω_0.

1-3-2) Deduce the expression of the proper period T_0 of the oscillations of the pendulum in terms of I, m, g and a.

1-4) The pendulum completes 9 oscillations in 25.2 seconds.

1-4-1) Calculate the proper period T_0 of the oscillations.

1-4-2) Deduce the value of I.

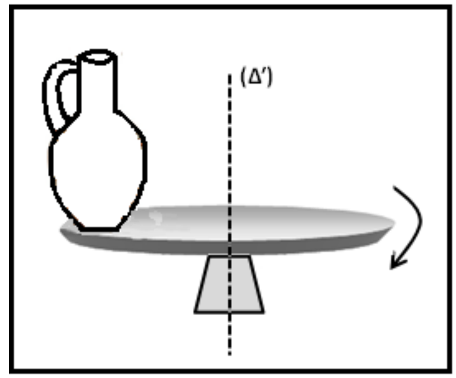
1-5) An appropriate device measures the angular speed of the pendulum. The angular speed of the pendulum when it passes in its equilibrium position is $\theta'_{eq} = 0.36$ rad/s. Apply the principle of conservation of mechanical energy for the system (pendulum, Earth) to determine again the value of I.

2- Moment of inertia of the vase about a vertical axis

Consider a horizontal turntable rotating clockwise at an angular speed of $\theta'_t = 0.7$ rad/s about a vertical axis (Δ') passing through its center of mass. The mass of the table is M = 20 kg and its radius is R = 50 cm.
Slowly, we put the vase on the rim of the turntable.
The system (turntable - vase) rotates clockwise with an angular speed of $\theta'_{system} = 0.45$ rad/s.

The moment of inertia of the table about (Δ') is: $I_t = \frac{1}{2}MR^2$.

The moment of inertia of the vase about (Δ') is I'.



Doc. 3

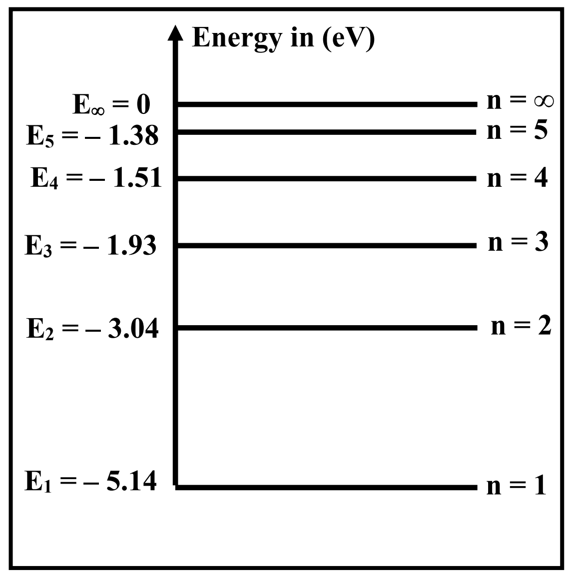
2-1) Name the external forces acting on the system (turntable-vase).
2-2) Show that the angular momentum σ, about (Δ'), of the system (turntable- vase) is conserved.
2-3) Deduce the value of I'.

<u>**Exercise 2**</u> **(7 ½ points)** **Sodium atom**

Document 1 represents some of the energy levels of the sodium atom.
Given: $h = 6.6 \times 10^{-34}$ J.s ; $c = 3 \times 10^{8}$ m/s ;
$1\text{ eV} = 1.6 \times 10^{-19}$ J ; $1\text{ u} = 931.5\text{ MeV}/c^2$.
The aim of this exercise is to study the excitation and the de-excitation of the sodium atom.

1- Excitation of the sodium atom

Consider a sample of sodium atoms, initially in the ground state. This sample is illuminated by white light that contains all the visible radiations: $0.4\ \mu m \leq \lambda_{visible} \leq 0.8\ \mu m$.



Doc. 1

1-1) Using document 1, show that the energy of the sodium atom is quantized.
1-2) Determine, in eV, the maximum energy and the minimum energy of the photons in the white light.
1-3) Using document 1, show that white light is not capable to ionize the sodium atom.
1-4) Determine, in nm, the wavelength of the photon that excites the sodium atom to the first excited state.

2- De-excitation of the sodium atom

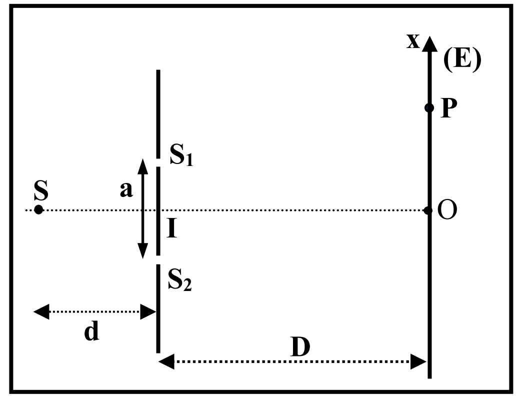
The emission spectrum, obtained from the low-pressure sodium vapor lamp, contains two very close yellow lines of wavelengths $\lambda_1 = 589.0$ nm and $\lambda_2 = 589.6$ nm, called the D-doublet of sodium.

2-1) The sodium atom de-excites from the energy level E_n to the ground state and emits the photon of wavelength $\lambda_1 = 589.0$ nm. Specify the value of E_n in eV.
2-2) The sodium atom undergoes a transition from the energy level E_3 to the energy level E_1. During this transition it loses energy $E_{3\to1}$ and its mass decreases by Δm.
2-2-1) Calculate, in MeV, the value of $E_{3\to1}$.
2-2-2) Deduce, in u, the value of Δm.
2-3) The power of the radiations of wavelengths λ_1 and λ_2 emitted by the sodium vapor lamp is P = 6 W. The power P_1 of the radiation of wavelengths λ_1 is twice the power P_2 of the radiation of wavelengths λ_2.
2-3-1) Show that $P_1 = 4$ W.
2-3-2) Determine the number of photons of the radiation of wavelength λ_1 emitted from the sodium vapor lamp in one second.

Exercise 3 **(7 points)** **Interference of light**

Document1 shows the set-up of Young's double- slit experiment. (OI) is the perpendicular bisector to $[S_1S_2]$.
A point source S, emitting a monochromatic light of wavelength $\lambda = 500$ nm in air, is placed in front of the two slits S_1 and S_2.
P is a point on the interference pattern on a screen (E), and it has an abscissa $x = \overline{OP}$ relative to the origin O of the x-axis. The distance between S_1 and S_2 is "a", and the distance between the plane of the slits and the screen (E) is D.

Given: $S_2P - S_1P = \frac{a\,x}{D}$.

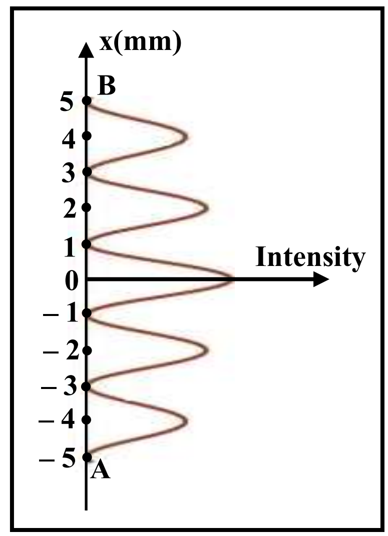


Doc. 1

The optical path difference at the point P is $\delta = SS_2P - SS_1P$.
The aim of this exercise is to determine "a" and D.

1- S is placed on the line (IO) as shown in document 1. In this case the optical path difference at the point P is $\delta = \frac{a\,x}{D}$.

1-1) Show that the point O is the center of the central bright fringe.
1-2) Determine the expression of the abscissa of the center of the k^{th} dark fringe.
1-3) Deduce the expression of the inter-fringe distance i, in terms of a, λ and D.
1-4) An appropriate device records the intensity of the light received from S on the screen (E) as a function of x. The graph of document 2 shows the intensity as a function of x between two points A and B.
Refer to document 2:
1-4-1) indicate the number of bright fringes between A and B;
1-4-2) give the expression of the distance AB in terms of the inter-fringe distance i;
1-4-3) indicate the order and nature of the fringe whose center is the point B;
1-4-4) give the abscissa of the center of the first dark fringe on the positive side of O.



Doc. 2

1-5) Deduce that D = 4000 a (in SI units).

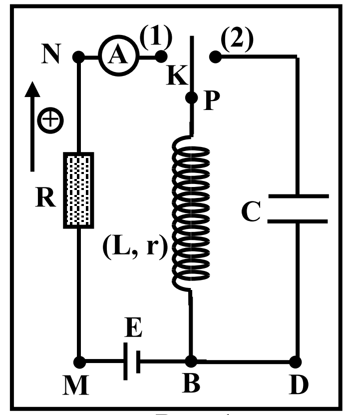
2- The point source S which is placed at a distance "d" from the plane of the slits is moved by a displacement z to the side of S_1 in a direction perpendicular to (IO) and normal to the slits.

Given: $SS_2 - SS_1 = \frac{a\,z}{d}$.

2-1) Prove that the optical path difference of the point P is $\delta = \frac{a\,z}{d} + \frac{a\,x}{D}$.
2-2) Deduce the expression of the abscissa of the center of the central bright fringe.
2-3) We notice that the center of the central bright fringe coincides with the position that was occupied by the center of the 10^{th} bright fringe, on the negative side of O, before the displacement of S.
Given: d = 40 cm and z = 0.4 cm.
Determine the values of a and D.

<u>Exercise 4</u> (7 ½ points) **Characteristics of a coil**

The aim of this exercise is to determine the characteristics of a coil. For this aim, consider the circuit of document 1 which includes a coil of inductance L and resistance r, an initially neutral capacitor of capacitance C, an ideal DC generator of e.m.f E, a resistor of resistance R, a double switch K, and an ammeter (A) of negligible resistance.



Doc. 1

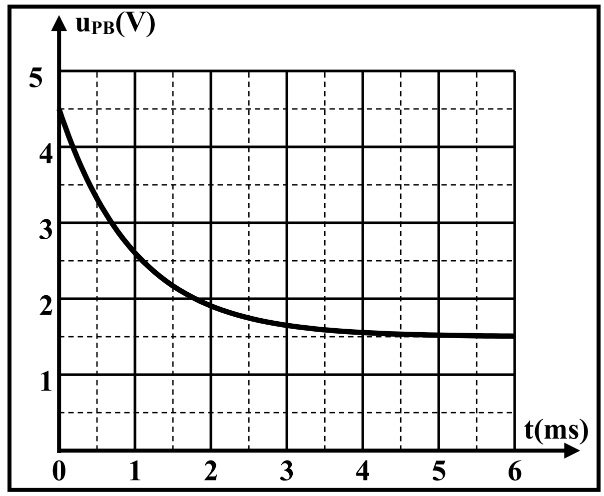
1- First experiment

K is put at position (1) at $t_0 = 0$. The ammeter (A) indicates a current i which increases from zero to its maximum value $I_0 = 0.1$ A and the steady state is attained.

1-1) Name the phenomenon that takes place in the coil during the growth of the current.

1-2) Determine, using the law of addition of voltages, the expression of I_0 in terms of E, R and r.

1-3) A suitable device allows us to record the voltage u_{PB} between the terminals of the coil as a function of time as indicated by the curve of document 2.



Doc.2

1-3-1) Applying the law of addition of voltages, and using the curve of document 2 , show that E = 4.5 V.

1-3-2) Using document 2, prove, without calculation that the value of r is not zero.

1-3-3) Deduce that r = 15 Ω.

1-4) Show that R = 30 Ω.

1-5) Establish, by applying the law of addition of voltages, the differential equation that describes the variation of the current i as a function of time.

1-6) The solution of this differential equation has the form:

$i = I_0(1 - e^{\frac{-t}{\tau}})$, where τ is constant.

1-6-1) Determine the expression of τ in terms of L, r and R.

1-6-2) Determine at t = τ the value of the voltage $u_R = u_{MN}$ across the resistor.

1-6-3) Show, at t = τ, that the voltage across the coil is $u_{PB} = 2.61$ V.

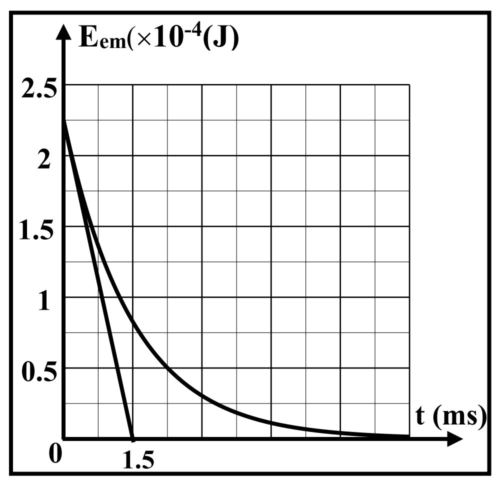
1-6-4) Deduce, using document 2, the value of τ.

1-7) Calculate the value of L.

2- Second experiment

When the steady state of the current in the coil is attained ($i = I_0$), K is moved abruptly from position (1) to position (2) at an instant $t_0 = 0$ taken as a new origin of time. The electromagnetic energy in the circuit at an instant t is $E_{em} = E_{electric} + E_{magnetic}$.

An appropriate device allows us, to trace the curve of the electromagnetic energy as a function of time and the tangent to this curve at $t_0 = 0$ (Doc. 3).



Doc. 3

2-1) Using document 3, indicate the value of E_{em} at $t_0 = 0$.

2-2) Deduce the value of L.

2-3) Calculate the slope of the above tangent.

2-4) Deduce the value of r, knowing that $\frac{dE_{em}}{dt} = -r\,i^2$.

Exercise 1 (8 points)

Part			Answer	Mark
1	1-1		GPE = m g h_G . But h_G = GH = a – a cos θ , where a = OG = OG_o Then **GPE = m g a (1 – cos θ)**. θ_m is small , so $\cos\theta = 1 - \frac{\theta^2}{2}$, then GPE = $\frac{1}{2}$ m g a θ^2 ME = KE + GPE , then ME = $\frac{1}{2}\, I\, \theta'^2 + \frac{1}{2}\, m\, g\, a\, \theta^2$	1
	1-2		The pendulum oscillates without friction and air resistance is neglected, so the sum of works of non conservative forces is zero, then the mechanical energy of the system is conserved. $ME = \frac{1}{2}\, I\, \theta'^2 + \frac{1}{2}\, m\, g\, a\, \theta^2$ = constant , then $\frac{d\,ME}{dt} = 0$, thus $2\,(\frac{1}{2}\, I'\, \theta'') + 2\,(\frac{1}{2}\, mg\, a\, \theta') = 0 \Rightarrow \theta'\,(I\,\theta'' + mga\,\theta) = 0$. But θ′ = 0 is rejected, therefore: $\theta'' + \frac{m\,g\,a}{I}\,\theta = 0$ 2nd order differential equation in θ.	1
	1-3	1-3-1	$\theta = \theta_m \sin(\omega_o t + \varphi)$, then $\theta' = \omega_o\, \theta_m \cos(\omega_o t + \varphi)$ $\theta'' = -\,\omega_o^2\, \theta_m \sin(\omega_o t + \varphi) = -\,\omega_o^2\, \theta$ Substitute θ″ in the differential equation: $-\,\omega_o^2\, \theta + \frac{m\,g\,a}{I}\,\theta = \theta\,(-\,\omega_o^2 + \frac{m\,g\,a}{I}) = 0$ θ = 0 is rejected , then $\omega_o^2 = \frac{m\,g\,a}{I}$, therefore $\omega_o = \sqrt{\frac{m\,g\,a}{I}}$	0.75
		1-3-2	$T_o = \frac{2\pi}{\omega_o}$, then $T_o = 2\pi\sqrt{\frac{I}{mga}}$	0.5
	1-4	1-4-1	$T_o = \frac{25.2}{9}$, thus T_o = 2.8 s	0.5
		1-4-2	$T_o = \frac{2\pi}{\omega_o} = 2\pi\sqrt{\frac{I}{mga}}$, then $T_o^2 = \frac{4\,\pi^2\, I}{m\,g\,a}$; $2.8^2 = \frac{4 \times 3.14^2 \times I}{2 \times 10 \times 0.24}$, therefore I = 0.95 kg.m^2	0.75
	1-5		M.E = $\frac{1}{2}\, I\, \theta_m'^2 = \frac{1}{2}\, m\, g\, a\, \theta_m^2$; I $\times 0.36^2 = 2 \times 10 \times 0.24 \times 0.16^2$; I = 0.95 kg.m^2.	1
2	2-1		System: (Turntable - vase). External forces: the weight $M\vec{g}$ of the turntable ; the weight $m\vec{g}$ of the vase ; and the reaction $\vec{R}$ at the axle of rotation	0.5
	2-2		Moments relative to (Δ): $M_{\vec{R}} = M_{M\vec{g}} = 0$ since these forces are passing through the axis of rotation $M_{m\vec{g}} = 0$, since this force is parallel to the axis of rotation. $\sum M = M_{m\vec{g}} + M_{\vec{R}} + M_{M\vec{g}} = 0$. But $\sum M = \frac{d\,\sigma}{dt}$, then $\frac{d\,\sigma}{dt} = 0$. Therefore σ = constant..	1
	2-3		$I_t = \frac{1}{2} M R^2 = \frac{1}{2} \times 20 \times 0.5^2 = 2.5$ kg.m2 The angular momentum of the system is conserved, then $\sigma_{initial} = \sigma_{final}$ $I_t\, \theta'_t + 0 = (I' + I_t)\, \theta'_{system}$, so $2.5 \times 0.7 = (I' + 2.5)\,(0.45)$,then I′ = 1.39 kg.m^2	1

Exercise 2 (7.5 points)

Part			Answer	Mark
1	1-1		Each energy level has a specific value , therefore the energy of the atom is quantized.	0.5
	1-2		$E_{ph} = \frac{hC}{\lambda}$; E_{ph} max if λ is minimum ; $E_{ph(max)} = \frac{6.6\times10^{-34}\times3\times10^{8}}{0.4\times10^{-6}} = 4.95\times10^{-19}$ J = 3.093 eV $E_{ph(min)} = \frac{6.6\times10^{-34}\times3\times10^{8}}{0.8\times10^{-6}} = 2.475\times10^{-19}$J = 1.546 eV	0.5 0.5
	1-3		$W_{ion} = E_\infty - E_1 = 0 - (-5.14) = 5.14$ eV, $E_{ph(max)} = 3.093\text{eV} < W_{ion} = 5.14$ eV Therfore the white light cannot ionize the atom	1
	1-4		$E_{ph} = E_2 - E_1$, then $\frac{hC}{\lambda} = -3.04 + 5.14 = 2.1\text{eV} = 3.36\times10^{-19}$J $\lambda = \frac{6.6\times10^{-34}\times3\times10^{8}}{3.36\times10^{-19}} = 0.589\times10^{-6}$m = 589 nm.	1
2	2-1		$E_n = E_2 = -3.04$ eV since this photon excites the atom from E_1 to E_2 so it is emitted when the atom **OR** : $E_n - E_1 = E_{photon}$; $E_{photon} = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{589\times10^{-9}\times1.6\times10^{-19}} = 2.1$ eV $E_n - = E_{photon} + E_1 = 2.1 - 5.14 = -3.04$ eV	1
	2-2	2-2-1	$E_{3/1} = E_3 - E_1 = 3.21$ eV = $3.21\ \times10^{-6}$ MeV.	0.75
		2-2-2	$E_{3/1} = \Delta mc^2$ $\Delta m = \frac{3.21\ \times10^{-6}}{931.5} = 3.446\times10^{-9}$u.	0.75
	2-3	2-3-1	$P = P_1 + P_2$ But $P_1 = 2P_2$, then$P = 3P_2$, thus $P_2 = 2$W and $P_1 = 4$ W.	0.5
		2-3-2	$P_1 = \frac{nE_1}{t}$ then $n = \frac{t\times P_1}{E_1} = \frac{1\times4}{3.36\times10^{-19}} = 1.19\times10^{19}$ photons.	1

Exercise 3 **(7 points)** **Interference of light**

Part			Answer	Mark
1	1-1		At O, x = 0 , then $\delta_O = 0$, then O is the center of the central bright fringe.	0.5
	1-2		Dark fringe: $\delta = (2k+1)\frac{\lambda}{2}$, $k \in Z$, then $(2k+1)\frac{\lambda}{2} = \frac{a\,x}{D}$ thus $x = \frac{(2k+1)\lambda D}{2a}$	0.75
	1-3		$i = x_{K+1} - x_K = (2(k+1)+1)\frac{\lambda D}{2a} - (2k+1)\frac{\lambda D}{2a} = \frac{\lambda D}{a}$	0.5
	1-4	1-4-1	5 dark fringes	0.5
		1-4-2	AB = 5 i	0.5
		1-4-3	B is the center of the third dark fringe on the positive side of O.	0.5
		1-4-4	First dark fringe $x_1 = 1$ mm	0.5
	1-5		$x_1 = \frac{(2k+1)\lambda D}{2a}$, k = 0,then $D = \frac{2\,x_1}{\lambda}\,a = \frac{2 \times 1 \times 10^{-3}}{500 \times 10^{-9}}$ a , therefore D = 4000 a. **Or :** $x_B = \frac{(2k+1)\lambda D}{2a}$, k = 2 , then $D = \frac{2\,x_B}{5\lambda}\,a = \frac{2 \times 5 \times 10^{-3}}{5 \times 500 \times 10^{-9}}$ a , therefore D = 4000 a.	0.75
2	2-1		$\delta = SS_2P - SS_1P = (SS_2 - SS_1) + (S_2P - S_1P) = \frac{aZ}{d} + \frac{ax}{D}$.	0.5
	2-2		Central bright fringe : $\delta = 0$, then $0 = \frac{aZ}{d} + \frac{ax}{D}$. $x = -\frac{Z\,D}{d}$	0.5
	2-3		10^{th} bright fringe , then : $x = -10i = -10\frac{\lambda D}{a} = -\frac{Z\,D}{d}$ $a = \frac{10\lambda d}{Z} = 5\times10^{-4}$ m D = 4000a = 2m	1.5

Exercise 4 (7.5 points)

Characteristics of coil

Part			Answer	Mark
1	1-1		Self electromagnetic induction.	0.25
	1-2		Law of addition of voltage: $u_{MB} = u_{MN} + u_N$, then $ri + L\frac{di}{dt} + Ri = E$ At steady state: $i = I_0$= constant , thus $\frac{di}{dt} = 0$, therefore $I_0 = \frac{E}{r+R}$	0.75
	1-3	1-3-1	A t = 0 : i= 0 then $u_R = 0$, then E = $u_R + u_{coil}$ from graph E = 4.5 V.	0.5
		1-3-2	At steady state: $\frac{di}{dt} = 0$, then $u_{coil} = 0 + rI_0$; graphically : $u_{coil} \neq 0$ then ; $r \neq 0$	0.5
		1-3-3	rI_0= 1.5 V , then r = 15 Ω.	0.5
	1-4		$I_0 = \frac{E}{r + R_0}$, then $R_0 = -r + E/I_0 = 30\ \Omega$.	0.5
	1-5		$u_{MB} = u_{MN} + u_N$, thus $ri + L\frac{di}{dt} + Ri = E$; $(r + R)\,i + L\frac{di}{dt} = E$	0.5
	1-6	1-6-1	$\frac{di}{dt} = \frac{I_0}{\tau}e^{-\frac{t}{\tau}}, then\ E = (r + R_0)\left(I_0 - I_0e^{-\frac{t}{\tau}}\right) + L\frac{I_0}{\tau}e^{-\frac{t}{\tau}}$ thus: $\tau = \frac{L}{r + R_0}$	0.75
		1-6-2	A t = τ : i = 0.63 I_0 = 0.063 A , then $u_R = Ri = 1.89$ V	0.75
		1-6-3	$u_{coil} = E - u_R = 2.61$ V	0.25
		1-6-4	Graphically τ = 1 ms	0.25
	1-7		$L = \tau(r + R_0) = 0.045$H.	0.5
2	2-1		$E_{em} = 2.25\times10^{-6}$ J	0.25
	2-2		$\frac{1}{2}LI_0^2 = 2.25\times10^{-6}$, therefore L= 0.045H	0.5
	2-3		Slope = $-2.25 \times 10^{-4}/1.5 \times 10^{-3} = -0.15$ J/s	0.5
	2-4		Slope = $-rI_0^2$, therefore r = 15 Ω.	0.25

وزارة التربية والتعليم العالي	امتحانات الشهادة الثانوية العامة	دورة العام ٢٠١٧ الاستثنائيّة
المديرية العامة للتربية	الفرع: علوم عامة	الثلاثاء في ٨ آب ٢٠١٧
دائرة الامتحانات الرسميّة		

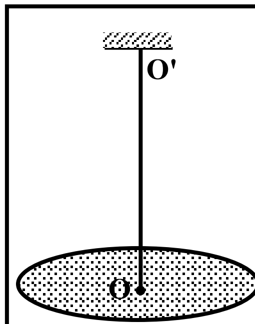
مسابقة في مادة الفيزياء	الاسم:
المدة: ثلاث ساعات	الرقم:

<u>This exam is formed of four obligatory exercises in 4 pages.</u>
<u>The use of non-programmable calculator is recommended</u>

<u>Exercise 1</u> (7 ½ points)

Torsion pendulum

Consider a torsion pendulum formed of a homogeneous thin disk (D), suspended from its center O by means of a vertical massless torsion wire while the other end of the wire is fixed to point O' (Document 1).



Doc.1

The aim of this exercise is to determine the moment of inertia I of (D) with respect to the axis (OO') and the torsion constant C of the wire.

The disk is in the equilibrium position. The disk is rotated from its equilibrium position in the horizontal plane about the vertical axis (OO'), by an angle θ_m and then it is released from rest at $t_0 = 0$. At an instant t, the angular abscissa of the disk relative to its equilibrium position is θ and its angular velocity is $\theta' = \frac{d\theta}{dt}$.

Take the horizontal plane passing through the center of mass of the disk as a reference level of gravitational potential energy.

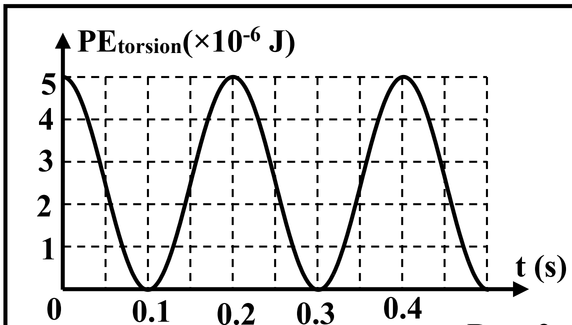
Neglect all frictional forces.

1- Theoretical study

1-1) Write, at the instant t, the expression of the mechanical energy ME of the system (torsion pendulum, Earth) in terms of I, C, θ and θ'.

1-2) Derive the differential equation in θ that describes the motion of the disk.

1-3) Deduce, in terms of C and I, the expression of the proper frequency f_0.



Doc. 2

2- Experimental study

An appropriate apparatus allows us to trace the variation of the torsion potential energy of the torsion wire as a function of time as shown in document 2.

2-1) Using the graph of document 2:

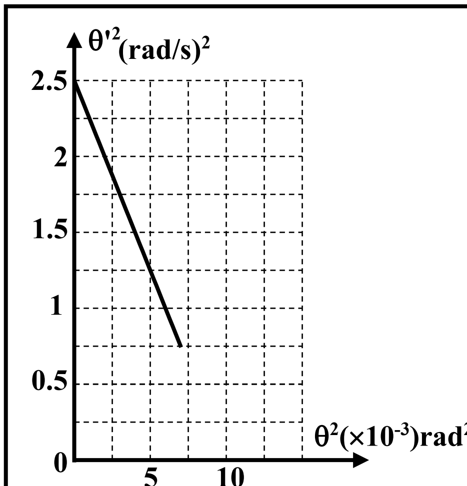
2-1-1) justify that the pendulum performs un-damped oscillations;

2-1-2) determine the value of f_0, knowing that $f_E = 2 f_0$, where f_E is the frequency of the torsion potential energy;

2-1-3) determine the value of the mechanical energy ME of the system (torsion pendulum, Earth).

2-2) Write, using the expression of the mechanical energy, the expression of θ'^2 in terms of θ, C, I and ME.

2-3) The curve of document 3 represents the variation of θ'^2 as a function of θ^2.



Doc. 3

2-3-1) Show that the curve of document 3 is in agreement with the expression of θ'^2 established in part (2-2).

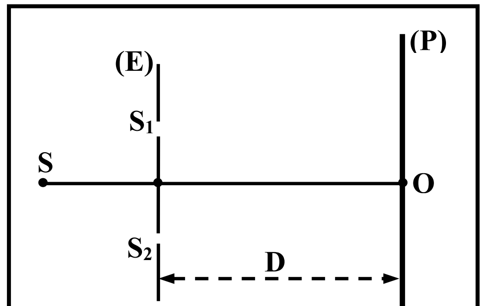
2-3-2) Determine, using the curve of document 3, the value of I.

2-4) Determine, by two different methods, the value of C.

<u>Exercise 2</u> (7 ½ points)

Interference of light

Consider Young's double slit apparatus that is represented in document 1. (S_1) and (S_2) are two parallel thin slits separated by a distance $a = S_1S_2$. (P) is the screen of observation that placed parallel to the plane of the slits (E) at a distance D.



Doc.1

(S) is a point source of monochromatic radiation of wavelength λ in air placed on the perpendicular bisector of [S_1S_2].

The aim of this exercise is to determine the expression of the interfringe distance « i ».

1- Interference pattern

1-1) (S_1) and (S_2) satisfy two properties in order to obtain the phenomenon of interference. What are these two properties?

1-2) Describe the interference pattern observed on the screen (P).

2- Expression of the interfringe distance « i »

2-1) Using different monochromatic point sources of different wavelengths, we measure the distance between the centers of the first and the eleventh fringe of the same nature, for each wavelength. The results obtained are listed in the table of document 2.

Doc.2

λ (nm)	400	500	600	650	700	750
10 i (mm)	36	45	54	58.5	63	68.5
i (mm)						

2-1-1) Copy and complete the table of document 2.

2-1-2) Draw the graph representing the variation of the interfringe distance « i » in terms of the wavelength λ using the scale:
On abscissa axis: 1 cm $\leftrightarrow$100 nm; On ordinate axis: 1 cm $\leftrightarrow$1 mm.

2-1-3) Determine, using the preceding graph, the expression of « i » in terms of λ.

2-2) We propose the following six expressions, for « i » (C is a unit less positive constant).

(a)	(b)	(c)	(d)	(e)	(f)
$i = C\,\lambda\,D\,a$	$i = C\dfrac{D}{\lambda a}$	$i = C\dfrac{\lambda D}{a}$	$i = C\lambda\dfrac{D^2}{a^2}$	$i = C\lambda\dfrac{a^2}{D^2}$	$i = C\lambda^2\dfrac{D}{a}$

2-2-1) Based on the preceding experimental study, the expressions (b) and (f) should be eliminated.
Justify.

2-2-2) The analysis of units permits us to eliminate expression (a). Justify.

2-2-3) By increasing the distance D, the interfringe distance « i » also increases. Specify the expression among (c) , (d) and (e), which does not satisfy this result.

2-2-4) To choose the correct expression of « i » between the two remaining expressions; we double the distance D, we notice that « i » is also doubled. Specify the correct expression of « i ».

2-2-5) Deduce the value of C knowing that D = 1.8 m and a = 0.2 mm.

<u>Exercise 3</u> (7 ½ points)

Solar spectrum

In 1814, Fraunhofer discovered the absorption lines present in the solar spectrum. He studied 570 lines and designated the main of these lines by the letters A, B, C, etc…(Doc.1).
He aimed to identify the elements in the solar atmosphere.

Doc.1										
Rays	A	B	C	a	D-Doublet		E	F	G	h
Wavelength (nm)	759.370	686.719	657.289	627.661	589.592	588.410	527.039	486.881	434.715	410.805

<u>Given</u>: speed of light in vacuum $c = 2.998\times10^{8}$ m/s; Planck's constant $h = 6.626\times10^{-34}$J.s; 1 eV = 1.60×10^{-19}J.

The energy levels of the hydrogen atom are given by the relation: $E_n = -\dfrac{E_0}{n^2}$; with E_0 = 13.6 eV and n is a non-zero whole positive number.

1- Solar spectrum

Justify the presence of absorption lines (dark lines) in the solar spectrum.

2- Balmer series of the hydrogen atom

The Balmer series is a series of spectral lines of hydrogen atom. The line « C » of the spectrum of document 1 corresponds to the alpha line (α) of this series. Three other lines beta, gamma and delta (β, γ and δ) of the same series are in this document.

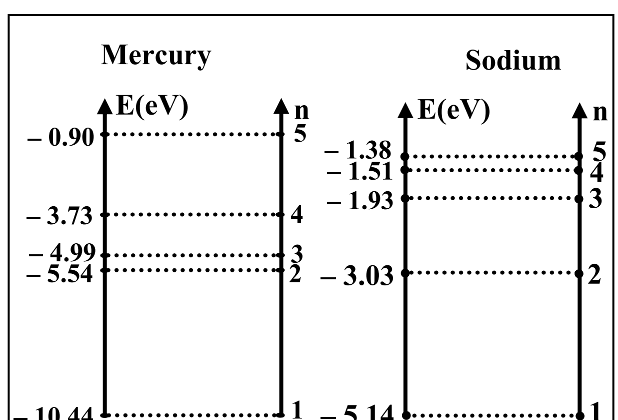
2-1) To what domain, visible, infrared or ultraviolet, do the lines of Balmer series belong?

2-2) Each line of this series corresponds to an absorption from the first excited state E_2 to a higher energy level E_n.

2-2-1) Show that the wavelengths of the lines of this series are given by: $\lambda = \dfrac{4n^2hc}{E_0(n^2-4)}$.

2-2-2) λ_α , λ_β , λ_γ and λ_δ are the wavelengths of α , β, γ and δ respectively. The line α corresponds to
n = 3. Indicate the values of n corresponding to the other three lines beta, gamma and delta and
calculate the values of the wavelengths λ_β, λ_γ , λ_δ , knowing that $\lambda_\beta > \lambda_\gamma > \lambda_\delta$.

2-2-3) Deduce, using document 1, which lines in the solar spectrum are those of Balmer series.



Doc.2

3- D-doublet of an atom

The D-doublet in document 1 corresponds to the transition of a certain atom from its fundamental state to the first excited state.

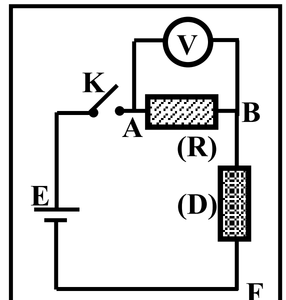
3-1) Calculate the energy of each photon corresponding to each line of the D-doublet in document 1.

3-2) Document 2 shows two simplified diagrams of the energy levels of sodium and mercury atoms. Show that one of the lines of the D-doublet corresponds to one of the two atoms.

Exercise 4 (7 ½ points)

Pacemaker

The aim of this exercie is to identify an electric component (D), and to study its usage in medicine. (D) may be a resistor, a coil with negligible resistance or a capacitor.



Doc.1

1- Identification of the component (D)

The component (D) is connected in series with a resistor of resistance $R = 8\times10^5\ \Omega$ across an ideal DC generator of e.m.f. E. A voltmeter (V) is connected across R to measure the voltage $u_R = u_{AB}$ as shown in document 1. The switch K is closed at an instant t = 0 and the readings of the voltmeter are tabulated in the table below:

Doc. 2									
t(s)	0	0.4	0.8	1.2	1.6	2	2.4	2.8	3.2
u_R (V)	12	7.28	4.44	2.68	1.62	1	0.6	0.36	0.2

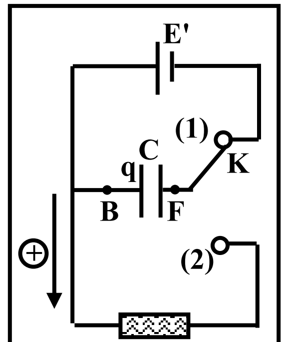
1-1) Show that, using document 2, (D) is a capacitor.

1-2) Deduce the value of E.

1-3) Let $u_C = u_{BF}$ be the voltage across the capacitor at an instant t. Calculate the ratio $\frac{u_C}{E}$ at t = 0.8 s.

1-4) Deduce, referring to document 2, the value of the time constant τ of the circuit.

1-5) Show that the capacitance of the capacitor is C = 1μF.



Doc.3

2- Usage of the capacitor in medicine: Pacemaker

When the human heart does not function correctly, the surgery permits to implant in the human body an artificial stimulator called pacemaker sending artificial electric pulses to the heart. This pacemaker can be modeled by an electric circuit as shown in document 3.

This circuit consists of:

An ideal DC generator of e.m.f. E', a resistor of resistance R', the capacitor of capacitance C = 1 μF and an electronic double switch (K).

At t = 0 the switch is at position 1, the capacitor is totally charged instantly, then the switch is turned automatically to position 2 and the capacitor discharges slowly through R'. At an instant t_1 the voltage across the capacitor is $u_C = u_{BF} = 2.08$ V, the circuit sends an electric pulse to the heart to get one beat, at this instant the switch turns automatically to the position 1 and so on (Doc. 4).

2-1) Establish the differential equation of $u_C = u_{BF}$ during the discharging.

2-2) The solution of the obtained differential equation has the form of $u_C = a + b\ e^{\frac{-t}{\tau'}}$. Determine the expressions of the constants a, b and τ', in terms of R', E' and C.

2-3) Determine graphically the value of τ'.

2-4) Deduce the value of R'.

Doc.4

3- Heart beat

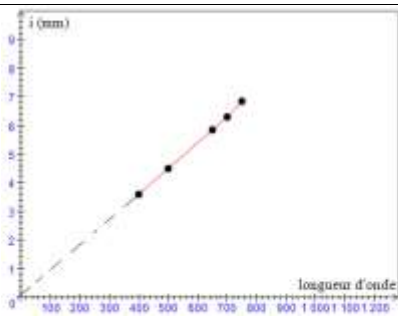
3-1) Indicate, referring to document 4, the value of t_1.

3-2) Deduce the duration Δt separating two successive pulses.

3-3) Deduce the number of beats of the heart per one minute.

وزارة التربية والتعليم العالي	امتحانات الشهادة الثانوية العامة	دورة الـعام ٢٠١٧ الاستثنائيّة
المديرية العامة للتربية	الفرع: علوم عامة	الثلاثاء في ٨ آب ٢٠١٧
دائرة الامتحانات الرسميّة	أسس التصحيح	

Exercise 1 : torsion pendulum				7½
1	1-1		$ME = \frac{1}{2}I\theta'^2 + \frac{1}{2}C\theta^2$	1
	1-2		Since no friction (or work done by the non conservative forces is zero) then ME = const, so $\frac{dME}{dt} = 0$; $I\theta'\theta'' + C\theta\theta' = 0 \Rightarrow \theta'' + \frac{C}{I}\theta = 0$	1
	1-3		The differential equation is of the form : $\theta'' + \omega_0^2\theta = 0$; $\omega_0 = \sqrt{\frac{C}{I}}$ $$\omega_0 = 2\pi f_0 \ ,then\ f_0 = \frac{1}{2\pi}\sqrt{\frac{C}{I}}$$	1
2	2-1	2-1-1	$(E_{ptorsion})$ max = constant so the oscillations are undamped	¼
		2-1-2	Since $f_E = 2f_0$, then = $2T_E = 2 \times 0.2 = 0.4$ s ; $f_0 = \frac{1}{T_0} = \mathbf{2.5\ Hz}$	1
		2-1-3	$ME = (E_{ptorsion})_{max} = 5 \times 10^{-6}$ J.	½
	2-2		$ME = \frac{1}{2}I\theta'^2 + \frac{1}{2}C\theta^2$; $\theta'^2 = -\frac{C}{I}\theta^2 + \frac{2ME}{I}$	½
	2-3	2-3-1	Decreasing straight line does not passing through the origin that is compatible with the expression of θ'^2 that is of the form ; y = -bx + c	½
		2-3-2	for $\theta = 0$; $\theta'^2 = \frac{2ME}{I} = 2.5$ so $I = \frac{2ME}{\theta'^2} = \frac{2\times5\times10^{-6}}{2,5} = \mathbf{4\times10^{-6} kg.m^2}$	½
	2-4		First method : $f_0 = \frac{1}{2\pi}\sqrt{\frac{C}{I}}$, so **C = $\mathbf{10^{-3}}$ N.m/rad** Second method : slope of the straight line = $-\frac{C}{I} = -\frac{2.5}{0.01} = -250$; Therefore, C = $250 \times 4 \times 10^{-6}$ = **$\mathbf{10^{-3}}$ N.m/rad**	1 ¼

Exercise 2 : Interference of light (7.5 pts)				
1		**1.1**	(S_1) and (S_2) are two synchronous and coherent secondary sources	**0.5**
		1.2	Rectilinear band, bright and dark, their centers are equidistant and parallel to the slits.	**1**
2	**2.1**	**2.1.1**	3.6 – 4.5 – 5.4 – 5.85 – 6.3 – 6.85	**0.5**
		2.1.2	 λ(nm)	**1.25**
		2.1.3	The form of i(λ) is a straight line and passing through the origin slope $\alpha = 9000$ so i = 9000 λ.	**0.25** **0.75**
	2.2	**2.2.1**	i is directly proportional to λ . In expression (b): i and λ are inversely proportional; In expression (f): i is proportional to the square of λ.	**0.5** **0.5**
		2.2.2	In expression (a): The unit of i is m^3	**0.5**
		2.2.3	Expression (e) since: as D increases, i decreases.	**0.5**
		2.2.4	The interfringe- distance and D are proportional that is satisfied in the equation (c).	**0.5**
		2.2.5	For any couple of values in the table : (500 nm, 4.5 mm) $C = \frac{i \times a}{\lambda D} = \frac{4.5 \times 10^{-3} \times 0.2 \times 10^{-3}}{500 \times 10^{-9} \times 1.8} = 1$	**0.75**

Exercice 3 : Solar spectrum (7.5 pts)			**7 ½**
1		the presence of the lines in the absorption spectrum is due to the absorption of photons of the gas in the atmosphere (each missing line corresponds to a certain transition in an atom of the gas in the atmosphere from a lower level to a higher level).	**0.5**
2	**2.1**	visible	**0.5**
2.2	**2.2.1**	$E_{photon} = E_n - E_2$, so $\frac{hc}{\lambda} = \frac{-E_0}{n^2} + \frac{-E_0}{2^2}$, then $\frac{1}{\lambda} = \frac{E_0}{hc}\left(\frac{1}{4} - \frac{1}{n^2}\right)$ Therefore, $\lambda = \frac{4n^2hc}{E_0(n^2-4)}$	**1.5**
	2.2.2	line $\alpha \to n = 3$(given) ; line $\beta \to n = 4$; line $\gamma \to n = 5$; line $\delta \to n = 6$ $\lambda_\alpha = 657.289$ nm (given); $\lambda_\beta = 486.881$ nm ; $\lambda_\gamma = 434.715$ nm ; $\lambda_\delta = 410.805$nm	**1.5**
	2.2.3	line $\alpha \to$ C ; line $\beta \to$ F ; line $\gamma \to$ G ; line $\delta \to$ h	**0.75**
3	**3.1**	for $\lambda = 589.592$ nm ; $E_{photon} = \frac{hc}{\lambda} = \mathbf{2.10\ eV}$. for $\lambda = 588.410$ nm ; $E_{photon} =$ **2.11 eV**.	**1.5**
	3.2	Mercury : $E_2 - E_1 = 4.9$ eV Sodium : $E_2 - E_1 = 2.11$ eV $= E_{photon}$ So the gas is the **sodium**.	**1.25**

Exercise 4 Pacemaker (7.5 pts)			
1	1-1	u_D increase with time, $u_D = E - u_R$	0.5
	1-2	$E = 12$ V at $t = 0$ $u_R = 12$ V $u_C = 0$	0.5
	1-3	$\frac{u_C}{E} = \frac{12 - 4.44}{12} = 0.63$	0.5
	1-4	**$\tau = 0.8$ s** since at $t = \tau$: $u_C = 0.63E$	0.5
	1.5	$\tau = RC$ so $C = \frac{\tau}{R} = \frac{0.8}{8\times10^5} = 10^{-6}$ F	0.75
2	2.1	$U_{BF}(C) = u_{BF}(R)$, then $u_C = Ri$ $\quad i = -\frac{dq}{dt} = -C\frac{du_C}{dt}$, then $u_C + RC\frac{du_C}{dt} = 0$	1
	2.2	$u_C = a + be^{\frac{-t}{\tau'}}; \frac{du_c}{dt} = -\frac{b}{\tau'}e^{\frac{-t}{\tau'}}, so\ -\frac{b}{\tau'}e^{\frac{-t}{\tau'}} + \frac{1}{R'C}\left(a + be^{\frac{-t}{\tau'}}\right) = 0$ $be^{\frac{-t}{\tau'}}\left(+\frac{1}{R'C} - \frac{1}{\tau'}\right) + \frac{a}{R'C} = 0$, then $\tau' = R'C\ and\ a = 0$ At $t = 0$: $u_C = E'$, therefore, $b = E'$	1.5
	2-3	Graphically: at $t = \tau'$: $u_C = 0.37 \times E' = 2.086$ V , so $\tau' =$ **$t_1 = 0.8$ s**	0.75
	2-4	$R' = \frac{\tau'}{C} = \frac{0.8}{10^{-6}} =$ **800000 Ω**	0.5
3	3-1	**$t_1 = 0.8$ s**	0.25
	3-2	Δt = time of charging + time of discharging = $t_1 + 0 =$ **0.8 s**	0.25
	3-3	$N_b = \frac{60}{0.8} =$ **75**	0.5

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

This exam is formed of four exercises in four pages

The use of non-programmable calculators is recommended

Exercise 1 (7 ½ pts)

Rolling of a disk along a vertical string

A vertical thin string is fixed to a ceiling from its top end while the other end is wound around a uniform homogeneous disk of center of mass (G), radius R and mass m = 2 kg (Doc. 1).

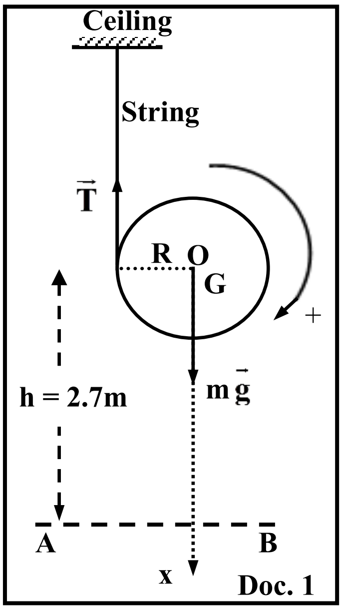
Ox is a vertical axis oriented positively downward and of origin O.

At $t_0 = 0$, the disk is released from rest, (G) coincides with O and at a height h = 2.7 m from a horizontal line (AB).

(G) moves then in rectilinear motion along the x-axis and the disk rotates, with an angular speed θ′ around its horizontal axis (Δ) passing through O.

During the motion the string remains tangent to the disk. Neglect air resistance.

The aim of this exercise is to determine the speed and the acceleration of (G) when it passes through the line (AB) by two different methods.



Given:

- the horizontal plane containing (AB) is a reference level for gravitational potential energy;
- the linear speed of (G), at an instant t, is $v = R\,\theta'$;
- the moment of inertia of the disk about (Δ) is $I = \frac{mR^2}{2}$;
- $g = 10\ m/s^2$.

1- First method: Newton's second law

The disk is acted upon by two forces: its weight $m\vec{g}$ and the tension $\vec{T}$ of the string (Doc. 1).

1-1) Determine, with respect to (Δ), the expression of the moment of $\vec{T}$ and the value of the moment of $m\vec{g}$.

1-2) Apply Newton's second law of rotation (theorem of the angular momentum) to prove that $T = \frac{I\theta''}{R}$ [θ″ is the angular acceleration of the disk with respect to (Δ)].

1-3) Apply Newton's 2^{nd} law of translation to prove that T = mg – ma [$\vec{a}$ is the acceleration of (G)].

1-4) Show that $a = \frac{2g}{3}$.

1-5) Deduce, in terms of g and t, the expression of:

1-5-1) the speed v of (G);

1-5-2) the abscissa x of (G).

1-6) Determine the speed of (G) when it passes through the line (AB).

2- Second method: principle of conservation of the mechanical energy

2-1) Calculate the mechanical energy of the system [disk, Earth] at $t_0 = 0$.

2-2) Write, in terms of v , m , θ′ and I, the expression of the mechanical energy of the system [disk, Earth] when (G) passes through the line (AB).

2-3) Apply the principle of the conservation of the mechanical energy to determine the speed of (G) when it passes through the line (AB).

2-4) Write the expression of the mechanical energy of the system [disk, Earth] at any instant t in terms of v, m, θ′, I, g , h and the abscissa x of (G).

2-5) Deduce that $a = \frac{2g}{3}$.

Exercise 2 (7 pts)

Fission of uranium-235

In a nuclear power plant uranium-235 captures a thermal neutron; it forms a new unstable nucleus $^{A}_{Z}X$ (Reaction 1).

$^{A}_{Z}X$ is divided into two nuclei krypton and barium (possible fission fragments) with an emission of certain number of neutrons and γ-radiation (Reaction 2).

Reaction 1: $^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{A}_{Z}X$

Reaction 2: $^{A}_{Z}X \rightarrow {}^{A'}_{36}Kr + {}^{141}_{Z'}Ba + 3\,{}^{1}_{0}n + \gamma$

Given:

the mass of $^{235}_{92}U$ nucleus is 234.99346 u;

the mass of $^{A'}_{36}Kr$ nucleus is 91.90641 u;

the mass of $^{141}_{Z'}Ba$ nucleus is 140.88369 u;

the mass of $^{1}_{0}n$ is 1.00866 u;

$1\ u = 931.5\ MeV/c^2$;

$1\ eV = 1.6 \times 10^{-19}\ J$.

1- Determine the values of A, Z , A′, and Z′.

2- Deduce the name of the isotope $^{A}_{Z}X$.

3- The overall equation (fission reaction) of the above reactions is:

$^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{A'}_{36}Kr + {}^{141}_{Z'}Ba + 3\,{}^{1}_{0}n + \gamma$.

This fission reaction leads to a chain fission reaction. Why?

4- At least one of the fission fragments is born in the excited state. Why?

5- Show that the energy liberated by the fission of one uranium-235 is $E_{lib} \cong 2.8 \times 10^{-11}$ J.

6- The first fission reaction gives off 3 neutrons (first generation). Suppose that the three neutrons stimulate other fissions similar to the above one. These fissions in turn give off 9 neutrons (second generation), and so on....

6-1) Determine the number N of neutrons given off by the 100th generation.

6-2) Suppose that each one of the above emitted neutrons bombards one uranium-235 nucleus. Deduce the total energy released due to the fission of uranium-235 nuclei bombarded by the above N neutrons.

6-3) In a nuclear power plant, the fission reaction is controlled: on average only one of three neutrons produced by each fission is allowed to stimulate another fission reaction.

Suppose that a nuclear power plant operates according to the above fission reaction and has an efficiency of 33 %. In the nuclear reactor, 1.5×10^{25} uranium-235 nuclei undergo fission during one day.

6-3-1) Determine the electric energy E_{elec} delivered by this station during one day.

6-3-2) Deduce the average electric power P_{elec} of the station.

7- Once fusion nuclear reaction started it is difficult to control. Deduce one advantage of fission nuclear reaction over fusion nuclear reaction.

<u>Exercise 3</u> (8 pts)

Thermal energy released by electric circuits

The aim of this exercise is to determine the thermal energy released by two different electric circuits.

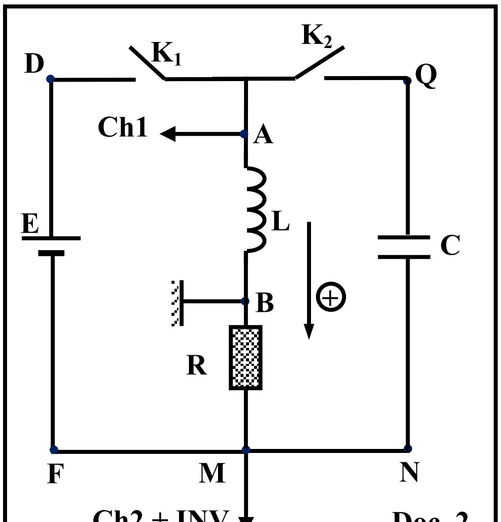
The circuit of document 2 is composed of:

an ideal battery of voltage E = 10 V, a resistor of resistance R = 100 Ω, a coil of inductance L, two switches K_1 and K_2, and a capacitor of capacitance C = 5 μF.

The two channels (Ch1 and Ch2) of an oscilloscope are connected across the terminals of the coil and that of the resistor respectively.

The ″INV″ button of the oscilloscope is pressed.

Initially, K_1 and K_2 are open; the capacitor and the coil have no energies.



Doc. 2

1- Determination of the thermal energy released by RL series circuit

We close K_1 at an instant $t_0 = 0$. The curves of document 3 represent $u_{coil} = u_{AB}$ and $u_R = u_{BM}$ as functions of time t.

The straight line (Δ) is tangent to $u_R(t)$ at $t_0 = 0$.

1-1) During the growth of the current, the magnetic energy stored in the coil increases. Justify.

1-2) Referring to document 3, indicate the value of the voltage across the coil at the steady state.

1-3) Deduce that the coil has negligible resistance.

1-4) Derive the differential equation that describes the variation of u_R as a function of time t.

1-5) Use the differential equation to determine $\frac{du_R}{dt}$ in terms of R, L and E, at the instant $t_0 = 0$.

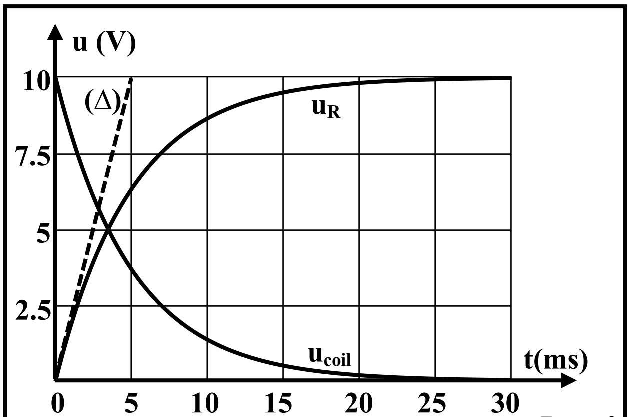
1-6) Show that L = 0.5 H by using the tangent (Δ).

1-7) Determine the maximum magnetic energy W_{mag} stored in the coil.

1-8) The steady state is attained at t = 25 ms, the thermal energy released by the resistor during the time interval [0 , 25 ms] is $W_R = 7\ W_{mag}$.

1-8-1) Calculate W_R during the time interval [0 , 25 ms].

1-8-2) Determine the thermal energy released by the resistor during the interval [0 , 30ms].



Doc. 3

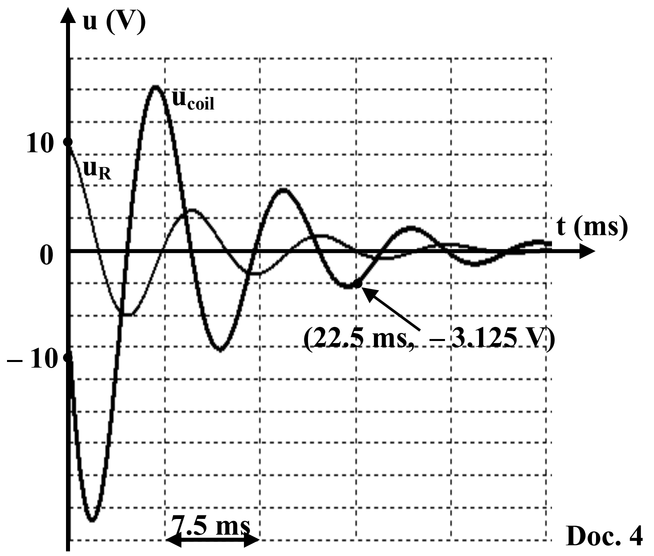
2- Determination of the thermal energy released by RLC series circuit

When the steady state in the circuit is attained, we close K_2 and open K_1 simultaneously at an instant taken as a new initial instant $t_0 = 0$. The graph of document 4, shows $u_R = u_{BM}$ and $u_{coil} = u_{AB}$ as functions of time t.

2-1) Give, at $t_0 = 0$, the initial electromagnetic energy stored in the RLC circuit.

2-2) At an instant t_1 = 22.5 ms:

$u_{coil} = u_{AB} = -3.125$ V. (Doc. 4)



Doc. 4

2-2-1) Use document 4 to specify the value of the current in the circuit at the instant t_1.

2-2-2) Apply the law of addition of voltages to determine $u_{NQ} = u_C$ at the instant t_1.

2-2-3) Determine the electromagnetic energy in this circuit at t_1.

2-2-4) Deduce the thermal energy released by this circuit during the time interval [0 , 22.5 ms].

Exercise 4 (7 ½ pts)

Interference of light

Document 5 represents the set-up of Young's double slit experiment. The vertical screen (E) is movable and remains parallel to an opaque plate (P) containing two horizontal and parallel thin slits S_1 and S_2 separated by a distance $S_1S_2 = a$.

S is a thin horizontal slit placed at a distance d from (P).

D is the distance between (E) and (P).

M, N and O, are three points on (E) belonging to a vertical axis (Ox).

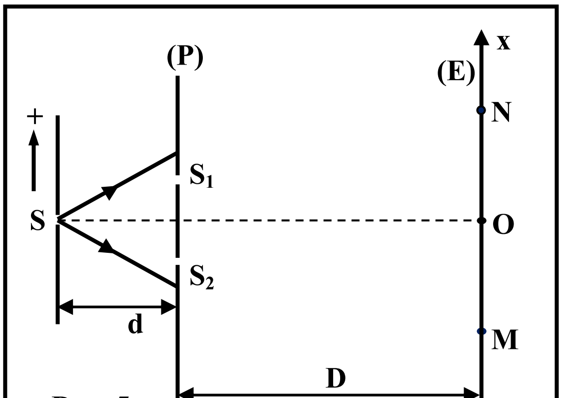
O is the midpoint of [MN] and equidistant from S_1 and S_2.

A laser light of wavelength λ in air illuminates the thin slit S.

Given:

$SS_1 = SS_2$; $\lambda = 600$ nm; a = 0.1 mm; MN = 30 mm; d = 20 cm.

The abscissa of the point N is $x_N = 15$ mm.



Doc. 5

1- Qualitative study

1-1) The conditions of interference are satisfied. Why?

1-2) Name the phenomenon that takes place at each of S_1 and S_2.

1-3) The fringes on (E) are directed along the horizontal. Why?

2- Experimental study

The optical path difference at any point Q, on the interference pattern in the screen, having an abscissa $x = \overline{OQ}$ is: $\delta = (SS_2 + S_2Q) - (SS_1 + S_1Q) = \frac{ax}{D}$.

2-1) In the interference region, the point O is the center of a bright fringe for any value of D. Justify.

2-2) The distance between (P) and (E) is $D = D_1 = 3$ m.

2-2-1) Define the interfringe distance "i" and calculate its value.

2-2-2) Deduce that between M and N there is only one bright fringe of center O.

2-3) Now the distance between (P) and (E) is $D = D_2 = 5$ m.

2-3-1) Show that the point N is a center of a dark fringe.

2-3-2) We move gradually the screen (E) towards (P) parallel to itself. For a distance $D = D_3$, the point N becomes the center of the first bright fringe. Calculate D_3.

2-4) We displace the slit S by a displacement z in a direction parallel to (P) towards the side of one of the two slits.

The optical path difference, at the point N, becomes: $\delta' = \frac{az}{d} + \frac{ax_N}{D}$.

2-4-1) Determine the relation between z and D so that N remains the center of the first bright fringe.

2-4-2) Deduce the value of the displacement z if D = 2 m.

2-4-3) Indicate then the direction of the displacement of (S).

مسابقة في مادة الفيزياء
أسس التصحيح

Exercise 1 (7.5 points) Rolling of a disk along a vertical string				
Part			**Answer**	**Mark**
1	1-1		$\mathcal{M}_{m\vec{g}} = 0$ since $m\vec{g}$ passes through (Δ). $\mathcal{M}_{\vec{T}} = T \times R$.	0.5
	1-2		$\Sigma\mathcal{M}_{ext} = \frac{d\sigma}{dt} = I\,\theta''$, then $\mathcal{M}_{m\vec{g}} + \mathcal{M}_{\vec{T}} = 0 + TR$, then $TR = I\,\theta''$; therefore, $T = \frac{I\theta''}{R}$	0.5
	1-3		$\Sigma\vec{F}_{ext} = m\vec{a}$; $m\vec{g} + \vec{T} = m\vec{a}$. Projection along Ox, We obtain : $mg - T = ma$ Then, $T = mg - ma$	0.75
	1-4		$T = \frac{I\theta''}{R} = \frac{mR^2a}{2R^2} = \frac{ma}{2}$ But $T = mg - ma$, then $mg = \frac{ma}{2} + ma = \frac{3ma}{2}$, Therefore, $a = \frac{2g}{3}$	0.5
	1-5	1	Primitive of the acceleration we obtain $v = a\,t + V_0$ Then, $v = \frac{2g}{3}\,t$ $(V_0 = 0)$	0.5
		2	Primitive of the speed we obtain $x = \frac{1}{2}\frac{2g}{3}t^2 = \frac{g}{3}t^2$	0.5
	1-6		$h = \frac{g}{3}t^2$; $t = \sqrt{\frac{3h}{g}} = \sqrt{\frac{3\times 2.7}{10}}$, then $t = 0.9$ S $v = \frac{2g}{3}t = \left(\frac{2g}{3}\times 0.9\right) + 0 = \frac{2\times 10}{3}\times 0.9 = 6$ m/s	1
2	2-1		$ME_0 = KE + GPE = 0 + mgh = 2\times 10\times 2.7 = 54$ J	0.5
	2-2		$ME_f = \frac{1}{2}mv^2 + \frac{1}{2}I\theta'^2 + 0$	0.5
	2-3		$ME_0 = ME_f$, $54 = \frac{1}{2}\left(mv^2 + \frac{mR^2v^2}{2R^2}\right) = \frac{1}{2}\left(\frac{3mV^2}{2}\right)$ Then, $v = \sqrt{\frac{4\times 54}{3\times 2}} = 6$ m/s	1
	2-4		$ME = \frac{1}{2}mv^2 + \frac{1}{2}I\theta'^2 + mg(h - x)$	0.5
	2-5		$\frac{1}{4}mR^2\theta'^2 = -\,mgh + mgx - \frac{1}{2}mv^2 + mgh$ $(Em_{(t)} = Em_0)$ $\frac{1}{4}mR^2\frac{v^2}{R^2} + \frac{1}{2}mv^2 = mgx$; $\frac{3}{4}mv^2 = mgx$; $v^2 = \frac{4gx}{3}$ Differentiate both sides with respect to time, so $2\,vv' = \frac{4g}{3}x'$ Therefore, $a = \frac{2g}{3}$	0.75

<table>
<tr><th colspan="5">Exercise 2 (7 pts) Fission of uranium-235</th></tr>
<tr><th colspan="3">Part</th><th>Answer</th><th>Mark</th></tr>
<tr><td colspan="3">1</td><td>Law of conservation of charge number :
$Z = 92 + 0 = 92.$
Law of conservation of mass number :
$A = 235 + 1 = 236.$
$236 = A' + 141 + 3(1)$, alors $A' = 92.$
$92 = 36 + Z' + 3(0)$, then $Z' = 56$</td><td>1</td></tr>
<tr><td colspan="3">2</td><td>${}^{A}_{Z}X$ is uranium since $Z = 92.$</td><td>0.25</td></tr>
<tr><td colspan="3">3</td><td>Since each fission reaction liberates 3 neutrons.</td><td>0.5</td></tr>
<tr><td colspan="3">4</td><td>Since γ radiation is emitted</td><td>0.25</td></tr>
<tr><td colspan="3">5</td><td>$E_{lib} = \Delta m\, c^2$
$\Delta m = m_{before} - m_{after}$
$= [1.00866 + 234.99346]$
$- [140.88369 + 91.90641 + 3(1.00866)] = 0.18604$ u
$E_{lib} = \Delta m\, c^2 = 0.18604 \times 931.5 \frac{MeV}{c^2} \times c^2 = 173.3$ Mev
$E_{lib} = 173.3 \times 1.6 \times 10^{-13}$, so $E_{lib} \cong 2.8 \times 10^{-11}$ J</td><td>1.5</td></tr>
<tr><td rowspan="4">6</td><td colspan="2">6-1</td><td>1 generation → 3^1 neutrons.
2 generations → $3^2 = 9$ neutrons …
100^{th} generations → $N = 3^{100} = 5.15 \times 10^{47}$ neutrons</td><td>0.5</td></tr>
<tr><td colspan="2">6-2</td><td>$E_{total} = N\, E_{lib} = 5.15 \times 10^{47} \times 2.8 \times 10^{-11} = 1.44 \times 10^{37}$ J</td><td>0.5</td></tr>
<tr><td rowspan="2">6-3</td><td>1</td><td>$E_{nuleaire} = 1.5 \times 10^{25} \times E_{lib} = 1.5 \times 10^{25} \times 2.8 \times 10^{-11}$
$= 4.2 \times 10^{14}$ J
$E_{electrical} = 0.33 \times E_{nuclear} = 0.33 \times 4.2 \times 10^{14}$
$= 1.39 \times 10^{14}$ J</td><td>1</td></tr>
<tr><td>2</td><td>$P_{electrical} = \frac{E_{electrical}}{\Delta t} = \frac{1.39 \times 10^{14}}{24 \times 3600} = 1.6 \times 10^{9}$ W</td><td>1</td></tr>
<tr><td colspan="3">7</td><td>The released energy by fission nuclear reaction can be controlled so it can be used in nuclear power plant, while fusion nuclear reaction cannot be controlled so it cannot be used in nuclear power plant.</td><td>0.5</td></tr>
</table>

Exercise 3 (8 pts) Thermal energy consumed by an electric circuit				
Part			**Answer**	**Mark**
1	**1-1**		u_R increases then i increases , $W_{mag} = \frac{1}{2} L\, i^2$, i increases, then W_{mag} increases.	**0.5**
	1-2		$u_{coil} = 0$	**0.25**
	1-3		$u_{coil} = r\,i + L\frac{di}{dt}$. Steady state: $u_{coil} = 0$ et $\frac{di}{dt} = 0$ (since u_R is constant than i is constant) and $i \neq 0$, so $r = 0$	**0.25**
	1-4		$u_{DE} = u_{AB} + u_{BM}$; $E = L\frac{di}{dt} + u_R$. $u_R = iR$, then, $\frac{di}{dt} = \frac{1}{R}\frac{du_R}{dt}$, then $\frac{du_R}{dt} + \frac{R}{L}u_R = \frac{R}{L}E$	**0.75**
	1-5		At $t_o = 0$; $u_R = 0$, then at $t_o = 0$: $\frac{du_R}{dt} = \frac{RE}{L}$	**0.5**
	1-6		The slope of the tangent to u_R at $t_o = 0$, $= \frac{du_R}{dt}$ So slope $= \frac{10}{0.005} = \frac{RE}{L}$, so $L = \frac{100\times10\times0.005}{10} = 0.5H$	**0.75**
	1-7		$W_{max} = \frac{1}{2}LI_{max}{}^2 = \frac{1}{2}\times 0.5\times(\frac{10}{100})^2 = 2.5\times10^{-3}J$	**0.75**
	1-8	**1**	$W_R = 7\ W_{mag} = 7\times 2.5\times10^{-3} = 17.5\times10^{-3}$ J	**0.5**
		2	$W_{heat[0\,,\,30\,ms]} = W_{heat[0\,,\,25\,ms]} + W_{heat[25\,ms\,,\,30\,ms]}$ $= 7\times 2.5\times10^{-3} + EI_{max}\Delta t = 17{,}5\times10^{-3} + (10\times0.1\times0.005)$ Then, $W_{heat[0\,,\,30\,ms]} = 22.5\times10^{-3}J$	**1**
2	**2-1**		$W_{em} = \frac{1}{2}Li^2 + \frac{1}{2}Cu_C{}^2$ at $t_o = 0$. $u_C = 0$, Then, $W_{em} = \frac{1}{2}Li^2 = \frac{1}{2}\times0.5\times(0{,}1)^2 = 2.5\times10^{-3}J$	**0.75**
	2-2	**1**	At t = 22.5ms; $u_R = 0$, then $i = 0$	**0.25**
		2	$u_{AB} + u_{BM} + u_{MN} + u_{NQ} + u_{QA} = 0$, then, $u_{coil} + u_R + 0 + u_C + 0 = 0$, so $-3.125 + 0 + u_C = 0$, then $u_C = 3.125$ V	**0.5**
		3	$W'_{em} = \frac{1}{2}Li^2 + \frac{1}{2}Cu_c{}^2 = 0 + \frac{1}{2}\times5\times10^{-6}\times3.125^2$ $= 2.44\times10^{-5}J$	**0.75**
		4	$W_{heat[\,0,\ 22.5\,ms]} = W_{em} - W'_{em} = 2.5\times10^{-3} - 2.44\times10^{-5}$ $= 2.47\times10^{-3}J$	**0.5**

Exercise 4 (7.5 pts) Interference of light				
Part			**Answer**	**Mark**
1	1-1		The two slits are illuminated by the same source.	0.5
	1-2		Diffraction	0.5
	1-3		The fringes on (E) are directed along the horizontal because The slits are directed along the horizontal and fringes are parallel to the slits.	0.5
2	2-1		At O: $\delta = \frac{a \times 0}{D} = 0$ for every value of D. Therefore, O is the center of the central bright fringe every value of D **Or** $\delta = (SS_2+S_2O)-(SS_1+S_1O) = (SS_2-SS_1)+(S_2O-S_1O) = 0 + 0 = 0$ Since : $SS_2 = SS_1$ et $S_1O = S_2O$	0.5
	2-2	1	The interfringe i is the distance between the centers of two consecutive fringes of same nature. $i = \frac{\lambda D}{a} = \frac{600 \times 10^{-9} \times 3}{0.1 \times 10^{-3}} = 18 \times 10^{-3}$m = 18 mm	1
		2	OM = ON = $\frac{30}{2}$ = 15 mm < i . Therefore, between N and M we have only one bright fringe at O.	0.5
	2-3	1	$\delta_N = \frac{ax}{D} = (2k+1)\frac{\lambda}{2}$, Then, $(2k+1) = \frac{2ax}{D\lambda} = \frac{2 \times 0.1 \times 15 \times 10^{-6}}{5 \times 600 \times 10^{-9}} = 1$, thus k = 0 OR: $i' = \frac{\lambda D}{a} = \frac{600\times10^{-9}\times 5}{0.1\times10^{-3}} = 30\times10^{-3}$ = 30 mm $x_N = 15 \text{ mm} = \frac{i'}{2}$, then N is the center of the first dark fringe. **Or** $\frac{\delta}{\lambda} = \frac{ax}{D\lambda} = \frac{x}{i'} = \frac{1}{2}$,so $\delta = \frac{1}{2}\lambda$ has the form $(2k+1)\frac{\lambda}{2}$ with K = 0 then N is the center of the first dark fringe	0.5
		2	For the first bright fringe, $\delta = k\lambda = \lambda$ (k = 1) $k\lambda = \frac{ax}{D_3}$; $D_3 = \frac{ax}{\lambda} = \frac{10^{-4} \times 15 \times 10^{-3}}{600 \times 10^{-9}} = \frac{15}{6}$ = 2.5 m	0.75
	2-4	1	$\delta' = \frac{az}{d} + \frac{ax_N}{D} = k\lambda = \lambda$ $\frac{az}{d} = -\frac{ax_N}{D} + \lambda$; $z = -\frac{d}{D}x_N + \frac{\lambda D}{a} = \frac{-3\times10^{-3}}{D} + 1.2\times10^{-3}$	1.25
		2	$z = \frac{-3\times10^{-3}}{2} + 1.2\times10^{-3} = -0.3\times10^{-3}$ m	0.5
		3	z < 0 ; then, S is moved downward.	0.5

دورة الـعام 2018 الاستثنائيّة	امتحانات الشهادة الثانوية العامة	وزارة التربية والتعليم العالي
الإثنين فـي 6 آب2018	الفرع: علوم عامة	المديرية العامة للتربية
		دائرة الامتحانـات الرسميّة
الاسم:	مسابقة في مادة الفيزياء	
الرقم:	المدة: ثلاث ساعات	

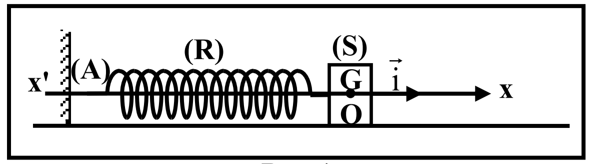
<u>This exam is formed of four obligatory exercises in 4 pages.</u>
<u>The use of non-programmable calculator is recommended.</u>

<u>Exercise 1</u> (8 points) Mechanical oscillations

The aim of this exercise is to study the oscillation of a horizontal elastic pendulum. The pendulum is formed of:

- A block (S) of mass m;
- A massless horizontal spring (R) of stiffness k=160N/m.

We fix the spring (R) from its end(A) to a support.The other end is connected to (S).



Doc.1

(S) canslide on a horizontal rail and its center of mass(G) can move along a horizontal x-axis of unit vector $\vec{i}$.
At equilibrium, (G) coincides with the origin O of the x-axis (Doc.1).
The horizontal plane containing (G) is taken as a gravitational potential energy reference.
Take $\pi^2 = 10$.

1- Free undamped oscillations

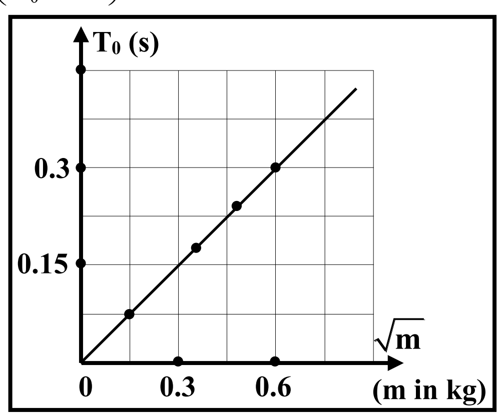
At the instant $t_0 = 0$, (S) is shifted to the left by a displacement $x_0 = -2\sqrt{2}$ cm and then it is launched with an initial velocity $\overrightarrow{v_0} = v_0\,\vec{i}$, where $v_0 < 0$. (S)oscillates without friction with an amplitude $X_m = 4$ cm and a proper period $T_0 = 0.35$s.

At an instant t, the abscissa of (G) is $x = \overline{OG}$ and the algebraic value of its velocity is $v = \frac{dx}{dt}$.

1.1) Calculate the mechanical energy of the system [(S) - spring - Earth].
1.2) Derive the second order differential equation in x that governs the motion of (G).
1.3) The solution of this differential equation is of the form $x = X_m\cos\left(\frac{2\pi}{T_0}t + \varphi\right)$,where φ is constant.

1.3.1) Determine the expression of the proper period T_0 in terms of m and k.
1.3.2) Deduce the value of m.
1.3.3) Determine the value of φ.

1.4) Using the principle of conservation of the mechanical energy, show that $\left(\frac{T_0}{2\pi}\right)^2 v_0^2 = X_m^2 - x_0^2$.
1.5) Deduce the value of v_0.
1.6) In order to verify the value of the stiffness k,we repeat the above experiment by attachingsuccessively blocks of different masses to the spring. We measure for each mass the corresponding value of the proper period. An appropriate device plotsthe graphofT_0versus $\sqrt{m}$ (Doc. 2).



Doc. 2

1.6.1) Determine the expression of T_0as a function of$\sqrt{m}$, using document 2.
1.6.2) Deduce the value of k.

2- Forced oscillations

Friction is no longer neglected. End (A) of the spring is now attached to a vibrator of adjustable frequency "f "vibrating along the axis of the spring. We notice that the amplitude of oscillation of (S) varies with "f ";theamplitude attains its maximum value for a frequency $f_1 = 2.86$ Hz.

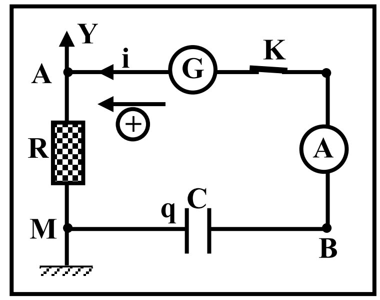
2.1) Name the exciter and the resonator.

2.2) Name the physical phenomenon that takes place for $f = f_1$.

2.3) Deduce again the value of k.

<u>Exercise 2</u> (8 points)Determination of the capacitance of a capacitor

The aim of this exercise is to determine, by two different methods, the capacitance C of a capacitor. For this aim, we consider: a capacitor of capacitance C initially uncharged, a resistor of resistance R, a switch K, an ammeter (A) of negligible resistanceand a generator (G).



Doc. 3

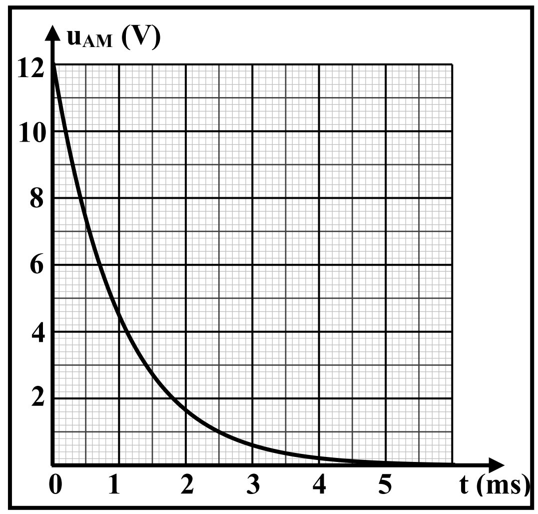
1. First experiment

(G) provides a constant voltage$u_{AB} = E = 12$ V.

We connect in series the capacitor, the resistor and the ammeter (A) across the terminals of (G)(Doc. 3).

At the instant $t_0 = 0$, we close K, thus the circuit carries a current i and the ammeterindicates a value $I_0 = 0.012$ A.

An oscilloscope is used to display the variation of the voltage u_{AM} across the resistor as a function of time (Doc. 4).



Doc. 4

1.1) Derive the differential equation that describes the variation of the voltage $u_C = u_{MB}$.

1.2) Deduce that the differential equation in i is: $i + RC\dfrac{di}{dt} = 0$.

1.3) The solution of this differential equation is of the form: $i = I_0 e^{\frac{-t}{\tau}}$, where I_0 and τ are constants.

Show that $I_0 = \dfrac{E}{R}$ and $\tau = RC$.

1.4) Using document4:

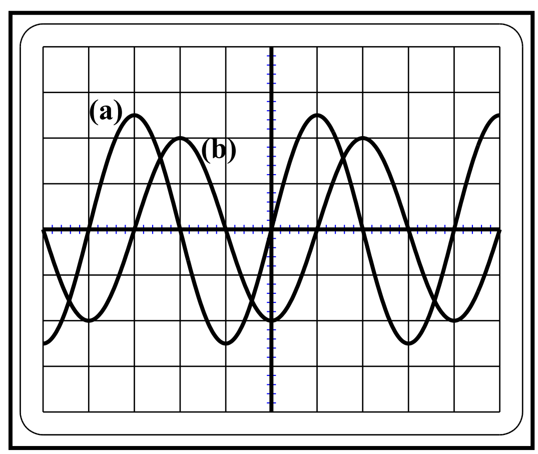
1.4.1)show that the value of R is 1kΩ ;

1.4.2)determine the value of τ ;

1.4.3)deduce the value of C.

2. Second experiment

(G) provides an alternating sinusoidal voltage. Anoscilloscope is connected in the circuit in order to display the voltages u_{AM} on channel (Y_1) and u_{MB} on channel (Y_2) [the "INV" button being pressed].



Doc. 5

Document 5 shows the curves of the voltages u_{AM} and u_{MB}.

Take: $\pi = 3.125$.

The adjustments of the oscilloscope are:

- horizontal sensitivity: 2.5 ms/div;
- vertical sensitivity: 5 V/div on channel (Y_1);
  10 V/div on channel (Y_2).

2.1) Waveform (b) representsthe voltage u_{MB}. Why?

2.2) Calculate the period of the voltageprovided by (G) and deduce the angular frequencyω.

2.3) Calculate the maximum value of the voltages u_{AM} and u_{MB}.

2.4) Calculate the phase difference φ between the voltage u_{MB} and the current i.

2.5) Knowing that the current i is given by: $i = I_m\cos(\omega t)$.

2.5.1) Determine the expressions of u_{AM} and u_{MB} as a function of time t;

2.5.2) Calculate the value of I_m.

2.6) Deduce the value of C.

<u>Exercise 3</u> (7 points)Determination of the age of a liquid

Tritium $^{3}_{1}H$ is a radioactive hydrogen isotope. Tritium is produced in the upper atmosphere by cosmic rays and brought to Earth by rain. The tritium can be used to determine the age of liquids containing this isotope of hydrogen.

In this exercise, we intend to determine the age of a liquid in an old bottle using the variation in the activity of tritium.

1. Radioactive decay of tritium

Tritium is a beta-minus (β^-) emitter. It decays into one of the isotopes of helium without the emission of gamma radiation.

1.1) Complete the equation of the decay of tritium and determine A and Z.

$^{3}_{1}H \rightarrow \, ^{A}_{Z}He + ...$

1.2) The helium nucleus is producedin the ground state. Why?

1.3) A particle X accompanies the above disintegration in order to satisfy a certain law. Name this particleand this law.

2. Determination of the radioactive period of tritium

Consider a sample of the radioactive isotope tritium $^{3}_{1}H$.

At an instant $t_0 = 0$, the number of nuclei in this sample is N_0.

The activity A of the radioactivesample represents the number of disintegrations per unit time.

The activity at an instant t is given by the following expression: $A = -\frac{dN}{dt}$, where N is the number of the remaining(undecayed) nuclei at the instant t.

2.1) Show that the first order differential equation that governs the variation of N is: $\frac{dN}{dt} + \lambda N = 0$, where λ is the decay constant of the radioactive isotope.

2.2) Verify that $N = N_0 e^{-\frac{t}{\tau}}$ is a solution of the above differential equation, where $\tau = \frac{1}{\lambda}$.

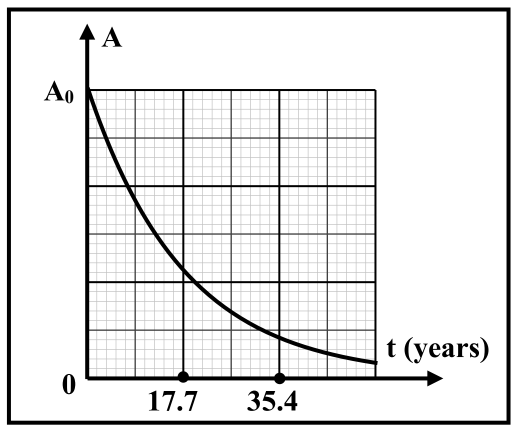
2.3) Deduce that the expression of the activity is given by: $A = A_0 e^{-\frac{t}{\tau}}$, where A_0 is the initialactivity of the sample.

2.4) Calculate A in terms of $A_0$when $t = \tau$.

2.5) Document 6 represents the activity of a sample of tritium as a function of time.

2.5.1) Show that τ = 17.7 years.

2.5.2) Deduce the radioactive period of tritium.



Doc. 6

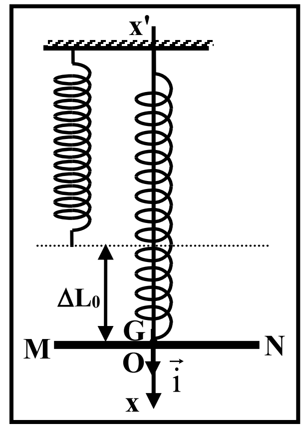
3. Determination of the age of a liquid

An old bottle containing a certainliquid is just opened (in 2018). It is found that the activity of tritium in thisliquid is 10.4 % of the initial activity of the same liquidfreshly prepared. Determine the year of production of theliquid in the old bottle.

Exercise4(7points)Electromagnetic induction

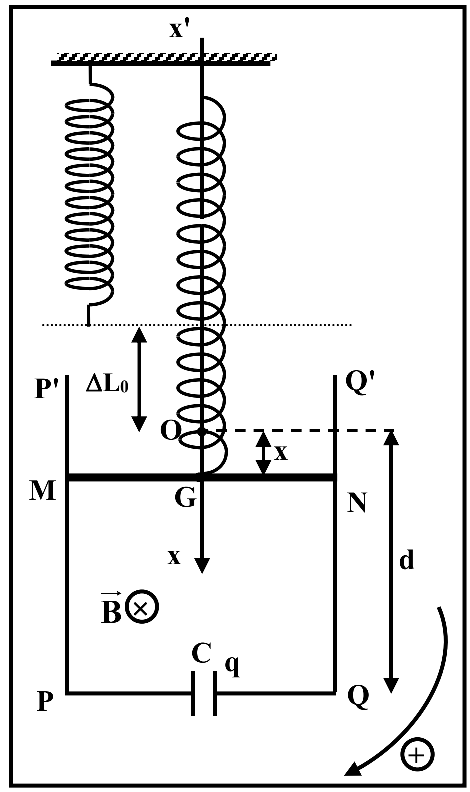
The aim of this exercise is to determine the magnitude B of a uniform magnetic field $\vec{B}$.

Consider a spring of stiffness k and of negligible mass attached from its upper end to a fixed support. Its lower end is attached to a copper rod MN of mass m and length ℓ. At equilibrium, the elongation of the spring is ΔL_0 and the center of mass G of the rod coincides with the origin O of a vertical x-axisof unit vector $\vec{i}$ (Doc.7).



Doc. 7

1. **Rod in equilibrium**
   1.1) Name the external forces acting on the rod at the equilibrium position.
   1.2) Determine the relation among m, g, k and ΔL_0.
2. **Electromagnetic induction**
   The rod MN may slide without friction along two vertical metallicrails (PP') and(QQ'). During sliding the rod remains perpendicular to the two rails.
   The two rails are separated by a distance ℓ and a capacitor, initially uncharged, of capacitance C is connected between P and Q.
   Neglect the resistance of the rod and of the rails.
   This set-up is placed in the region of a horizontal uniform magnetic field $\vec{B}$ perpendicular to the plane of the rails.
   At the equilibrium position G is found at a distance d from (PQ).
   The rod is pulled vertically downwards from its equilibrium position by a distance X_m, and then it is released without initial velocity, thus G oscillates about its equilibrium position O.
   At an instant t, G is defined by its abscissa $x = \overline{OG}$ and the algebraic value of its velocity is $v = \frac{dx}{dt}$ (Doc. 8).



Doc. 8

   2.1) Taking the positive sense, shown in document 8, into consideration,show that the expression of the magnetic flux crossing the area MNQP is given by $\varphi = B\ell d - B\ell x$.
   2.2) Deduce the expression of the electromotive force "e" induced in the rodin terms of B, ℓ and v.
   2.3) Knowing that $u_{QP} = u_C = e$, show that the expression of the current induced in the circuit MNQP is $i = C\,B\,\ell\,\frac{dv}{dt}$.
3. **Free oscillations**

The rod is subjected to an electromagnetic force (Laplace's force) $\vec{F} = -B^2\ell^2 C\frac{dv}{dt}\vec{i}$.

   3.1) Applying Newton's second law $\Sigma\overrightarrow{F_{ext}} = m\,x''\,\vec{i}$, show that the second order differential equation that governs the variation of the abscissa x is given by $x'' + \frac{k}{m + B^2\ell^2 C}x = 0$.
   3.2) Specify the nature of motion of the rod.
   3.3) Deduce the expression of the proper period T_0 of oscillation of the rod.
   3.4) The duration of 10 oscillations is 4.69 s. Determine the value of B, knowing that m = 10 g, ℓ = 10 cm, C = 8 mFand k = 1.8 N/m.

Exercise 1 (8 points) Mechanical oscillations

Part			Answer	Marks
1	1.1		$ME = \frac{1}{2} k X_m^2 = \frac{1}{2}(160)(4\times10^{-2})^2 = 0.128 J$	0.5
	1.2		$ME = KE + PE_e = \frac{1}{2} m v^2 + \frac{1}{2} k x^2$. Friction is neglected, so sum of works of nonconservative forces is zero, then ME is conserved. $\frac{d(ME)}{dt} = 0 = mvv' + kxx'$, so $x'(mx'' + kx) = 0$, thus $x'' + \frac{k}{m} x = 0$	0.75
	1.3	1.3.1	$x = X_m \cos\left(\frac{2\pi}{T_0} t + \varphi\right)$; $x' = -X_m \frac{2\pi}{T_0} \sin\left(\frac{2\pi}{T_0} t + \varphi\right)$; $x'' = -X_m (\frac{2\pi}{T_0})^2 \cos\left(\frac{2\pi}{T_0} t + \varphi\right)$; Substituting in the differential equation gives : $-X_m (\frac{2\pi}{T_0})^2 \cos\left(\frac{2\pi}{T_0} t + \varphi\right) + \frac{k}{m} X_m \cos\left(\frac{2\pi}{T_0} t + \varphi\right) = 0$; $(\frac{2\pi}{T_0})^2 = \frac{k}{m}$, so $T_0 = 2\pi\sqrt{\frac{m}{k}}$	1
		1.3.2	$T_0 = 2\pi\sqrt{\frac{m}{k}}$, so $m = \frac{T_0^2 . k}{4\pi^2}$, then $m = 0.49 kg = 490 g$	0.75
		1.3.3	$x_0 = x_m \cos\varphi$; $-2\sqrt{2} = 4\cos\varphi$; $\cos\varphi = -\frac{\sqrt{2}}{2}$; so $\varphi = \frac{3\pi}{4}$ rad or $\varphi = -\frac{3\pi}{4}$ rad. But , $v_0 = -X_m \frac{2\pi}{T_0} \sin\varphi$. Since $v_0 < 0$ then $\sin\varphi > 0$; therefore, $\varphi = 3\pi/4$ rad	1
	1.4		$ME\vert_{x_0} = ME\vert_{x_m}$, then $\frac{1}{2} m v_0^2 + \frac{1}{2} k x_0^2 = \frac{1}{2} k X_m^2$, then $m v_0^2 = k(X_m^2 - x_0^2)$. Substituting $m = \frac{kT_0^2}{4\pi^2}$ into the last expression gives : $\left(\frac{T_0}{2\pi}\right)^2 v_0^2 = X_m^2 - x_0^2$	0.75
	1.5		$v_0^2 = \frac{(X_m^2 - x_0^2)4\pi^2}{T_0^2}$, then $v_0 = 0.511$ m/s	0.5
	1.6	1.6.1	T_0 is proportional to $\sqrt{m}$ then $T_0 = \text{slope}\sqrt{m}$. slope $= \frac{\Delta T_0}{\Delta\sqrt{m}} = \frac{0.3}{0.6} = 0.5$ s/$\sqrt{kg}$ Then, $T_0 = 0.5 \times \sqrt{m}$ (S. I.)	1
		1.6.2	$T_0 = \frac{2\pi}{\sqrt{k}}\sqrt{m}$, then slope $= \frac{2\pi}{\sqrt{k}} = 0.5$, so $k = \frac{4\pi^2}{0.25} = \frac{4\times10}{0.25} = 160$ N/m	0.75
2	2.1		Exciter : the vibrator ; Resonator : the oscillator	0.5
	2.2	2.2.1	Amplitude resonance	0.25
		2.2.2	At resonance : $f_1 \cong f_0 = 2{,}86$ Hz. Replacing $T_0 = \frac{1}{2{,}86}$ into $T_0 = 2\pi\sqrt{\frac{m}{k}}$, gives $k \cong 160$ N/m	0.25

Exercise 2 (8 points) Determination of the capacitance of a capacitor

Part			Answer	Marks
1	1.1		$u_{AB} = u_{AM} + u_{MB}$, then $E = u_C + Ri$ and $i = dq/dt = C\,du_c/dt$ Then : $E = u_C + RC\,du_c/dt$	0.5
	1.2		Differentiating the last equation with respect to time gives : $0 = du_c/dt + RC\,d^2u_c/dt^2$, but $i = C\,du_c/dt$ and $\frac{di}{dt} = C\,d^2u_c/dt^2$, then : $0 = \frac{i}{C} + R\frac{di}{dt}$, then $0 = i+RC\,\frac{di}{dt}$	0.75
	1.3		$\frac{di}{dt} = -\frac{I_0}{\tau}e^{-t/\tau}$, substituting in the differential equation gives : $0 = I_0\,e^{-t/\tau} + RC\,(\frac{-I_0}{\tau})\,e^{-t/\tau}$ $0 = I_0\,(1 - \frac{RC}{\tau})\,e^{-t/\tau}$ for each value of t, then $\tau = RC$ At t = 0 : $i = I_0\,e^0 = I_0$ and At t = 0 : $i = \frac{E}{R}$, then $\frac{E}{R} = I_0$	1
	1.4	1.4.1	$I_o = \frac{E}{R}$ then $R = \frac{12}{0.012} = 1000\Omega$	0.5
		1.4.2	At $t = \tau$: $u_R = 0.37E = 0,37 \times 12 = 4.44$ V Graphically: $\tau = 1$ ms $= 10^{-3}$ s	0.5
		1.4.3	$C = \frac{\tau}{R} = \frac{10^{-3}}{10^{3}} = 10^{-6}$F = 1μF	0.5
2	2.1		In a series R-Ccircuit, i leads u_C. Curve of i is similar to that of u_R, then u_R leads u_C. Since curve (a) leadscurve (b),thencurve (b) represents u_C	0.5
	2.2		T = 4 × 2.5 = 10 ms $\omega = \frac{2\pi}{T} = \frac{2\pi}{10-2} = 200\,\pi$ rad/s = 625 rad/s	0.75
	2.3		$(u_{AM})_m = 2.5 \times 5 = 12.5$ v $(U_{MB})_m = 2 \times 10 = 20$ V	0.5
	2.4		$\varphi = \frac{2\pi d}{D} = \frac{2\pi \times 1}{4} = \frac{\pi}{2}$ rad	0.5
	2.5	2.5.1	$u_R = u_{AM} = 12.5\cos(200\,\pi t)$ S.I. u_C lags behind u_R by $\pi/2$ rad, then : $u_C = u_{MB} = 20\,\cos(200\,\pi t - \pi/2)$ S.I.	0.5
		2.5.2	$I_m = \frac{(U_{AM})_m}{R} = \frac{12.5}{10^3} = 12.5 \times 10^{-3}$ A	0.5
	2.6		$i = C\,\frac{du_C}{dt}$, then $i = C \times 20 \times [-200\pi\,\sin(200\pi t - \frac{\pi}{2})]$ and $i = I_m\cos(\omega t)$ $I_m\cos(\omega t) = -\,C \times 4 \times 10^3\pi\,\sin(200\pi t - \frac{\pi}{2})$ $I_m\cos(\omega t) = C \times 4 \times 10^3\pi\cos(200\pi t)$, so $I_m = C \times 4 \times 10^3\pi$ Then: $12.5 \times 10^{-3} = C \times 4 \times 10^3 \times \pi$ So: $C = \frac{12.5 \times 10^{-3}}{4 \times 10^3 \times \pi} = \frac{12.5 \times 10^{-6}}{2 \times 6.25} = 10^{-6}$ F = 1μF	1

Exercise 3 (7 points) **Determination of the age of a liquid**

Part		Answer	Marks
1	1.1	${}^{3}_{1}H \rightarrow {}^{A}_{Z}He + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}$ Applying the law of conservation of mass number: 3 = A + 0 , then A = 3 Applying the law of conservation of charge number: 1 = z -1 , then z = 2	1
	1.2	Tritium decays into one of the isotopes of helium without the emission of gamma radiation; therefore, the helium nucleus is produced in the ground state.	0.5
	1.3	The particle is the antineutrino. The law is: the law of conservation of total energy (or conservation of energy)	0.5
2	2.1	$A = -\frac{dN}{dt} = \lambda N$, then $\frac{dN}{dt} + \lambda N = 0$	0.5
	2.2	$N = N_o e^{-\frac{t}{\tau}}$, but $\frac{dN}{dt} = -\frac{N_o}{\tau} e^{-\frac{t}{\tau}} = -\frac{N}{\tau}$. Substituting in the differential equation, gives: $-\frac{N}{\tau} + \lambda N = 0$ But $\tau = \frac{1}{\lambda}$, then: $-\lambda N + \lambda N = 0$	0.75
	2.3	$A = \lambda N = \lambda N_o e^{-\frac{t}{\tau}}$, but $A_o = \lambda N_o$; therefore, $A = A_o e^{-\frac{t}{\tau}}$	0.75
	2.4	$A = A_o e^{-\frac{\tau}{\tau}} = A_o e^{-1}$, therefore $A = 0.37\ A_o$	0.75
	2.5 — 2.5.1	At $t = \tau$, $A = 0.37\ A_o$. Graphically, when $A = 0.37\ A_o$; $t = \tau = 17.7$ years.	0.5
	2.5 — 2.5.2	$\tau = \frac{1}{\lambda} = \frac{T}{\ell n\ 2}$, then $T = \tau\ \ell n\ 2 = 17.7\ (\ell n 2)$, therefore T = 12.3 years.	0.75
3		$A = A_o e^{-\frac{t}{\tau}}$,then $0.104\ A_o = A_o e^{-\frac{t}{\tau}}$, so $\ell n\ (0.104) = -t/\tau$ $t = -\ell n\ (0.104)\ (17.7) \cong 40$ years. Year of production = 2018 – 40 = 1978.	1

Exercise 4 (7 points) **Electromagnetic induction**

Part		Answer	Marks
1	1.1	The weight $\vec{W} = m\vec{g}$ and the spring force $\vec{T}$	0.5
	1.2	The rod is at equilibrium: $m\vec{g} + \vec{T} = \vec{0}$, so $\vec{T} = -m\vec{g}$, then $k\,\Delta L_0 = mg$	1
2	2.1	$\phi = BS\cos(\vec{n}, \vec{B}) = B(d - x)\ell\cos 0 = B\,d\,\ell - B\,\ell\,x$	0.75
	2.2	$e = -\frac{d\varphi}{dt} = B\,\ell\,v$	0.5
	2.3	$i = \frac{dq}{dt} = C\frac{du_C}{dt} = C\frac{de}{dt} = C\,B\,\ell\,\frac{dv}{dt}$	0.75
3	3.1	$m\vec{g} + \vec{T} + \vec{F} = mx''\vec{i}$; then : $m\,g - k(\Delta L_0 + x) - B^2\ell^2 C\frac{dv}{dt} = mx''$, $k\,\Delta L_0 = mg$; Then : $x'' + \frac{k}{m + B^2\ell^2 C}x = 0$	1.25
	3.2	The differential equation is of the form: $x'' + \omega_0^2\,x = 0$ with ω_0 being a positive constant, then it is a simple harmonic motion.	0.5
	3.3	$\omega_0^2 = \frac{k}{m + B^2\ell^2 C}$; The proper period $T_0 = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{m + B^2\ell^2 C}{k}}$	0.75
	3.5	$T_0 = \frac{4.69}{10} = 0.469\,s$; $T_0^2 k = 4\pi^2(m + B^2\ell^2 C)$ $B^2 = \frac{1}{\ell^2 C}\left[\frac{T_0^2 k}{4\pi^2} - m\right]$ substituting the data in this expression gives B = 0.7 T B = 0.699 T (if $\pi = 3{,}14$) B = 0.6 T (if we substitute the precise value of π)	1

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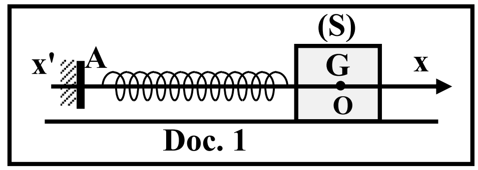
دائرة الامتحانات الرسميّة

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

<u>This exam is formed of four obligatory exercises in four pages.</u>
<u>The use of non-programmable calculators is recommended.</u>

Exercise 1 (8 points) Free damped mechanical oscillations

Consider a mechanical oscillator formed by a rigid object (S) of mass m and a horizontal spring of spring constant k and of negligible mass. (S) is attached to one end of the spring, and the other end is fixed to a support A. (S) may move on a horizontal surface with its center of mass G being on a horizontal x-axis (Doc. 1)



Doc. 1

At equilibrium, G coincides with the origin O of the x-axis. (S) is shifted horizontally in the positive direction from its equilibrium position. At the instant $t_0 = 0$, the abscissa of G is X_m and (S) is released without initial velocity.

At an instant t, the abscissa of G is $x = \overline{OG}$ and the algebraic value of its velocity $v = x' = \frac{dx}{dt}$.

During its motion, (S) is subjected to several forces including the tension force $\vec{F} = -k\,x\,\vec{i}$ of the spring and the friction force $\vec{f} = -h\,\vec{v}$, where h is a positive constant called the damping coefficient.

Take the horizontal plane containing G as a reference level for gravitational potential energy.

The aim of this exercise is to study the effect of friction on the oscillations and to determine the value of h.

1) Theoretical study

1-1) Show that: $m\frac{dv}{dt} + k\,x = -hv$ by applying Newton's second law $\sum \vec{F}_{ext} = m\frac{d\vec{v}}{dt}$.

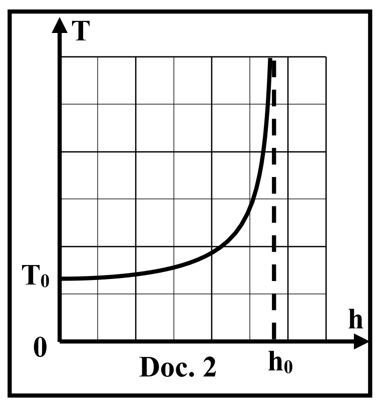
1-2) Write the expression of the mechanical energy ME of the system (Oscillator - Earth) at an instant t in terms of m, k, x and v.

1-3) Deduce that $\frac{dME}{dt} = -hv^2$.

1-4) Establish the second order differential equation that governs the variation of x.

1-5) The center of mass G oscillates with an angular frequency

$$\omega = \sqrt{\frac{k}{m} - \left(\frac{h}{2m}\right)^2}$$. Deduce the expression of the pseudo-period T.



Doc. 2

1-6) For different values of h, we obtain the curve of document 2 which represents T as a function of h, for $0 \leq h < h_0$.

1-6-1) How does T vary for $0 \leq h < h_0$?

1-6-2) T_0 represents the proper period of oscillation of G. Justify by referring to document 2.

1-7) Deduce the expression of T_0 in terms of m and k.

2) Experimental study

In the experimental study, we take m = 0.5 kg and k = 100 N/m.

2-1) Calculate the value of T_0.

2-2) The curve of document 3 represents x as a function of time t. Use document 3 to:

2-2-1) determine the pseudo-period T;

2-2-2) give two indicators showing that (S) is submitted to a friction force.

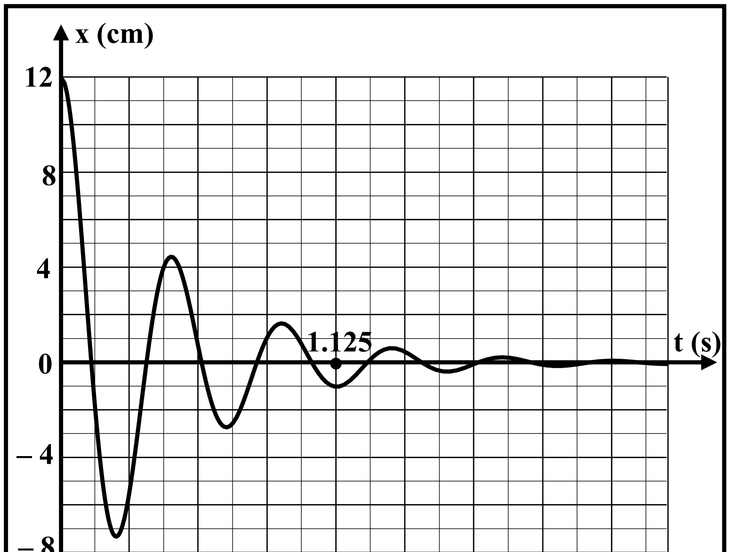
2-3) Calculate h.

2-4) In order to determine again the value of h, an appropriate device is used to trace the curves of ME and the kinetic energy KE of (S) as functions of time, and also the tangent to the curve of ME at t = 0.27 s (Doc. 4).

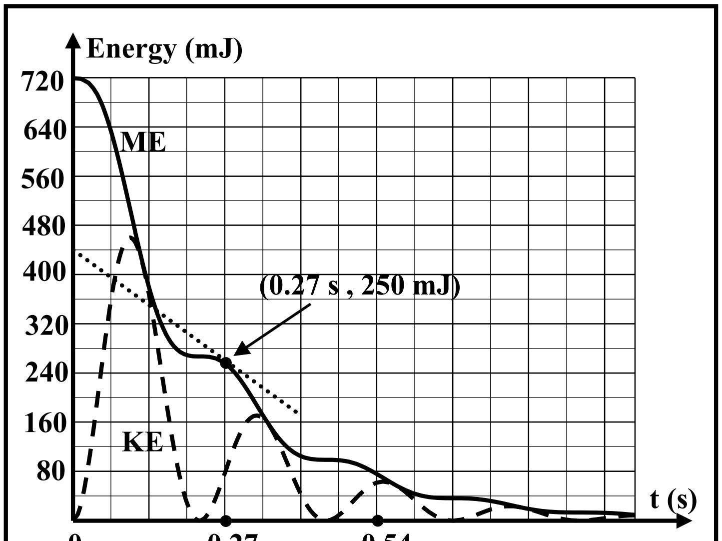
2-4-1) Determine the speed of G at t = 0.27 s by using the curve of KE.

2-4-2) Determine $\frac{dME}{dt}$ at t = 0.27 s.

2-4-3) Deduce again the value of h.



Doc. 3

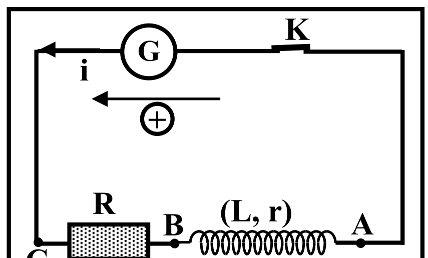


Doc. 4

Exercise 2 (8 points) **Characteristics of a coil**

The aim of this exercise is to determine the characteristics of a coil by two methods. We connect in series a generator (G), a switch K, a resistor of resistance R = 90 Ω and a coil of inductance L and resistance r (Doc. 5). We close the switch K at the instant $t_0 = 0$.

At an instant t, the circuit carries a current i.



Doc. 5

1) First method

(G) is a generator providing a constant voltage $u_{CA} = E$.

An appropriate device traces the curves of $u_{CB} = u_R$ and $u_{BA} = u_{coil}$ as functions of time (Doc. 6).

1-1) Using the curves of document 6:

1-1-1) determine the value of E;

1-1-2) determine the value of the current I_0 at the steady state;

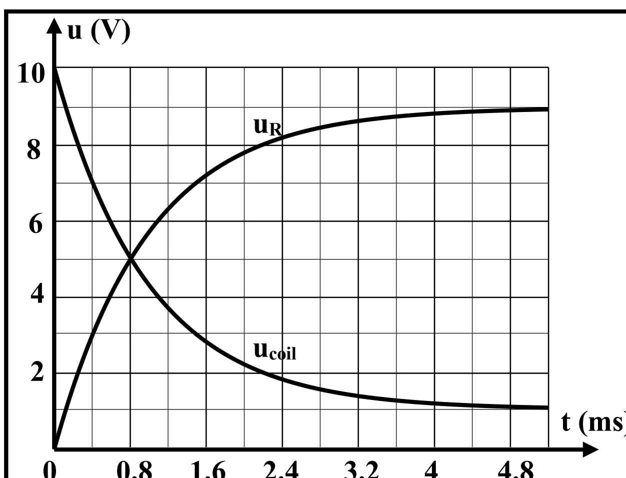
1-1-3) show that r = 10 Ω.

1-2) Establish the first order differential equation in i by applying the law of addition of voltages.

1-3) The solution of this differential equation is $i = I_0\left(1 - e^{\frac{-(R+r)}{L}t}\right)$. Deduce the expressions of u_R and u_{coil} in terms of R, r, L, I_0 and t.

1-4) $u_{coil} = u_R$ at an instant t_1.

Show that $t_1 = -\frac{L}{R+r}\ln\left(\frac{R-r}{2R}\right)$.



Doc. 6

1-5) Deduce the value of L using document 6.

2) Second method

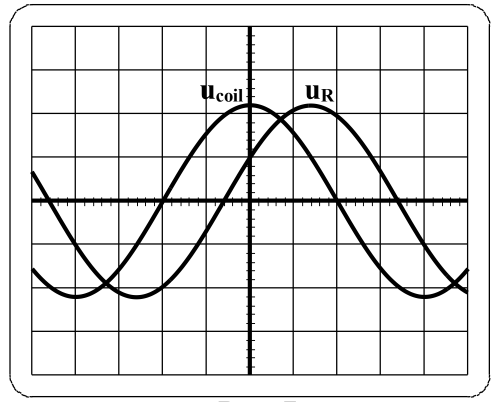
The generator (G) provides now an alternating sinusoidal voltage of angular frequency ω.

An oscilloscope is connected conveniently in the circuit in order to display $u_{CB} = u_R$ on channel 1 and $u_{BA} = u_{coil}$ on channel 2 (Doc. 7).

The adjustments of the oscilloscope:

Horizontal sensitivity: $S_h = 4$ ms/div

Vertical sensitivity: For Ch_1: $S_{V1} = 4$ V/div; For Ch_2: $S_{V2} = 1$ V/div



Doc. 7

2-1) The circuit carries an alternating sinusoidal current $i = I_m \sin(\omega t)$, (SI). Determine the expression of u_{coil} in terms of L, ω, I_m , r and t.

2-2) The expression of the voltage across the coil is of the form: $u_{coil} = A \sin(\omega t) + B \cos(\omega t)$ where A and B are constants. Determine A and B in terms of r, L, I_m and ω.

2-3) Use document 7 to calculate:

2-3-1) the values of I_m and ω;

2-3-2) the maximum voltage U_m across the coil;

2-3-3) the phase difference φ between u_{coil} and u_R.

2-4) Determine again the values of L and r knowing that $\tan \varphi = \dfrac{L\omega}{r}$ and $U_m^2 = A^2 + B^2$.

Exercise 3 (7 points) **Decay of radon-219**

The aim of this exercise is to determine the values of the power and the energy of the electromagnetic radiation γ emitted in the disintegration of radon-219.

The radionuclide radon ${}^{219}_{86}Rn$ decays into polonium ${}^{A}_{Z}Po$ with the emission of an α particle and γ radiation of energy E_γ according to the following equation: ${}^{219}_{86}Rn \rightarrow {}^{A}_{Z}Po + \alpha + \gamma$

Given: $m({}^{219}_{86}Rn) = 204007.3316$ MeV/c^2 ; $m({}^{A}_{Z}Po) = 200271.9597$ MeV/c^2 ; $m(\alpha) = 3728.4219$ MeV/c^2

1 MeV = 1.602×10^{-13} J ; Molar mass of ${}^{219}_{86}Rn$ is 219 g/mol ; $N_A = 6.022\times10^{23}$ mol^{-1}

1) Calculate A and Z, indicating the used laws.
2) Calculate the energy (in MeV) liberated by the decay of one nucleus of radon-219.
3) Deduce that the energy of the emitted γ radiation is $E_\gamma = 0.195$ MeV knowing that the radon nucleus is at rest, the kinetic energy of the emitted α particle is 6.755 MeV and the kinetic energy of the polonium nucleus is negligible.
4) The initial mass of a radon sample is $m_0 = 8$ g at $t_0 = 0$. Show that the initial number N_0 of radon nuclei present in the sample at $t_0 = 0$ is $N_0 = 21.998\times10^{21}$ nuclei.
5) Calculate the number of the α particles emitted between $t_0 = 0$ and $t_1 = 10$ s, knowing that the remaining number of radon nuclei at $t_1 = 10$ s is $N = 3.998\times10^{21}$ nuclei.
6) Calculate the values of the decay constant λ and the half-life T of radon-219.
7) Calculate, in becquerel, the activity A_1 of the radon sample at the instant $t_1 = 10$ s.
8) The energy of the emitted γ radiation between the instant $t_0 = 0$ and an instant t is $E = N_d E_\gamma$ where N_d is the number of the decayed nuclei of radon-219 between these two instants.

   8-1) Show that $E = N_0 E_\gamma (1 - e^{-\lambda t})$.

   8-2) Deduce the value of E during the time interval $[0, \infty[$.

9) The power p of the emitted γ radiation at an instant t is given by: $p = \frac{dE}{dt}$.

- **9-1)** Show that $p = \lambda N_0 E_\gamma e^{-\lambda t}$.
- **9-2)** Deduce the maximum power P_{max} of the γ radiation.
- **9-3)** Deduce the power of the γ radiation as $t \to \infty$.

Exercise 4 (7 points) Interference of light

The aim of this exercise is to study the phenomenon of interference of light using Young's double-slit set-up.

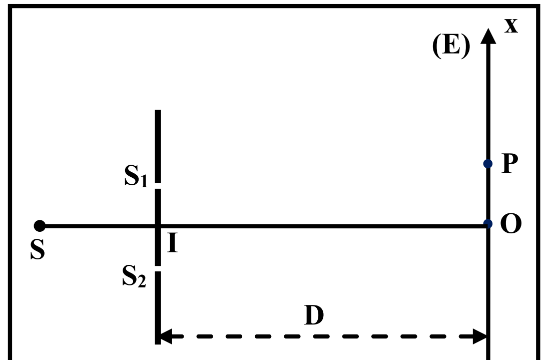
Document 8 shows Young's double-slit set-up, which is constituted of two thin parallel and horizontal slits S_1 and S_2 separated by a distance a = 0.5 mm, and a screen (E) placed parallel to the plane of the two slits at a distance D = 2 m.

A point source S, equidistant from S_1 and S_2, illuminates the two slits by monochromatic radiation of wavelength λ = 600 nm in air.

(OI) is the perpendicular bisector of the segment $[S_1S_2]$.

The expression of the optical path difference at point P on the vertical x-axis in the interference pattern is:

$$\delta = (SS_2 + S_2P) - (SS_1 + S_1P) = \frac{a\,x}{D} \text{ where } x = \overline{OP}.$$



Doc. 8

1) Describe the interference pattern on the screen (E).

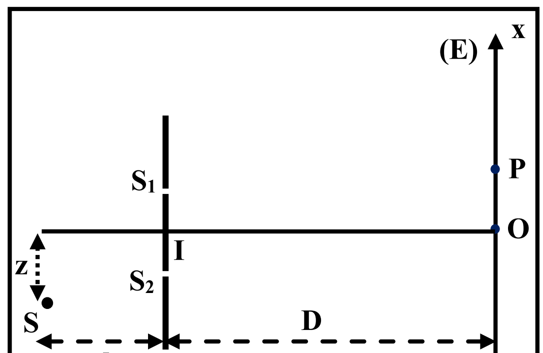
2) Show that O is the center of the central bright fringe.

3) Suppose that P is the center of a dark fringe of order k ($k \in \mathbb{Z}$).

- **3-1)** Give the expression of the optical path difference δ at point P in terms of k and λ.
- **3-2)** Deduce the expression of the abscissa x_k of P in terms of k, λ, D and a.
- **3-3)** Determine the order of the dark fringe at P knowing that x_k = 6 mm.

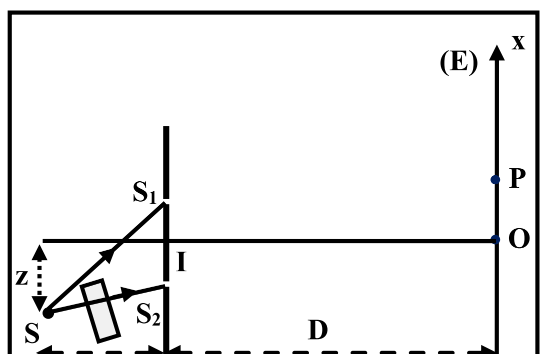
4) The point source S which is placed at a distance d from the plane of the slits, is moved by a displacement z, in the negative direction, to the side of S_2 parallel to the x-axis (Doc. 9).

The optical path difference at point P becomes: $\delta = \frac{a\,z}{d} + \frac{a\,x}{D}$.



Doc. 9

- **4-1)** Determine the position of the center O' of the central bright fringe in terms of D, z and d.
- **4-2)** Specify whether the central bright fringe is displaced to the side of S_1 or to the side S_2.
- **4-3)** A thin transparent plate of parallel faces, of thickness e = 0.02 mm and of refractive index n = 1.5, is placed in front of S_2 (Doc.10).



Doc. 10

The optical path difference at point P becomes:

$$\delta = \frac{a\,z}{d} + \frac{a\,x}{D} + e\,(n - 1).$$

We adjust the distance d in order that the center of the central bright fringe returns back to the point O. Determine the value of d knowing that $|z|$ = 0.4 cm.

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Exercise 1 (8 points) **Free damped mechanical oscillations**

Part			Answer	Mark
1	1-1		$m\vec{g} + \vec{N} + \vec{f} + \vec{T} = m\dfrac{d\vec{v}}{dt}$; projecting the vectors along the x-axis $0 + 0 + - hv - k\,x = m\frac{dv}{dt}$, thus $m\frac{dv}{dt} + k\,x = - hv$	0.75
	1-2		$ME = ½\, m\, v^2 + ½\, k\, x^2$	0.25
	1-3		$\frac{dME}{dt} = m\,v\frac{dv}{dt} + k\,x\frac{dx}{dt} = v\,(m\frac{dv}{dt} + k\,x)$; substituting $m\frac{dv}{dt} + k\,x = - hv$ gives $\frac{dME}{dt} = v\,(- hv)$, thus $\frac{dEM}{dt} = - h\,v^2$	0.5
	1-4		$\frac{dME}{dt} = v\,(m\frac{dv}{dt} + k\,x) = - h\,v^2$, then $m\,x'' + h\,x' + k\,x = 0$	0.5
	1-5		$T = \frac{2\,\pi}{\omega} = \frac{2\,\pi}{\sqrt{\frac{k}{m} - \left(\frac{h}{2m}\right)^2}}$	0.25
	1-6	1	As h increases T increases	0.25
		2	Graphically h = 0 , for $T = T_0$ therefore T_0 is the proper period	0.25
	1-7		For h = 0 , $T = T_o = \frac{2\,\pi}{\sqrt{\frac{k}{m} - 0}}$ so $T_o = 2\,\pi\sqrt{\frac{m}{k}}$	0.5
2	2-1		$T_o = 2\,\pi\sqrt{\frac{m}{k}} = 2 \times 3.14\sqrt{\frac{0.5}{100}} = 0.444$ s	0.5
	2-2	1	2.5 T = 1.125 s , thus T = 0.45 s.	0.5
		2	X_m decreases with time and T is greater than $T_o (T > T_o)$	0.5
	2-3		$T = \frac{2\pi}{\sqrt{\frac{k}{m} - \left(\frac{h}{2m}\right)^2}}$, so $\frac{k}{m} - \frac{h^2}{4m^2} = \frac{4\,\pi^2}{T^2}$, then $h^2 = 4mk - \frac{16\,m^2\pi^2}{T^2}$ so $h = \sqrt{4mk - \frac{16\,m^2\pi^2}{T^2}}$ $= \sqrt{4(0.5)(100) - \frac{16(0.5^2)(\pi^2)}{0.45^2}} = 2.24$ kg/s	1
	2-4	1	For t = 0.27 s, KE = 80 mJ ,alors $½\, m\, V^2 = 0.08$ et $V = \sqrt{\frac{2 \times 0.08}{0.5}} = 0.566$ m/s.	0.75
		2	$\frac{dEM}{dt} = \frac{\Delta EM}{\Delta t}$ = slope $= \frac{0.25 - 0.440}{0.27 - 0} = - 0.704$ J/s	0.75
		3	$\frac{dEM}{dt} = -0.704 = -h\,V^2$, thus $h = \frac{0.704}{0.566^2} = 2.2$ kg/s	0.75

Exercise 2 (8 points) **Characteristics of a coil**

Part			Answer	Mark
1	1-1	1	Law of addition of voltages: $u_{CA} = u_{CB} + u_{BA}$ At steady state $u_{CB} = u_R = 9V$ and $u_{BA} = u_{coil} = 1V$; thus $u_{CA} = E = 9+1 = 10$ V **Or** : $E = u_{coil} + u_R$. At t = 0, i = 0 so $u_R = 0$ then $E = u_{coil\ (0)} = 10V$	**0.75**
		2	At steady state $u_{CB} = u_R = 9 = R \times I_0$ thus $9 = 90 \times I_0$; $I_0 = 0.1$ A	**0.5**
		3	$u_{BA} = u_{coil} = ri + L\frac{di}{dt}$; at steady state $u_{BA} = 1V$ and $\frac{di}{dt} = 0$ so $1 = r I_0$; $r = \frac{1}{0.1} = 10\ \Omega$ **Or** : At the steady state $I_0 = E/(R+r)$, then $r = 10\ \Omega$	**0.5**
	1-2		Law of addition of voltages : $u_{CA} = u_{CB} + u_{BA}$; $E = Ri + ri + L\frac{di}{dt} = (R+r)i + L\frac{di}{dt}$	**0.5**
	1-3		$U_{coil} = ri + L\frac{di}{dt} = r I_0(1 - e^{\frac{-(R+r)}{L}t}) + L(R+r)\frac{I_0}{L} e^{\frac{-(R+r)}{L}t} = r I_0 + RI_0 e^{\frac{-(R+r)}{L}t}$ $u_R = Ri = RI_0(1 - e^{\frac{-(R+r)}{L}t})$	**0.5** **0.25**
	1-4		$u_{coil} = u_R$; $r I_0 + RI_0 e^{\frac{-(R+r)}{L}t} = RI_0\left(1 - e^{\frac{-(R+r)}{L}t}\right)$; $(R - r) I_0 = 2 RI_0 e^{\frac{-(R+r)}{L}t}$ then $e^{\frac{-(R+r)}{L}t} = \frac{R-r}{2R}$ so $-\frac{(R+r)t1}{L} = \ln(\frac{R-r}{2R})$ $t_1 = -\frac{L}{R+r} \times \ell n\left(\frac{R-r}{2R}\right)$	**0.75**
	1-5		$L = \frac{-(R+r)\times t1}{\ell n\left(\frac{R-r}{2R}\right)} = \frac{-(90+10)\times 0.0008}{\ell n(\frac{90-10}{180})} = 0.099$ H	**0.75**
2	2-1		$ucoil = ri + L\frac{di}{dt} = rI_m\sin(\omega t) + L\ \omega\ I_m\cos(\omega t)$	**0.5**
	2-2		$U_{coil} = rI_m\sin(\omega t) + L\ \omega\ I_m\cos(\omega t) = A\sin(\omega t) + B\cos(\omega t)$ therefore $A = rI_m$ and $B = L\ \omega\ I_m$	**0.5**
	2-3	1	$U_{Rm} = 4V/div \times 2.2div = 8.8$ V ; $I_m = \frac{URm}{R} = \frac{8,8}{90} = 0.097A$ $\omega = 2\pi f = \frac{2\pi}{T} = \frac{2\pi}{8\times 4\times 10^{-3}} = 62.5\pi\ rad/s = 196.35 rad/s$	**0.5** **0.5**
		2	$Um = 2.2div \times 1V/div = 2.2V$	**0.25**
		3	$\varphi = \frac{2\pi\times 1,4div}{8div} = \frac{7\pi}{20}$ rad =1.099 rad	**0.5**
	2-4		$\tan\varphi = \frac{L\omega}{r}$; $\tan 1.099 = \frac{L\times 62.5\pi}{r}$ donc $\frac{L}{r} = \frac{\tan 1,099}{62.5\pi}$; $L = \frac{\tan 1.099}{62.5\pi} \times r$. ① $U_m^2 = A^2 + B^2$; $9 = (rI_m)^2 + (L\ \omega I_m)^2$ ② By replacing ① in ② : $2.2^2 = r^2 \times I_m^2\ (1 + \omega^2 \times \left(\frac{\tan 1.099}{62.5\pi}\right)^2)$; Therfore r = 9.998 Ω and L = 0.0998 H **or**: $U_m^2 = A^2 + B^2$ then $U_m^2 = (L\omega)^2 I_{max}^2 + r^2 I_{max}^2$ but $\tan\varphi = \frac{L\omega}{r}$; $L\ \omega = r\tan\varphi$; Then $U_m^2 = r^2 I_{max}^2\ (1 + tan^2\varphi)$ we obtain : $r = \frac{U_m}{I_m\sqrt{1+(tan\varphi)^2}} = 10,3\ \Omega$ so L = 0,1 H	**0.75**

Exercise 3 (7 points) **Decay of radon-219**

Part		Answer	Mark
1		Law of conservation of mass number A : 219 = A + 4 + 0 , so A = 215. Law of conservation of charge number Z : 86 = Z + 2 + 0 so Z = 84.	**1**
2		$E_{lib} = \Delta m \times c^2 = [(m\ {}^{219}_{86}Rn) - (m\ {}^{A}_{Z}Po + m\alpha)]c^2$ $E_{lib} == 204007.3316 - (200271.9597 + 3728.4219) = 6.95MeV$	**0.75**
3		$E_{lib} = KE_{(\alpha)} + E_\gamma$, then $E_\gamma = 6.95 - 6.755$, then $E_\gamma = 0.195MeV$	**0.5**
4		$N_o = \frac{m_0}{M} N_A = \frac{8}{219} \times 6.022 \times 10^{23} = 21.998 \times 10^{21}$ noyaux	**0.5**
5		$N_\alpha = N_d = N_o - N = 21.998 \times 10^{21} - 3.998 \times 10^{21} = 18 \times 10^{21}$ nuclei	**0.5**
6		$N = N_o e^{-\lambda t}$, so $\lambda t = -\ln\frac{N}{N_o} = -\ln\left(\frac{3.998 \times 10^{21}}{21.998 \times 10^{21}}\right)$ then $\lambda = \frac{-1}{10} \times \ln\left(\frac{3.998 \times 10^{21}}{21.998 \times 10^{21}}\right) = 0.1705\ s^{-1}$ $T = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} = \frac{0.693}{0.1705} = 4.06\ s$	**1**
7		$A = \lambda N = 0.1705 \times 3.998 \times 10^{21} = 68.1659 \times 10^{19}$ Bq	**0.5**
8	8-1	$E = N_d E\gamma = (N_o - N)E\gamma = (N_o - N_o\ e^{-\lambda t})E\gamma$, so $E = N_o\ E\gamma\,(1 - e^{-\lambda t})$	**0.25**
	8-2	For $t \to \infty$, $E = N_o\ E_\gamma(1 - 0) = 21.998 \times 10^{21} \times 0.195 \times 1.602 \times 10^{-13}$ Then $E = 6.87 \times 10^6$ J	**0.5**
9	9-1	$P = \frac{dE}{dt} = \frac{d(N_o\ E_\gamma\ (1 - e^{-\lambda t}))}{dt} = \lambda\, N_o\, E_\gamma\ e^{-\lambda t}$	**0.5**
	9-2	For $t = 0$; $p = p_{max} = \lambda\, N_o\, E_\gamma\ e^{-\lambda(0)} = \lambda\, N_o\, E_\gamma$ $p = 0.1705 \times 21.998 \times 10^{21} \times 0.195 \times 1.602 \times 10^{-13} = 11.72 \times 10^7$ W	**0.75**
	9-3	For $t \to \infty$, $P_\infty = \lambda\, N_o\, E_\gamma\ e^{-\lambda(\infty)} = 0$	**0.25**

Exercise 4 (7 points) **Interference of light**

Part		Answer	Mark
1		We observe alternate bright and dark fringes which are rectilinear, equidistant and parallel to the slits	1
2		$x_O = 0$ then $\delta_o = \frac{a\,x}{D} = 0$	**0.5**
3	3-1	$\delta = (2K+1)\frac{\lambda}{2}$ with $k \in Z$	**0.5**
	3-2	$(2K+1)\frac{\lambda}{2} = \frac{a\,x}{D}$, then $x_k = (2k+1)\frac{\lambda D}{2a}$ with $k \in Z$	**1**
	3-3	$x_k = (2k+1)\frac{\lambda D}{2a}$ then $6 \times 10^{-3} = (2k+1)\frac{600\times10^{-9}\times2}{2\times0.5\times10^{-3}}$, we obtain $k = 2$	**1**
4	4-1	$\delta_{O'} = \frac{az}{d} + \frac{ax}{D} = 0$, so $x_{O'} = \frac{-zD}{d}$	**1**
	4-2	$Z < 0$ and $D > 0$; $d > 0$ then $x_{O'} > 0$, therefore the central bright fringe is displaced to the side of S_1	**0.75**
	4-3	$\delta_O = 0$ and $x_O = 0$, but $\delta = \frac{az}{d} + \frac{ax}{D} + e\,(n-1)$ $d = \frac{-a\,Z}{e\,(n-1)} = \frac{-(0.5\times10^{-3})(-0.4\times10^{-2})}{(0.02\times10^{-3})(1.5-1)}$, so $d = 0.2$ m	**1.25**

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

<u>This exam is formed of four exercises in 4 pages.</u>
<u>The use of a non-programmable calculator is recommended.</u>

<u>Exercise 1</u> (7.5 points) Compound pendulum of a clock

A clock, having a compound pendulum (S), can be equipped with a dry cell in order to function normally. The pendulum (S) of this clock consists of a rigid rod and a disk fixed from its lower end (Doc.1).

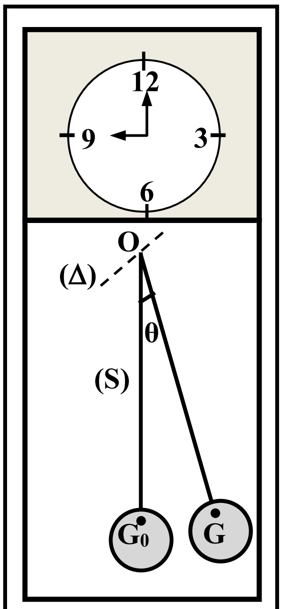
The pendulum can oscillate in the vertical plane about a horizontal axis (Δ) passing through the upper end O of the rod. The distance between O and the center of mass G of the pendulum is OG = a = 20 cm.

Let G_0 be the position of G when the pendulum is in its stable equilibrium position. The mass of (S) is m = 40 g and its moment of inertia about (Δ) is $I = 0.002\ kg.m^2$.

The pendulum is shifted from its equilibrium position by a small angle $\theta_m = 10^o = 0.1745$ rad, and then it is released from rest at $t_0 = 0$.

(S) then oscillates about (Δ).

At an instant t, the position of the pendulum is denoted by its angular abscissa $\theta = (\overrightarrow{OG_0}, \overrightarrow{OG})$ and its angular velocity is $\theta' = \frac{d\theta}{dt}$.



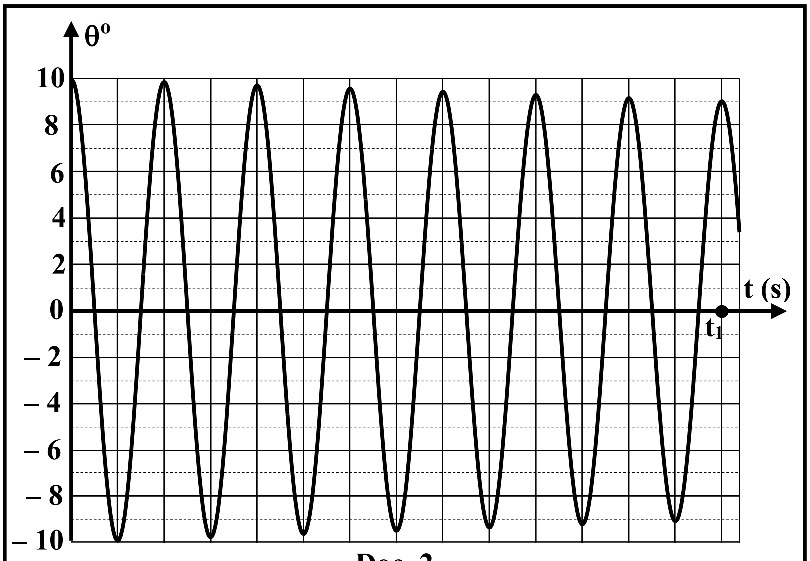
Doc .1

Take:

- the horizontal plane containing G_0 as a reference level for gravitational potential energy;
- $g = 9.8\ m/s^2$; $\cos\theta \cong 1 - \frac{\theta^2}{2}$ and $\sin\theta \cong \theta$ (in rad), for $\theta \le 10^o$.

1) Oscillations of (S) without a dry cell

The clock is not equipped with a dry cell. Document (2) represents θ as a function of time t.



Doc. 2

1-1) Determine, by using document 2, the mechanical energies ME_0 at $t_0 = 0$ and ME_1 at $t = t_1$ of the system [(S), Earth].

1-2) Deduce that the pendulum is submitted to a friction force.

1-3) Determine, between t_0 and t_1, the average loss of the mechanical energy of the system [(S), Earth] during one oscillation.

1-4) Specify the type of oscillation.

1-5) Calculate the approximate value of the pseudo-period of (S) knowing that $t_1 = 7.025$ s.

1-6) The moment of the weight of (S) about (Δ) is $\mathcal{M}_{\overrightarrow{mg}} = -\, mg\, a \sin\theta$. Show by applying the theorem of angular momentum, to (S), that the moment of the friction force is:

$\mathcal{M}_{\overrightarrow{f_r}} = 0.002\,\theta'' + 0.0784\,\theta$ (SI).

1-7) An appropriate system gives some values of: θ, θ' and $\theta'' = \dfrac{d\theta'}{dt}$ at certain instants as shown in the table below. Copy and complete the last three rows of the table.

t (S)	0	0.183	6.603	8.415	12.67
θ(rad)	0.1745	0.0714	– 0.1284	– 0.1306	– 0.0747
θ''(rad/s^2)	– 6.8404	– 2.7689	5.0153	5.1345	2.9042
θ'(rad/s)	0	– 1	0.6	– 0.5	0.8
$\mathcal{M}_{\vec{f_r}}$ (N.m)	0		-3.6×10^{-5}		-4.8×10^{-5}
$\dfrac{\mathcal{M}_{\vec{f_r}}}{\theta'}$ (N.m.s)					

1-8) Deduce the relation between $\mathcal{M}_{\vec{f_r}}$ and θ'.

2) Oscillations of (S) with a dry cell

The clock is now equipped with a dry cell in order to compensate the loss in the mechanical energy of the system [(S), Earth], then the pendulum performs driven oscillations with constant amplitude of $\theta_m = 10^0$ and of period T = 1 s.

At $t_0 = 0$, the dry cell is fully charged and has a maximum energy of $E_0 = 2880$ J. During a time interval $\Delta t = t - t_0$ the dry cell furnishes 10% of E_0 to the system [(S), Earth]. During this time interval, the clock functions normally (with a constant amplitude of θ_m).

2-1) Calculate the energy furnished by the dry cell to the system [(S), Earth] during the normal functioning of the clock.

2-2) Deduce, by using the result of part (1-3), the duration Δt (in days) during which the clock functions normally.

Exercise 2 (8 points) **Electric power consumed in an RLC circuit**

We consider the electric circuit represented in document 3.

This circuit includes a capacitor of capacitance C = 2.5 μF, a coil of inductance L and resistance r, and a resistor of resistance R = 170 Ω, all connected in series across an LFG, of adjustable frequency f. The LFG delivers an alternating sinusoidal voltage $u_G = u_{DM} = U_m \sin(1250\,t)$ (SI).

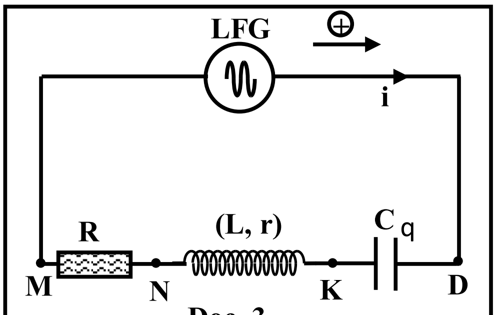
The circuit thus carries an alternating sinusoidal current i.

An oscilloscope, conveniently connected, allows us to display the voltage $u_G = u_{DM}$ across the LFG on channel (Y_1) and the voltage $u_R = u_{NM}$ across the resistor on channel (Y_2).

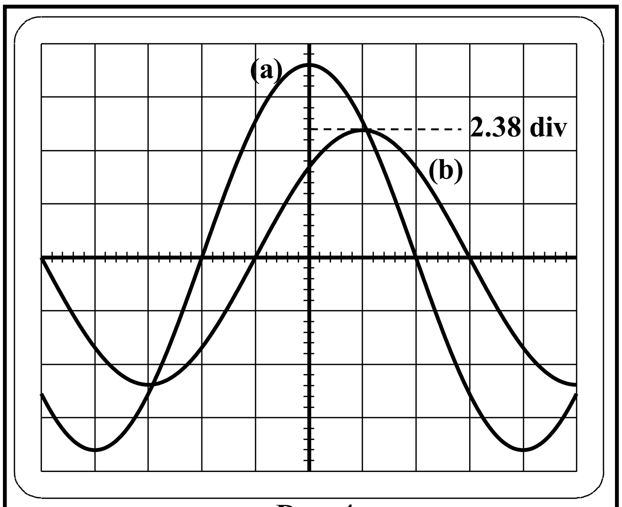
We obtain the waveforms (a) and (b) represented in document 4.

The vertical sensitivity on both channels is $S_V = 5$ V/div.

Take $0.32\,\pi = 1$.



Doc. 3



Doc. 4

1) Redraw the circuit of document 3 and show on it the connections of the oscilloscope.

2) Refer to document 4 to:

2-1) show that waveform (a) represents u_G;

2-2) determine the maximum value I_m of i;

2-3) determine the phase difference φ between u_G and u_R.

3) Write down the expression of i as a function of time.

4) Show that the voltage across the capacitor is:

$$u_{DK} = u_C = -22.4\cos\left(1250\,t - \frac{\pi}{4}\right) \quad \text{(SI)}.$$

5) Determine the expression of the voltage $u_{KN} = u_{coil}$ across the terminals of the coil in terms of L, r and t.

6) Show, by applying the law of addition of voltages and by giving the time t two particular values, that $L = 0.4$ H and $r = 10\ \Omega$.

7) The expression of the average electric power consumed in the circuit is:

$$P_{average} = \frac{(R+r)U_m^2}{2\left[(R+r)^2 + \left(L\omega - \frac{1}{C\omega}\right)^2\right]}, \text{ with } \omega = 2\pi f.$$

The power $P_{average}$ takes its maximum value P_1 for a frequency $f = f_1$.

7-1) Determine the value of f_1.

7-2) Calculate the value of P_1.

7-3) The phenomenon of current resonance takes place for $f = f_1$. Justify.

7-4) Deduce the new expression of i as a function of time for $f = f_1$.

Exercise 3 (7.5 points) Nuclear reactor

The first man-made nuclear reactor, or atomic pile as it was then known, in 1942 was the first step towards future nuclear power plants. The radioactive materials used in this reactor, such as uranium and plutonium, can be broken into several fragments under the impact of thermal neutrons. During this operation, other neutrons are emitted provoking in turn the splitting of new nuclei and releasing new neutrons and so on.

Doc. 5

1) Pick up from the text of document 5 the statement that refers to:

1-1) nuclear fission;

1-2) chain reaction.

2) One of the nuclear reactions that takes place inside a nuclear reactor is:

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{94}_{38}Sr + {}^{140}_{Z}Xe + x\,{}^{1}_{0}n$$

Given: $1u = 931.5$ MeV/c^2; Mass of neutron: $m({}^{1}_{0}n) = 1.00866$ u.

Masses of nuclei: $m({}^{235}_{92}U) = 234.99358$ u ; $m({}^{94}_{38}Sr) = 93.90384$ u ; $m({}^{140}_{Z}Xe) = 139.90546$ u.

2-1) The fission reaction of uranium-235 is provoked. Why?

2-2) Calculate Z and x, indicating the used laws.

2-3) Determine, in MeV, the energy liberated by this reaction.

2-4) The kinetic energy of the emitted neutrons represents 2.6 % of the energy liberated by this reaction. Assume that all the emitted neutrons have equal kinetic energies. Calculate the kinetic energy of each emitted neutron.

3) Studies show that most of the emitted neutrons have high kinetic energy (few MeV). In order to provoke a new nuclear fission of a uranium nucleus-235, the neutron emitted by the fission reaction must have a low kinetic energy around $E_{th} = 0.025$ eV (thermal neutron). In order to reduce the kinetic energy E_0 of an emitted neutron to E_{th}, this neutron of mass m and speed V_0, must undergo successive collisions with heavier nuclei at rest of mass $M = K\,m$ (K is a positive constant). We suppose that these collisions are elastic and all the velocities just before and after each collision are collinear.

3-1) Let V_1 be the speed of the neutron just after its first collision with a heavy nucleus.

Show, using the laws of conservation of linear momentum and kinetic energy, that $V_1 = \frac{(1-K)}{(1+K)}V_0$.

3-2) Deduce that the expression of the kinetic energy E_n of this neutron just after the n^{th} collision is:

$$E_n = \left[\frac{(1-K)^2}{(1+K)^2}\right]^n E_0.$$

3-3) If the initial kinetic energy of an emitted neutron is $E_0 = 2.1$ MeV. Calculate the approximate number « n » of collisions needed for the final kinetic energy of this neutron to become $E_n = 0.025$ eV, if it collides with:

3-3-1) deuterium nuclei (K = 2);

3-3-2) carbon nuclei (K = 12).

3-4) The deuterium nuclei are more convenient than the carbon nuclei to slow down the neutron. Justify.

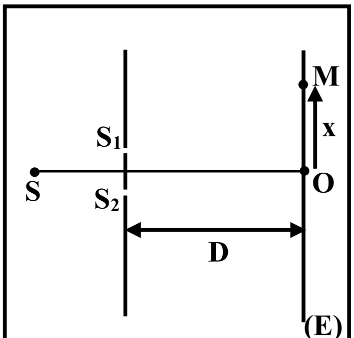
Exercise 4 **(7 points)** **Planck's constant**

The aim of this exercise is to determine Planck's constant h.
Given: 1 eV = 1.6×10^{-19} J; speed of light in air: $c = 3\times10^{8}$ m/s.

1) Interference

A source (S) emits a beam of monochromatic radiation of wavelength λ in air. The beam is incident normally in air on the two slits S_1 and S_2, of Young's double slit experiment, which are at a distance of $S_1S_2 = a = 0.5$ mm. The source (S) is placed on the perpendicular bisector of $[S_1S_2]$. A screen (E) is placed at distance D = 2 m from the plane of the two slits. The perpendicular bisector of $[S_1S_2]$ intersects (E) at point O. A sensor of electromagnetic waves is used to detect the interference fringes on (E).

The optical path difference at point M in the interference zone on the screen is $\delta = \frac{a\,x}{D}$, where $x = \overline{OM}$ (Doc. 6).



Doc. 6

1-1) Determine the expression of the abscissa of the center of a fringe of maximum intensity and that of the center of a fringe of zero intensity in terms of λ, D, a and k (k is a whole number).

1-2) (S) emits a monochromatic radiation (1) of wavelength $\lambda = \lambda_1$. The abscissa of the center of the fifth fringe of maximum intensity is x = 30 mm. Determine λ_1 and deduce that the frequency of radiation (1) is $\nu_1 = 2\times10^{14}$ Hz.

1-3) (S) emits now a monochromatic radiation (2) of wavelength $\lambda = \lambda_2$. The abscissa of the center of the second fringe of zero intensity is x = 6 mm.
Determine λ_2 and deduce that the frequency of radiation (2) is $\nu_2 = 3\times10^{14}$ Hz.

2) Excitation and ionization of the hydrogen atom

The energy levels of the hydrogen atom are given by:

$E_n = -\frac{13.6}{n^2}$ eV; where n is a non-zero positive integer.

2-1) A hydrogen atom, initially in the energy level of n = 3, absorbs one of the photons of radiation (2) of frequency ν_2. The hydrogen atom passes to the energy level of n = 7.
Show that the energy of this photon is $E_2 = 1.23$ eV.

2-2) A hydrogen atom, initially in the energy level of n = 7, absorbs one of the photons of radiation (1) of frequency ν_1. The atom is ionized and the liberated electron has a kinetic energy of 0.551 eV.
Show that the energy of this photon is $E_1 = 0.82$ eV.

3) Photoelectric effect

A metal of work function $W_0 = 1.625$ eV is illuminated by radiation (3) of frequency $\nu_3 = 5\times10^{14}$ Hz.
The maximum kinetic energy of an electron extracted from the surface of the metal is 0.445 eV.
Determine the energy E_3 of a photon of this radiation.

4) Planck's constant

4-1) Using the previous results, show that: $\frac{E_1}{\nu_1} \cong \frac{E_2}{\nu_2} \cong \frac{E_3}{\nu_3}$.

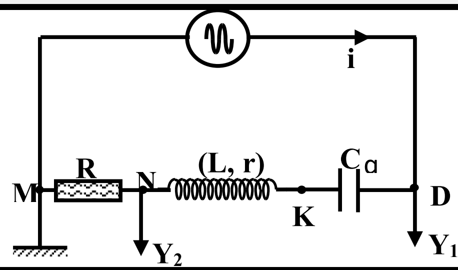
4-2) Deduce, in SI, the value h of Planck's constant.

Exercise 1 (7 points)

Compound pendulum of a clock

<table>
<tr><th colspan="3">Part</th><th>Answer</th><th>Marks</th></tr>
<tr><td rowspan="8">1</td><td>1</td><td>1</td><td>$ME_0 = \frac{1}{2}I\theta'^2 + mga(1-\cos\theta) = 0 + mga\frac{\theta_0{}^2}{2} = 0.04 \times 9.8 \times 0.2 \times \frac{(0.1745)^2}{2}$
Then , $ME_0 = 1.2\times 10^{-3}$ J
Or :
$ME_0 = \frac{1}{2}I\theta'^2 + mga(1-\cos\theta) = 0 + 0.04 \times 9.8 \times 0.2 \times (1-\cos 10^o)$
Then , $ME_0 = 1.19\times 10^{-3}$ J
$ME_1 = 0 + mga\frac{\theta_1{}^2}{2} = 0.04 \times 9.8 \times 0.2 \times \frac{(0.157)^2}{2} = 0.966\times 10^{-3}$ J
$ME_0 = \frac{1}{2}I\theta'^2 + mga(1-\cos\theta) = 0 + 0.04 \times 9.8 \times 0.2 \times (1-\cos 9^o)$
Then , $ME_1 = 0.965\times 10^{-3}$ J</td><td>1.5</td></tr>
<tr><td colspan="2">2</td><td>$ME_7 < ME_0$, thus the pendulum (S) is submitted to a friction force</td><td>0.5</td></tr>
<tr><td colspan="2">3</td><td>$ME_{lost} = \frac{ME_0 - Em_7}{7} = \frac{(1.2\times10^{-3}) - (0.966\times10^{-3})}{7} = 3.34 \times 10^{-5}$ J
Or :
$ME_{lost} = \frac{Em_0 - Em_7}{7} = \frac{(1.19\times10^{-3}) - (0.965\times10^{-3})}{7} = 3.322 \times 10^{-5}$ J</td><td>1</td></tr>
<tr><td colspan="2">4</td><td>The type is free damped oscillations, since the mechanical energy decreases.</td><td>0.25</td></tr>
<tr><td colspan="2">5</td><td>$T = \frac{t_1}{n} = \frac{7{,}025}{7} = 1.0035\ s \cong 1$ s</td><td>0.5</td></tr>
<tr><td colspan="2">6</td><td>The forces acting on (S): the weight ($m\vec{g}$) ; the support reaction at O ($\vec{R}$) ; the friction force ($\vec{fr}$)
$\sum \mathcal{M}_{ext} = \frac{d\sigma}{dt} = I\theta''$, so $\mathcal{M}_{m\vec{g}} + \mathcal{M}_{\vec{R}} + \mathcal{M}_{\vec{fr}} = I\,\theta''$, then $-$ mg a $\sin\theta$ + 0 + $\mathcal{M}_{\vec{fr}} = I\,\theta''$
$\mathcal{M}_{\vec{fr}} = 0.002\theta'' + (0.04 \times 9.8 \times 0.2 \times \theta)$; therefore, $M_{\vec{fr}} = 0.002\,\theta'' + 0.0784\,\theta$</td><td>1</td></tr>
<tr><td colspan="2">7
7</td><td>
<table>
<tr><td>θ'(rad/s)</td><td>0</td><td>- 1</td><td>0.6</td><td>- 0.5</td><td>0.8</td></tr>
<tr><td>$M_{\vec{fr}}$ (N.m)</td><td>0</td><td>6×10⁻⁵</td><td>3.6×10⁻⁵</td><td>3×10⁻⁵</td><td>-4.8×10⁻⁵</td></tr>
<tr><td>$\frac{M_{\vec{fr}}\ (N.m)}{\theta'}$ S.I</td><td></td><td>-6×10⁻⁵</td><td>-6×10⁻⁵</td><td>-6×10⁻⁵</td><td>-6×10⁻⁵</td></tr>
</table>
</td><td>1</td></tr>
<tr><td colspan="2">8</td><td>$\mathcal{M}_{\vec{fr}} = C\,\theta'$, so C = $-6\times10^{-5}\ S.I$
Therefore, $\mathcal{M}_{\vec{fr}} = -6\times10^{-5}\,\theta'$</td><td>0.5</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">1</td><td>The furnished energy is : $E_{furnished} = 0.1E_0 = 0.1 \times 2880 = 288$ J</td><td>0.5</td></tr>
<tr><td colspan="2">2</td><td>$\left\{ \begin{array}{l} 1s \xrightarrow{loss} 3.34\times10^{-5}\ J \\ \Delta t \xrightarrow{loss} 288\ J \end{array} \right\}$, then $\Delta t = \frac{1\times288}{3.34\times10^{-5}} = 8.62\times10^6$ s = 99.76 days
Or :
$1s \xrightarrow{loss} 3.322\times10^{-5}$ J
$\Delta t \xrightarrow{loss} 288$ J , then $\Delta t = \frac{1\times288}{3.322\times10^{-5}} = 8.669\times10^6$ s = 100.34 days</td><td>0.75</td></tr>
</table>

Exercice 2 (8 points) **Electric power in an RLC circuit**

Part		Answer	Marks
1			0.25
2	1	The vertical sensitivity is the same for both channels, and ; $U_{max(a)} > U_{max(b)}$. Therefore, waveform (a) represents u_G	0.5
	2	$I_m = \frac{U_{Rmax}}{R} = \frac{2.38div \times 5V/div}{170} = 0.07A$	0.5
	3	$\varphi = \frac{2\pi \times 1div}{8\ div} = \frac{\pi}{4} rad$	0.5
3		$i = I_m \sin(2\pi ft - \frac{\pi}{4}) = 0.07 \sin(1250t - \frac{\pi}{4})$ (i in A and t in s)	0.5
4		$u_{DK} = u_c = \frac{1}{C}\int i dt = \frac{1}{C}\int 0.07 \times \sin\left(1250t - \frac{\pi}{4}\right) dt = \frac{-0.07}{2.5\times10^{-6}\times1250}\cos\left(1250t - \frac{\pi}{4}\right)$ $u_{DK} = u_c = -22.4\cos\left(1250 - \frac{\pi}{4}\right)$	1
5		$U_{KN} = u_{coil} = ri + L\frac{di}{dt} = 0.07r \sin(1250 - \frac{\pi}{4}) + 0.07\ L\times1250 \times \cos(1250t - \frac{\pi}{4})$ $U_{KN} = u_{coil} = 0.07r \sin(1250t - \frac{\pi}{4}) + 87.5\ L \cos(1250t - \frac{\pi}{4})$	1

6		$u_{DM} = u_{DK} + u_{KN} + u_{NM}$
		$18 \sin(1250t) = -22.4\cos\left(1250t - \frac{\pi}{4}\right) + 0.07r \sin(1250t - \frac{\pi}{4})$
		$+ 87.5\ L \cos(1250t - \frac{\pi}{4}) + 0.07\times170 \sin(1250t - \frac{\pi}{4})$
		For ($1250t = \frac{\pi}{4}$ rad) : $18\frac{\sqrt{2}}{2} = -22.4 + 87.5L$; therefore, $L = 0.4H$
		For ($1250t = 0$) : $0 = -22.4\frac{\sqrt{2}}{2} - 0.07r\frac{\sqrt{2}}{2} + 87.5\times0.4\times\frac{\sqrt{2}}{2} - 11.9\frac{\sqrt{2}}{2}$
		$0 = -22.4 - 0.07r + (87.5\times0.4) - 11.9$
		Therefore, $r = 10\ \Omega$
			1.5

7	1	P takes its maximum value for: $(L\omega - \frac{1}{C\omega}) = 0$, so , then $L\omega = \frac{1}{C\omega}$, so $\omega^2 = \frac{1}{LC} = \omega_0^2$ Then, $f_2 = \frac{1}{2\pi\sqrt{LC}} = \frac{0.32}{2\sqrt{0.4\times2.5\times10^{-6}}} = 160Hz$	0.75
	2	$P_1 = \frac{U_m^2}{2(R+r)} = \frac{18^2}{2(170+10)} = 0.9W$	0.5
	3	Since $L\omega = 1/C\omega$ so $LC\omega^2 = 1$	0.25
	4	$I_m = \frac{U_m}{R+r} = \frac{18}{170+10} = 0.1A$, then $i = 0.1 \sin(1000\ t)$	0.75

Exercice 3 **(7,5 points)** **Nuclear reactor**

Part			Answer	Marks
1	1		Nuclear fission : . The radioactive materials used in this reactor, such as uranium and plutonium, can be broken into several fragments under the impact of thermal neutrons	0,25
	2		Chain reaction : other neutrons are emitted provoking in turn the splitting of new nuclei and releasing new neutrons and so on.	0,25
2	1		The reaction is provoked since the uranium nucleus is divided into two nuclei under the impact of a neutron. **Or**: The reaction takes place by an external intervention	0,25
	2		Low of conservation of mass number : 235 + 1 = 94 + 140 + x , then x = 236 – 234 = 2 Low of conservation of charge number : 92 = 38 + Z , then Z = 54	1
	3		$\Delta m = m_{before} - m_{after} = (m_U + m_n) - (m_{Sr} + m_{Xe} + 2m_n)$ $\Delta m = (234.99358 + 1.00866) - (93.90384 + 139.90546 + 3\,(1.00866)) = 0.17562$ u $E_{lib} = \Delta m\, c^2 = 0.17562 \times 931.5 \frac{MeV}{c^2} \times c^2$, then $E_{lib} = 163.59$ MeV	1
	4		$2KE = \frac{2.6}{100} \times 163.59 = 4.25334\ MeV$, then kinetic energy of each neutron is KE = 2,127 Mev	0,75
3	1		Conservation of linear momentum : $m\vec{v}_0 = m\vec{v}_1 + K\,m\vec{v}$ $\vec{v}_0 = \vec{v}_1 + K\vec{v}$, then $v_0 - v_1 = kv$ (Equation 1) The collision is elastic, then : $\frac{1}{2}mv_0^2 = \frac{1}{2}mv_1^2 + \frac{1}{2}Kmv^2$ $v_0^2 = v_1^2 + K\,v_1^2$, so $(v_0 - v_1)(v_0 + v_1) = Kv^2$ (Equation 2) Dividing eq (2)by eq (1) gives: $(v_0 + v_1) = v$, so $v_0 = v_1 + kv = v_1 + k(v_0 + v_1)$ Therefore, $v_1 = \frac{1-k}{1+k} v_0$	1,5
	2		Right after the first collision : $E_1 = ½\, mv_1^2 = ½\, m\,(\frac{1-k}{1+k})^2 v_0^2 = \frac{(1-k)^2}{(1+k)^2} E_0$ Right after the n^{th} collision : $E_n = \left(\frac{(1-k)^2}{(1+k)^2}\right)^n E$	1
	3	1	n = 8 or 9 collisions	0,5
		2	n = 54 or 55 collisions	0,5
	4		The number of collisions needed to slow down a neutron is smaller if it collides with deuterium nuclei.	0,5

Exercice 4 (7 points) **Plancks constant**

Part		Answer	Marks
1	1	Center of a fringe of maximum intensity : $\delta = \frac{ax}{D} = k\lambda_1$, then $x = \frac{k\lambda_1 D}{a}$ Center of a fringe of zero intensity : $\delta = \frac{ax}{D} = (2k+1)\frac{\lambda_1}{2}$, then $x = \frac{(2k+1)\lambda_1 D}{2a}$	0,5 0,5
	2	The order of the fifth fringe of maximum intensity is $k = 5$ $x = \frac{5\lambda_1 D}{a}$, then $\lambda_1 = 1{,}5 \times 10^{-6}\mathrm{m}$, thus $\nu_1 = \frac{c}{\lambda_1} = 2 \times 10^{14}\mathrm{Hz}$	1
	3	The order of the second fringe of zero intensity is $k = 1$, so $x = \frac{3\lambda_2 D}{2a}$, then $\lambda_2 = 10^{-6}\mathrm{m}$, thus $\nu_2 = 3 \times 10^{14}\mathrm{Hz}$	1
2	1	$E_2 = (E_7 - E_3) = \frac{-13.6}{49} + \frac{13.6}{9} = 1.23\mathrm{eV}.$	0,75
	2	$E_1 = (E_\infty - E_7) + Ec_{electron} = (0 - \frac{13.6}{49}) + 0.551 = 0.82\ \mathrm{eV}$	1
3		Einestein photoelectric equation : $E_{Photon\ 3} = W_0 + Ec_{max}$ $E_{Photon\ 3} = 1.625 + 0.445 = 2.07\mathrm{eV}$	0,75
4	1	$\frac{E_1}{\nu_1} = 4{,}1 \times 10^{-15}\mathrm{eV.s} = 6{,}56 \times 10^{-34}\mathrm{J.s}$; $\frac{E_2}{\nu_2} = 4{,}1 \times 10^{-15}\mathrm{eV.s} = 6{,}56 \times 10^{-34}\mathrm{J.s}$; $\frac{E_3}{\nu_3} = 4{,}14 \times 10^{-15}\mathrm{eV.s} = 6{,}62 \times 10^{-34}\mathrm{J.s}$ Then , $\frac{E_1}{\nu_1} \cong \frac{E_2}{\nu_2} \cong \frac{E_3}{\nu_3}$	0,75
	2	$E = h\nu$, then $h \cong 6.6 \times 10^{-34}\mathrm{J.s}$	0,75

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

<u>This exam is formed of four obligatory exercises in four pages.</u>
<u>The use of non-programmable calculators is recommended.</u>

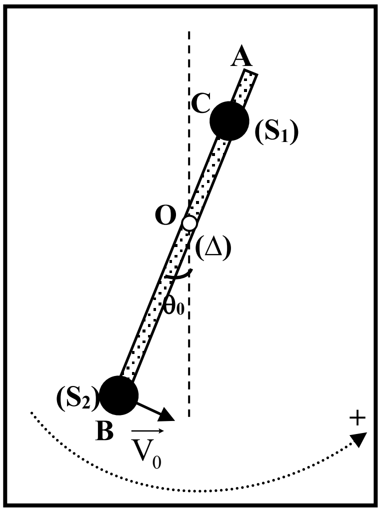
Exercise 1 (7.5 points) Two periodic motions of a system

Consider a system (S) formed by a uniform rigid thin rod (AB) of length $\ell = 0.6$ m and mass M = 1 kg, and two identical particles (S_1) and (S_2) each of mass m = 0.5 kg. (S_2) is fixed at one end B of the rod whereas (S_1) is fixed, on the rod, at an adjustable distance from its midpoint O.

Let G be the center of (S) with $\overline{OG} = a$.

The system is shifted in a vertical plane by an angle $\theta_0 = -0.08$ rad from its stable equilibrium position ($\theta = 0$), and then it is launched with an initial angular velocity $\theta'_0 = 0.3$ rad/s at $t_0 = 0$. The system thus moves without friction in the vertical plane about a horizontal axis (Δ) passing through O.

At an instant t, the position of the rod is denoted by its angular abscissa θ and its angular velocity $\theta' = \frac{d\theta}{dt}$.



Doc. 1

The moment of inertia of the rod about (Δ) is $I_R = \frac{1}{12}M\ell^2$.

The aim of this exercise is to study two periodic motions of this system corresponding to two different positions of (S_1).

1) First motion

(S_1) is fixed at a point C such that $\overline{OC} = -0.2$ m (Doc. 1). The formed system is a compound pendulum that oscillates with a maximum angle $\theta_m < 10^o$.

Given: $g = 10$ m/s^2 ; $\cos\theta \cong 1 - \frac{\theta^2}{2}$ and $\sin\theta \cong \theta$ (θ in rad) for $\theta \le 10^o$.

1-1) Prove that a = 0.025 m.

1-2) Calculate the moment of inertia I of the pendulum about (Δ).

1-3) Name the external forces acting on (S).

1-4) Given that the moment of the weight of the system about (Δ) is: $\mathcal{M} = -(2m + M)\, g\, a \sin\theta$.
Apply the theorem of angular momentum, to prove that the differential equation that governs the variation of θ is $\theta'' + \frac{(2m+M)ga}{I}\theta = 0$.

1-5) Deduce that the motion of the pendulum is periodic and show that its period T_0 does not depend on θ'_0.

1-6) Calculate T_0.

1-7) The expression of the angular abscissa of the pendulum is $\theta = \theta_m \sin(\frac{2\pi}{T_0}t + \varphi)$. Deduce the values of θ_m and φ.

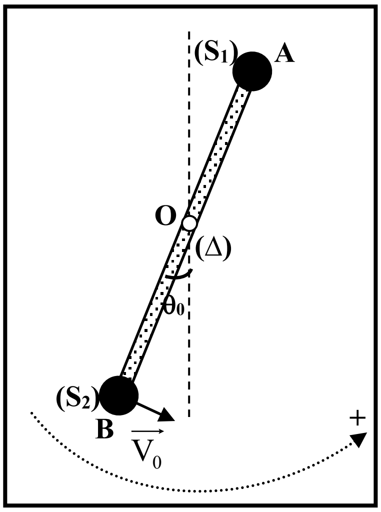
2) Second motion

(S_1) is fixed at the point A such that $\overline{OA} = -0.3$ m (Doc. 2).

2-1) Prove that G coincides with point O (a = 0).

2-2) Using the differential equation established in part (1-4), show that the system (S) is now in uniform rotational motion.

2-3) The period T of the motion of the system (S) depends on θ'_0. Write the relation between T and θ'_0. Calculate the value of T.

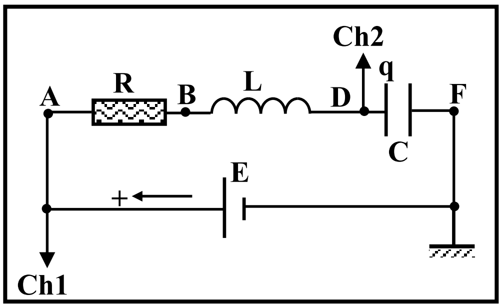


Doc. 2

Exercise 2 (7.5 points) RLC series circuit

A capacitor of capacitance C = 6 μF, a purely inductive coil of inductance L = 0.8 H, and a resistor of resistance R = 100 Ω, are connected in series between two points A and F.

The aim of this exercise is to determine the electric energy consumed by this circuit when fed by two different voltages.



Doc. 3

1) RLC circuit fed by a constant voltage

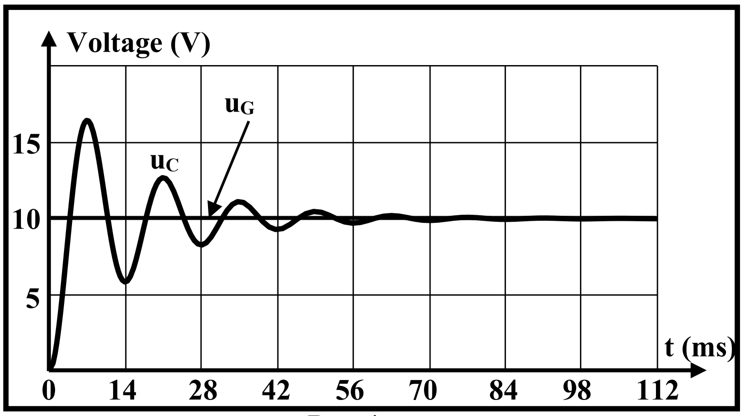
The circuit is connected across an ideal battery of e.m.f $E = u_G = u_{AF} = 10$ V (Doc. 3).

The capacitor is initially uncharged. An oscilloscope is connected in the circuit in order to display the voltages u_{AF} and $u_{DF} = u_C$ across the battery and the capacitor respectively.

Document (4) is a graph that shows the voltages u_G and u_C as functions of time.

1-1) Apply the law of addition of voltages to show that the second order differential equation of u_C:

$$u''_C + \frac{R}{L}u'_C + \frac{u_C}{LC} = \frac{E}{LC}.$$



Doc.4

1-2) Use document (4) to answer the following questions:

1-2-1) Choose, among a), b) and c) the correct expression.

a) u_C is alternating sinusoidal;

b) u_C oscillates and finally becomes zero;

c) u_C oscillates about E and then becomes equal to E.

1-2-2) Determine the angular frequency of oscillations of u_C.

1-2-3) Specify a time interval during which the capacitor consumes energy and a time interval during which the capacitor supplies energy.

1-3) After a certain time, the steady state is attained.

1-3-1) Prove, using document (4), that the capacitor neither consumes nor supplies energy;

1-3-2) Calculate the electric energy stored in the capacitor;

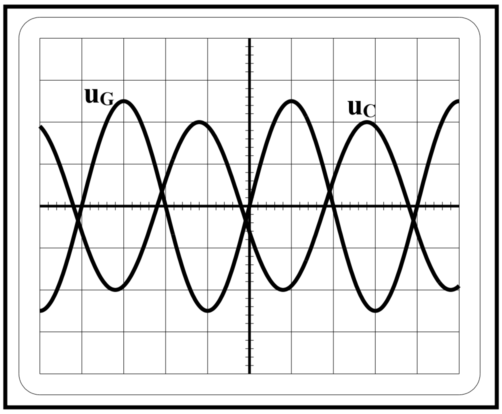
1-3-3) Determine the value of the current in the circuit;

1-3-4) Deduce that the circuit neither consumes nor supplies electric energy.

2) RLC circuit fed by an alternating sinusoidal voltage

The battery is replaced by a function generator (G) providing an alternating sinusoidal voltage. The voltage across the terminals of (G) is $u_G = u_{AF} = 10\sin(215\pi t)$ (SI) and the voltage across the capacitor in the steady state is $u_C = U_{C(m)}\sin(215\pi t + \varphi)$ (SI)

The curves of document (5) represent, in the steady state, the voltages u_G and u_C displayed on the screen of the oscilloscope. The vertical sensitivity on both channels is $S_V = 4$ V/div.



Doc. 5

2-1) Indicate the value of the angular frequency of u_C.

2-2) u_C performs forced electromagnetic oscillations. Justify.

2-3) Calculate, using document 5, $U_{C(m)}$ and $|\varphi|$.

2-4) Deduce that the expression of the current in the circuit is $i = 0.032\cos(215\pi t - 2.83)$ (SI).

2-5) Determine the average power consumed by the circuit.

2-6) Deduce the electrical energy consumed by the circuit during one period of the voltage.

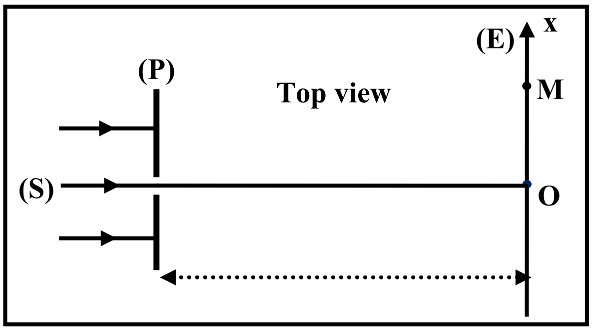
Exercise 3 (7.5 points) Identification of two monochromatic lights

Consider a dichromatic light source (S) emitting two monochromatic lights (A) and (B) of wavelengths in air λ_1 and λ_2 respectively. The color of the light beam emitted from (S) appears magenta.
The aim of this exercise is to determine λ_1 and λ_2.
Given:

- The range of wavelength of visible light in air: $400 \text{ nm} \leq \lambda \leq 800 \text{ nm}$;
- $\lambda_1 < \lambda_2$.

1) Diffraction of light

(S) illuminates in air, at normal incidence, a vertical thin slit, of width a = 0.2 mm, which is cut in an opaque plane (P). We observe a diffraction pattern on a screen (E) placed parallel to (P) at a distance D = 2 m away from it. A point M on the screen belongs to the obtained diffraction pattern, and it has a position $x = \overline{OM}$ relative to the center O of the central bright fringe (Doc. 6).
The diffraction angles of the fringes in the following questions are small.



Doc. 6

1-1) A filter is placed in front of source (S). It transmits light (B) only of wavelength $\lambda = \lambda_2$.
Let M be the center of a dark fringe of order n (n is integer)

1-1-1) Write in terms of a, n, and λ, the expression of the diffraction angle θ of M.

1-1-2) Prove that the abscissa of M O is $x = \frac{n\lambda D}{a}$.

1-1-3) The central bright fringe obtained by the diffraction of a monochromatic light of wavelength λ separates the centers of two dark fringes.
Deduce using part (1-1-2) that the width of the central bright fringe is $L = \frac{2\lambda D}{a}$.

1-2) We remove the filter, so that the two lights (A) and (B) reach the screen.

1-2-1) Compare the width of the central bright fringe obtained by the diffraction of light (A) to that obtained by the diffraction of light (B).

1-2-2) We notice that the central fringe on the diffraction pattern appears magenta. The width of this fringe is 9.3 mm. Deduce that $\lambda_1 = 465$ nm.

1-3) The two lights (A) and (B) still reaching the screen. The abscissa of a point Q in the diffraction pattern is x = 27.9 mm. Q is the center of a dark fringe of order n_1 for light (A) and at the same time Q is the center of a dark fringe of order n_2 for light (B).

1-3-1) Determine the value of n_1.

1-3-2) Prove that $n_2 \times \lambda_2 = 2790$ nm.

1-3-3) Prove that $4 \leq n_2 < 6$.

1-3-4) Deduce that the possible values of λ_2 are 558 nm and 697.5 nm.

2) Photoelectric effect

The filter is placed again in front of the source (S). The Light (B) of wavelength λ_2 emitted from this filter illuminates a pure cesium plate of threshold wavelength $\lambda_0 = 590$ nm.
A convenient apparatus is placed near the plate in order to detect the electrons ejected from the cesium plate. No emission of photoelectrons from cesium takes place. Deduce λ_2.

Exercise 4 (7.5 points) **Radioactive human body**

Our bodies contain trace amounts of some radionuclides because we eat, drink, and breathe radioactive substances that are naturally present in the environment.
Document 7 represents the mass and the activity of natural radionuclides found in a human body of mass m = 70 kg based on a research center publication.
The aim of this exercise is to specify whether these radionuclides have harmful effects on the human body.

Nuclide	Mass	Activity
Potasium 40	17 mg	4.4 kBq
Uranium	90 µg	1.1 Bq
Thorium	30 µg	0.11 Bq
Carbon 14	22 ng	3.63 kBq
Radium	31 pg	1.1 Bq
Polonium	0.2 pg	37 Bq
Tritium	0.06 pg	23 Bq

Doc. 7

Given: $m({}^{14}_{6}C) = 13.99995$ u ; $m({}^{A}_{Z}N) = 13.99923$ u ;

$m_{(e^-)} = 5.486 \times 10^{-4}$u; $1\text{ u} = 931.5 \frac{\text{MeV}}{c^2}$, $1\text{ u} = 1.66\times10^{-27}$ kg ; $1\text{ eV} = 1.6\times10^{-19}$ J.

1) Decay of carbon 14

Carbon-14 is a beta-minus emitter. Its decay equation is:

$${}^{14}_{6}C \rightarrow {}^{A}_{Z}N + {}^{M}_{D}e + X$$

1-1) Particle X is an antineutrino. Why?

1-2) Complete with justification the above equation.

1-3) Define the activity of a radioactive sample.

1-4) Carbon 14 is constantly renewed by ingestion. Deduce that the activity of carbon 14 inside the person's body remains constant with time.

1-5) Use document 7 to:

1-5-1) calculate the number N_0 of ${}^{14}_{6}C$ nuclei present in the person's body. ($1\text{ng} = 10^{-9}$ g)

1-5-2) determine the half-life (in years) of carbon 14.

1-6) Determine, in MeV and in J, the energy liberated by the decay of one nucleus of carbon 14. Neglect the mass of particle X.

1-7) Prove that the energy liberated during one year by the decay of carbon 14 inside the person's body is $E' \cong 2.94\times10^{-3}$ J.

2) Effects of the radiation on the human body

2-1) The person's body does not absorb the energy of the antineutrino.
Give a property of the antineutrino that justifies this statement.

2-2) Knowing that:

- the physiological equivalent of dose, in Sv, received by the person's body of mass m from the decay of carbon 14 in one year is $ED_1 = \frac{E'}{m} \times QF$, where QF = 1 is the quality factor of the beta-minus radiation;
- the physiological equivalent of dose received by the person's body in one year from the decay of the other radionuclides found in the body is $ED_2 = 0.268$ mSv;
- the total physiological equivalent of dose received by the person's body is $ED = ED_1 + ED_2$;
- the maximum permissible physiological equivalent of dose received by the human body is 5 mSv per year.

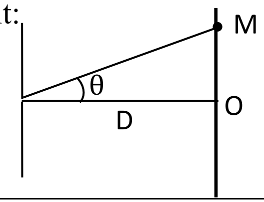
2-2-1) Calculate the total physiological equivalent of dose received by this person's body in one year.

2-2-2) Deduce if these radionuclides are dangerous for this person in one year.

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

First Exercise		Solution	7.5 pts
1	1	$a = \frac{m\,x_A + m\,x_B + M(0)}{m + m + M} = \frac{0.5 \times (-0.2) + (0.5)(0.3) + 0}{0.5 + 0.5 + 1}$ **= 0.025 m**	0.5 0.25
	2	$I = I_R + I_A + I_B = \frac{1}{12}M\ell^2 + md^2 + m(OB)^2 = \frac{1}{12} \times 1 \times 0.6^2 + 0.5(0.3^2 + 0.2^2)$ I = **0.095 kgm²**	0.75
	3	Weight $\overrightarrow{W}$ of the system, and the support reaction $\overrightarrow{R}$ at O.	0.25
	4	$\Sigma\mathcal{M}_{ext} = \frac{d\sigma}{dt} = \frac{d(I\theta')}{dt} = I\,\theta''$, so $\mathcal{M}_{\overrightarrow{W}} + \mathcal{M}_{\overrightarrow{R}} = I\,\theta''$, but $\mathcal{M}_{\overrightarrow{R}} = 0$ since $\overrightarrow{R}$ intersects (Δ) $-(2m + M)g\,a\sin\theta = I\,\theta''$, so $-(2m + M)g\,a\,\theta = I\,\theta''$, hence $\boldsymbol{\theta'' + \frac{(2m + M)g\,a}{I}\theta = 0}$	0.75
	5	The differential equation is of the form $\theta'' + \omega_0^2\,\theta = 0$ **,** where $\omega_0^2 = \frac{(2m + M)g\,a}{I}$ is a positive constant **,** then, the motion is simple harmonic so it is periodic. $T_o = \frac{2\pi}{\omega_o} = \boldsymbol{2\pi\sqrt{\frac{I}{(2m + M)ga}}}$, so it **does not depend** on the value of θ'_o.	0.5 0.75
	6	$T_o = 2\pi\sqrt{\frac{0.095}{(2 \times 0.5 + 1) \times 10 \times 0.025}}$ = **2.74 s**	0.25
	7	$\theta_o = -0.08 = \theta_m\sin(\varphi)$, then $\sin(\varphi) = \frac{-0.08}{\theta_m}$ eq (1) $\theta' = \frac{2\pi\,\theta_m}{T_o}\cos(\frac{2\pi}{T_o}t + \varphi)$, so $0.3 = \frac{2\pi\,\theta_m}{2.74}\cos(\varphi)$, then $\cos(\varphi) = \frac{0.131}{\theta_m}$ eq (2) $\sin^2\varphi + \cos^2\varphi = 1$, then $\left(\frac{0.08}{\theta_m^2}\right)^2 + \left(\frac{0.131}{\theta_m^2}\right)^2 = 1$; therefore, $\boldsymbol{\theta_m}$ **= 0.153 rad** $\sin(\varphi) = \frac{-0.08}{0.153} = -0.5228$, so $\varphi = -0.55$ rad or $\varphi = 3.69$ rad From eq (2) $\cos\varphi > 0$; therefore , **φ = -0.55 rad**	0.75 1
2	1	$a = \frac{0.5(0.3) + 0.5(-0.3) + 0}{2}$ = **0**	0.25
	2	$\theta'' + \frac{(2m + M)g\,a}{I}\theta = 0$, for a = 0 , then $\theta'' = 0$ Since $\theta'_o \neq 0$, therefore the motion is uniform rotational .	0.75
	3	$T = \frac{2\pi}{\theta'_o}$ $T = \frac{2\pi}{0.3}$ = **20.9 s**	0.5 0.25

Second Exercise			Solution	7.5 pts
1	1		$u_{AF} = u_{AB} + u_{BD} + u_{DF}$, then $E = Ri + L\frac{di}{dt} + u_C$, but $i = \frac{dq}{dt} = C\frac{du_C}{dt}$ $E = RC\frac{du_C}{dt} + LC\frac{d^2u_C}{dt^2} + u_C$, then $\mathbf{\frac{d^2u_C}{dt^2} + \frac{R}{L}\frac{du_C}{dt} + \frac{u_C}{LC} = \frac{E}{LC}}$	0.75
	2	1	Answer c) u_C oscillates about E and then becomes equal to E.	0.25
		2	T = 14 ms , then $\omega = \frac{2\pi}{T} = \frac{2\pi}{14 \times 10^{-3}}$ = **448.8 rad/s**	0.75
		3	$W_C = \frac{1}{2}Cu_C^2$, so the capacitor consumes energy when $\lvert u_C \rvert$ increases During **] 0, 7 ms[**: $\lvert u_C \rvert$ increases , then the capacitor consumes energy The capacitor consumes energy when $\lvert u_C \rvert$ decreases During **]7ms, 14 ms[**: $\lvert u_C \rvert$ decreases , then the capacitor supplies energy	0.25 0.25 0.25
	3	1	The voltage across the capacitor becomes equal to E which is constant	0.25
		2	$W_C = \frac{1}{2}Cu_C^2 = \frac{1}{2} \times 6 \times 10^{-6} \times 10^2 = \mathbf{3 \times 10^{-4}\ J}$	0.5
		3	$i = C\frac{du_C}{dt}$, since u_C = E = constant , then **i = 0**	0.5
		4	$W_L = \frac{1}{2}Li^2$ and the thermal power of R is $P_R = R\,i^2$ In the steady state, i = 0 ; therefore, $W_R = W_L = 0$ $W_{C(Consumed)} = 0$, then the circuit neither consumes nor supplies electric energy. OR Since i = 0 , then the circuit neither consumes nor supplies electric energy.	0.5
2	1		$\omega = 215\,\pi$ rad/s	0.25
	2		The angular frequency of u_C is equal to that of the function generator Or the amplitude of u_C remains constant	0.25
	3		$U_{C(m)} = S_V \times Y_m = 4 \times 2 =$ **8 V** $\lvert\varphi\rvert = \frac{2\pi d}{D} = \frac{2\pi \times 1.8}{4}$ = **2.83 rad**	0.25 0.25
	4		u_C lags behind u_G by $\lvert\varphi\rvert$, then $u_C = U_{C(m)}\sin(215\pi t - \lvert\varphi\rvert) = 8\sin(215\pi t - 2.83)$ $i = C\frac{du_C}{dt} = 6 \times 10^{-6} \times 215\,\pi \times 8\cos(215\pi t - 2.83) = 0.032\cos(215\pi t - 2.83)$ SI	0.75
	5		$i = 0.032\cos(215\pi t - 2.83) = 0.032\sin(215\pi t - 2.83 + \frac{\pi}{2})$ $i = 0.032\sin(215\pi t - 1.26)$ $P_{av} = I_{eff}\,U_{G(eff)}\cos\beta = \frac{0.032}{\sqrt{2}} \times \frac{10}{\sqrt{2}}\cos 1.26 =$ **0.049 W**	0.75
	6		$T = \frac{2\pi}{\omega} = \frac{2\pi}{215\,\pi} = 9.3 \times 10^{-3}$ s $W = P_{av} \times T = 0.049 \times 9.3 \times 10^{-3} = \mathbf{4.6 \times 10^{-4}\ J}$	0.75

Third Exercise			Solution	7.5 pts
1	1	1	$\sin\theta = \frac{n\lambda}{a}$, since the angles are small then $\sin\theta \cong \theta$, then $\boldsymbol{\theta = \frac{n\lambda}{a}}$	0.5
		2	Consider the right triangle formed by O, M, and the center of the slit: $\tan\theta \cong \theta = \frac{x}{D}$, then $x = \theta\, D = \frac{\mathbf{n\,\lambda\,D}}{\mathbf{a}}$  	1
		3	The first dark fringes situated on both sides of the central bright fringe, then $L = x_1 - x_{-1} = \frac{\lambda D}{a} - \frac{-\lambda D}{a} = \frac{\mathbf{2\lambda D}}{\mathbf{a}}$	1
	2	1	Since $\lambda_1 < \lambda_2$, then $L_1 < L_2$ Therefore, the width of the central bright fringe of (B) is longer than that of (A). The width of the central bright fringe of (B) is longer than that of (A) The color appears magenta in the common area of the central fringes of (A) and (B). Therefore, the 0.2 mm represents the **width of the central bright fringe of light (A)**	0.25 0.5
		2	$L_1 = \frac{2\,\lambda_1\,D}{a}$, then $\lambda_1 = \frac{a\,L_1}{2D} = \frac{0.2\times10^{-3}\times9.3\times10^{-3}}{2\times2} = 4.65\times10^{-7}$ m = **465 nm**	0.5
	3	1	$x = \frac{n_1\,\lambda_1 D}{a}$, then $n_1 = \frac{a\,x}{D\,\lambda_1} = \frac{0.2\times10^{-3}\times27.9\times10^{-3}}{2\times465\times10^{-9}} = \mathbf{6}$	0.5
		2	$x = \frac{n_2\,\lambda_2 D}{a}$, then $n_2\,\lambda_2 = \frac{a\,x}{D} = \frac{0.2\times10^{-3}\times27.9\times10^{-3}}{2}$, hence $\mathbf{n_2\,\lambda_2 = 2.79\times10^{-6}\ m}$ Or: $\mathbf{n_2\,\lambda_2 = 2790\ nm}$	0.75
		3	$n_2 = \frac{2790}{\lambda_2}$ and 465 nm $< \lambda_2 \leq$ 800 nm $n_2 \geq \frac{2790}{800}$, so $n_2 \geq 3.49$ but $n \in N$; therefore, $n_2 \geq 4$ $n_2 < \frac{2790}{400}$; therefore $\mathbf{n_2 < 6}$ or $n_2\,\lambda_2 = n_1\,\lambda_1$, but $\lambda_2 > \lambda_1$, then $n_2 < n_1$; therefore $\mathbf{n_2 < 6}$	1
		4	$\lambda_2 = \frac{a.x}{n_2 D}$ if $n_2 = 4$ then $\lambda_2 = \mathbf{697,5\ nm}$ if $n_2 = 5$ then $\lambda_2 = \mathbf{558\ nm}$	0.75
2			Photoelectrons takes place if $\lambda_2 \leq \lambda_o$, but we have no emission of electrons, then $\lambda_2 > \lambda_o$; therefore , $\mathbf{\lambda_2 = 697.5\ nm}$	0.75

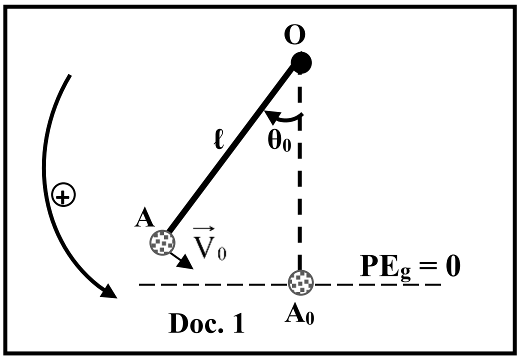
Fourth Exercise			Solution	7.5 pts
1	1		Since the type of radioactivity is β^- Or : Since in radioactivity the emission of the electron is accompanied by the emission of an antineutrino.	0.25
	2		Law of conservation of mass number: 14 = A + 0 + 0 , then A = 14 Law of conservation of charge number: 6 = Z - 1 + 0 , then Z = 7 $\mathbf{{}^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu}}$	0.5 0.5 0.25
	3		Activity is the number of disintegrations per unit time.	0.5
	4		A = λ N. Since λ and N are constant with time , then A remains constant with time	0.5
	5	1	$N_o = \frac{m}{m\ {}^{14}_{6}C} = \frac{22 \times 10^{-9}}{13.99995 \times 1.66 \times 10^{-24}} = \mathbf{9.466 \times 10^{14}}$ **nuclei**	0.75
		2	$A_o = \lambda\ N_o$, then $\lambda = \frac{3630}{9.466 \times 10^{14}} = 3.835 \times 10^{-12}\ s^{-1}$ $T = \frac{\ln 2}{\lambda} = \frac{\ln 2}{3.835 \times 10^{-12}} = 1.807 \times 10^{11}$ s = **5730 y**	1
	6		$E_{lib} = \Delta mc^2 = (13.99995) - (13.99923 + 5.486 \times 10^{-4})] \times 931.5\ \frac{MeV}{c^2} \times c^2$ E_{lib} = **0.1596591 MeV** = $0.1596591 \times 1.6 \times 10^{-13}$ J = $\mathbf{2.55 \times 10^{-14}}$ **J**	1 0.25
	7		$E' = E_{lib} \times N_{decay} = E_{lib} \times A \times t = 2.55 \times 10^{-14} \times 3650 \times 3600 \times 24 \times 365$ Therefore, $\mathbf{E' = 2.94 \times 10^{-3}}$ **J**	0.75
2	1		Antineutrino does not interact with matter	0.25
	1		$ED_1 = \frac{E'}{m} \times QF = \frac{2.94 \times 10^{-3}}{70} \times 1 = 4.2 \times 10^{-5}$ Sv = 0.042 mSv $ED = ED_1 + ED_2 = 0.042 + 0.268 = 0.31$ mSv	0.75
	2		0.31 mSv ≪ 5 mSv Therefore, **it is safe** for this person form himself radiation	0.25

مسابقة في مادة الفيزياء	الاسم:	
المدة: ساعتان ونصف	الرقم:	

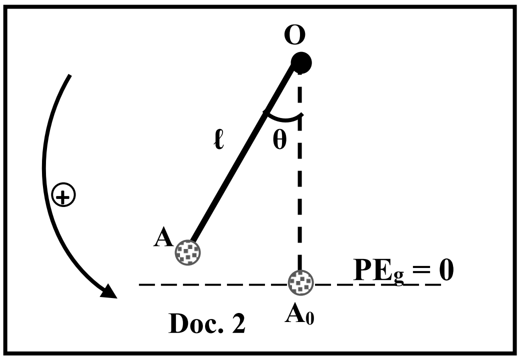
This exam is formed of four obligatory exercises in four pages.
The use of non-programmable calculator is recommended.

Exercise 1 (5 pts) Simple pendulum

A simple pendulum consists of a particle of mass m = 50 g attached from the lower end A of a massless and inextensible string OA of length ℓ.
This pendulum may oscillate in the vertical plane about a horizontal axis (Δ) passing through the upper extremity O of the string.
The pendulum is shifted in the negative direction from its equilibrium position. At an instant $t_0 = 0$, the angular abscissa of the pendulum is $\theta_0 = -\frac{\pi}{36}$ rad, and the particle is launched in the positive direction with a velocity $\vec{V}_0$ of magnitude V_0 (Doc. 1).
At an instant t, the angular abscissa of the pendulum is θ and the speed of the particle is $v = \ell\,|\theta'| = \ell\left|\frac{d\theta}{dt}\right|$ (Doc. 2).



Doc. 1



Doc. 2

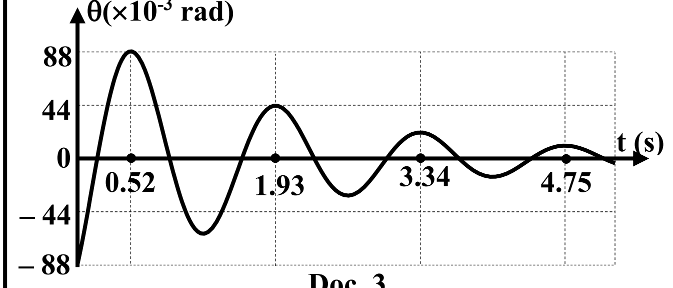
Take:
- the horizontal plane containing A_0, the position of A at equilibrium, as the reference level for gravitational potential energy;
- $g = 10\ m/s^2$.

1) Suppose that the pendulum oscillates without friction.
The second order differential equation in θ that describes the motion of the pendulum is:

$$\theta'' + 20\,\theta = 0 \quad \text{(SI)}.$$

1.1) The pendulum performs simple harmonic motion. Justify.
1.2) Calculate the value of the proper (natural) period T_0 of the pendulum.
1.3) Knowing that the proper period of the pendulum is $T_0 = 2\pi\sqrt{\frac{\ell}{g}}$, show that ℓ = 50 cm.
1.4) The mechanical energy of the system (Pendulum, Earth) at an instant t is ME.
1.4.1) Show that the expression of the mechanical energy is $ME = \frac{1}{2}\,m\,v^2 + m\,g\,\ell\,(1 - \cos\theta)$.
1.4.2) Deduce the value of V_0 knowing that $ME_0 = 1.95 \times 10^{-3}$ J at $t_0 = 0$.

2) In reality the pendulum is submitted to a force of friction. We repeat the above experiment and an appropriate device shows the angular abscissa θ of the pendulum as a function of time (Doc. 3).
Using document 3:
2.1) indicate the type of oscillations;
2.2) calculate the mechanical energy of the system (Pendulum, Earth) at t = 0.52 s;
2.3) deduce the average power lost by the system (Pendulum, Earth) between $t_0 = 0$ and t = 0.52 s.

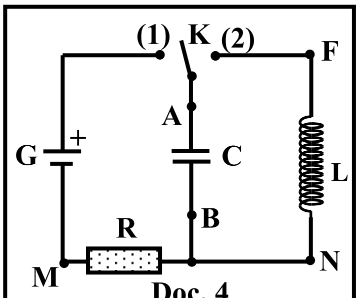


Doc. 3

Exercise 2 (5 pts) Characteristics of electric components

The aim of this exercise is to determine the capacitance C of a capacitor and the inductance L of a coil. For this purpose, we connect the circuit of document 4 which includes:

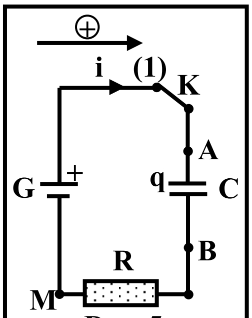
- an ideal battery G of electromotive force E = 2 V;
- a resistor of resistance R = 1 kΩ;
- a capacitor of capacitance C;
- a coil of inductance L and negligible resistance;
- a switch K.



Doc. 4

1) Series (R-C) circuit

The capacitor is initially uncharged. At the instant $t_0 = 0$, we turn K to position (1). At an instant t, the charge of plate A is q and the current in the circuit is i (Doc. 5).



Doc. 5

1.1) Name the physical phenomenon that takes place in the circuit.

1.2) Show that the differential equation that governs the variation of the voltage $u_{AB} = u_C$ across the capacitor is: $\tau \frac{du_C}{dt} + u_C = E$, where $\tau = RC$ is the time constant of the circuit.

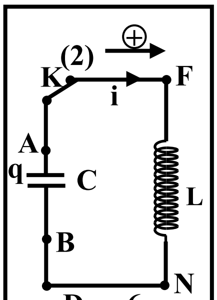
1.3) $u_C = 2(1 - e^{-1000\,t})$ (u_C in V and t in s) is a solution of this differential equation. Determine the value of τ.

1.4) Deduce the value of C.

2) (L-C) circuit

The capacitor is fully charged. At an instant $t_0 = 0$, taken as a new initial time, we turn K to position (2).

At an instant t, the charge of plate A is q and the current in the circuit is i (Doc.6).



Doc. 6

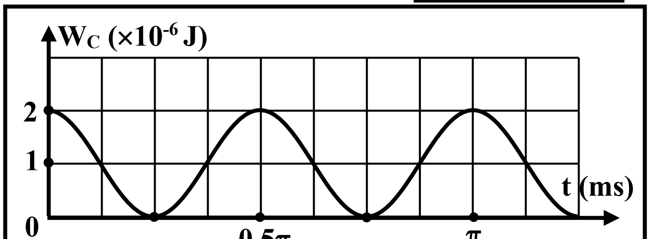
2.1) Derive the differential equation that governs the variation of the charge q.

2.2) Deduce that the expression of the proper (natural) period T_0 of the circuit is $T_0 = 2\pi\sqrt{LC}$.

2.3) The curve of document 7 represents the electric energy W_C stored in the capacitor as a function of time.

Determine the value of T_0 knowing that $T_0 = 2T_E$, where T_E is the period of the electric energy.

2.4) Deduce the value of L.



Doc. 7

Exercise 3 (5 pts) Self induction

We consider a coil of inductance L and resistance r, a resistor of resistance R = 8 Ω, a switch K, an incandescent lamp and an ideal battery (G) of electromotive force E = 10 V.

The aim of this exercise is to study the effect of the coil on the brightness of the lamp in a DC series circuit, and to determine its characteristics.

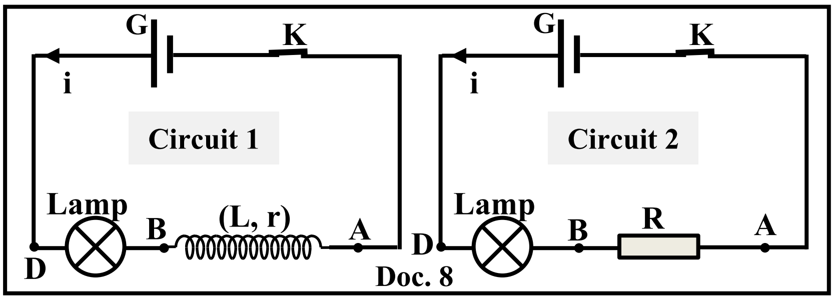
1) Brightness of the lamp

We set up successively circuit 1 and circuit 2 of document 8.

Statements 1 and 2 below describe the brightness of the lamp after closing K.

<u>**Statement 1**</u>: The lamp glows instantly at the instant of closing the switch.

<u>**Statement 2**</u>: After closing the switch, the brightness of the lamp increases gradually and becomes stable after a certain time.



Doc. 8

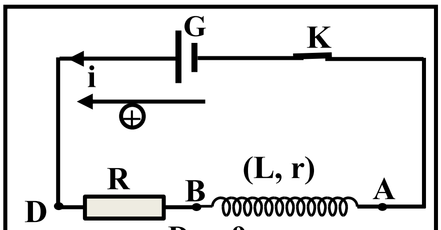
Match each statement to the convenient circuit.

2) Determination of L and r

We connect the coil and the resistor in series across (G) as shown in document 9.

At the instant $t_0 = 0$, K is closed.

At an instant t, the circuit carries a current i.



Doc. 9

2.1) Prove, by applying the law of addition of voltages, that the differential equation that describes the variation of the voltage $u_{DB} = u_R$ is: $\frac{L}{R}\frac{du_R}{dt} + \left(\frac{R+r}{R}\right)u_R = E$.

2.2) Deduce that the expression of the voltage across the resistor in the steady state is: $U_{Rmax} = E\frac{R}{R+r}$.

2.3) The solution of this differential equation is $u_R = U_{Rmax}\,(1 - e^{\frac{-t}{\tau}})$, where $\tau = \frac{L}{R+r}$.

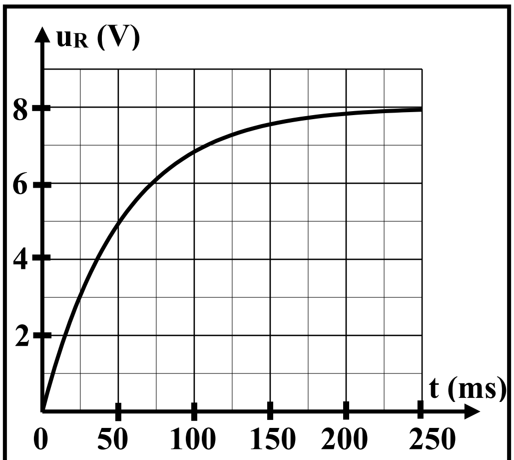
A convenient apparatus draws u_R as a function of time (Doc. 10).

2.3.1) Use document 10 to indicate the value of U_{Rmax}.

2.3.2) Determine the value of r.

2.3.3) Use document 10 to determine the value of τ.

2.3.4) Deduce the value of L.



Doc. 10

Exercise 4 (5 pts) **Stray bullets**

The aim of this exercise is to determine the thermal energy produced during the motion of a bullet fired from a rifle and to show its danger.

A bullet (S) taken as a particle of mass $m = 7\times10^{-3}$ kg is fired from point O on the ground with an initial velocity $\vec{V}_0 = V_0\ \vec{j}$. During the whole motion, the bullet is submitted to air resistance.

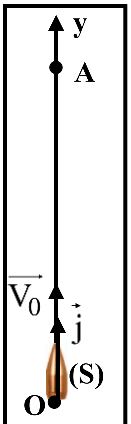
Take:

- $g = 10\ m/s^2$;
- the horizontal plane containing O as a reference level for gravitational potential energy.

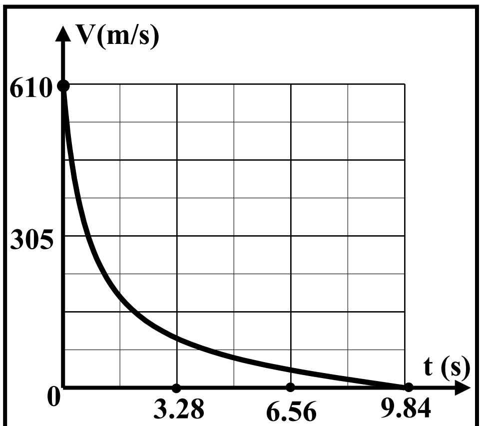
1) Upward motion of the bullet

The bullet (S) is fired vertically upward from point O at an instant $t_0 = 0$. (S) moves along the y-axis of origin O oriented positively upward. (S) reaches point A of maximum height h at $t_1 = 9.84$ s (Doc.11).

The graph of document 12 represents the speed V of (S) as a function of time during its upward motion between O and A.



Doc. 11



Doc. 12

1.1) Determine, using document 12, the linear momenta $\vec{P}_0$ and $\vec{P}_1$ of (S) at $t_0 = 0$ and at $t_1 = 9.84$ s respectively.

1.2) Deduce the variation in the linear momentum $\Delta\vec{P}$ of (S) between t_0 and t_1.

1.3) Given that $m\vec{g} + \vec{f} = \frac{\Delta\vec{P}}{\Delta t}$, where $\Delta t = t_1 - t_0$ and $\vec{f}$ is the average friction force acting on (S) during Δt. Prove that the magnitude of $\vec{f}$ is $f \cong 0.364$ N.

1.4) Calculate the mechanical energy ME_0 of the system [(S)-Earth] at $t_0 = 0$.

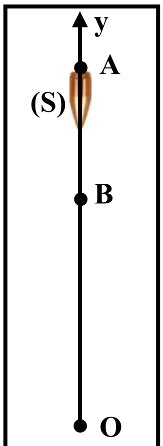
1.5) Given that $\Delta ME = - f \times h$, where ΔME is the variation in the mechanical energy of the system [(S)-Earth] during $\Delta t = t_1 - t_0$. Prove that $h \cong 3000$ m.

1.6) Deduce the value of the thermal energy W_{th1} produced during the upward motion of (S) knowing that $W_{th1} = |\Delta ME|$.

2) Downward motion of the bullet

Assume that the trajectory of (S) remains vertical.

(S) starts its downward motion from point A and passes through point B (AB = 352 m) and reaches the ground at O with a speed V = 44 m/s (Doc. 13). The magnitude of the friction force acting on (S) during its motion between B and O is $f_1 = 0.07$ N.



Doc. 13

2.1) Determine the value of the thermal energy W_{th2} produced during the motion of (S) between B and O knowing that $W_{th2} = |W_{\vec{f_1}}|$.

2.2) Calculate the thermal energy produced during the downward motion of (S) between A and O, knowing that the thermal energy produced during the downward motion of (S) between A and B is 18 J.

3) Danger of the stray bullet

The bullet can penetrate the skin of a human if its speed exceeds 61 m/s.

A bullet (S') identical to (S) is fired upward at a slight angle from the vertical (around 15^0), it follows a curvilinear path and reaches the ground at a speed 90 m/s.

Specify whether (S) or (S') is more dangerous when hitting a human as it reaches the ground.

مسابقة في مادة الفيزياء	الاسم:
المدة: ساعتان ونصف	الرقم:

Exercise 1 (5 pts) **Simple pendulum**

Part			Answer	Mark
1	1.1		The differential equation $\theta'' + 20\,\theta = 0$ is of the form: $\theta'' + \omega_0^2\theta = 0$, then it is a simple harmonic motion.	0.25
	1.2		$\omega_0 = \sqrt{20}$ rad/s $T_0 = \frac{2\pi}{\omega_0} = \frac{2\pi}{\sqrt{20}}$, then $T_0 = 1.405$ s	0.75
	1.3		$T_0 = 2\pi\sqrt{\frac{\ell}{g}}$, then $1.405 = 2\pi\sqrt{\frac{\ell}{10}}$, hence $1.974 = 4\pi^2 \frac{\ell}{10}$, so $\ell = 0.5$ m	0.5
	1.4	1	ME = KE + GPE But, GPE = m g z = m g ($\ell - \ell\cos\theta$) = m g ℓ ($1 - \cos\theta$) (Figure) $KE = \frac{1}{2} I \theta'^2$, but $I = m\ell^2$ and $v = \ell\theta'$ Then, $ME = \frac{1}{2} m v^2 + mg\ell(1 - \cos\theta)$	1
		2	$ME_o = \frac{1}{2} m V_0^2 + mg\ell(1 - \cos\theta_0)$ $1.95 \times 10^{-3} = \frac{1}{2} \times 0.05\, V_0^2 + 0.05 \times 10 \times 0.5\,[1 - \cos(\frac{-\pi}{36})]$, then $V_0 = 0.2$ m/s	0.75
2	2.1		Free damped mechanical oscillations	0.25
	2.2		$ME_{(0.52)} = 0 + mg\ell(1 - \cos\theta_{(0.52)}) = 0.05 \times 10 \times 0.5\,[1 - \cos(88\times10^{-3})]$ Then, $ME_{(0.52)} = 9.67 \times 10^{-4}$ J	0.5
	2.3		$P_{average} = \frac{ME_{lost}}{\Delta t} = \frac{1.95\times10^{-3} - 9.67\times10^{-4}}{0.52}$ Then, $P_{average} = 1.89 \times 10^{-3}$ W	0.5 0.5

Exercise 2 (5 pts) **Characteristics of electric components**

Part		Answer	Mark
1	1.1	Charging the capacitor	0.25
	1.2	$q = C u_C$ and $i = +\frac{dq}{dt}$, then $i = C\frac{du_C}{dt}$ $u_{AM} = u_{AB} + u_{BM}$, thus $E = u_C + R\,i = u_C + RC\frac{du_C}{dt}$ But, $\tau = RC$, hence $E = u_C + \tau\frac{du_C}{dt}$	0.75
	1.3	$u_C = 2\,(1 - e^{-1000\,t})$, then $\frac{du_C}{dt} = 2000\ e^{-1000\,t}$ Substituting in the above differential equation gives: $E = 2 - 2\ e^{-1000\,t} + \tau \times 2000\,e^{-1000\,t}$ $E = 2 + (-2 + 2000\,\tau)e^{-1000t}$, but $e^{-1000t} = 0$ is rejected Then, $-2 + 2000\,\tau = 0$, hence $\tau = 10^{-3}$ s	1
	1.4	$\tau = RC$, then $C = \frac{\tau}{R} = \frac{10^{-3}}{1000}$, so $C = 10^{-6}$ F = 1 μF	0.5
2	2.1	$u_{AB} = u_{AF} + u_{FN} + u_{NB}$, then $\frac{q}{C} = 0 + L\frac{di}{dt} + 0$ $i = -\frac{dq}{dt} = -q'$, then $i' = -\frac{d^2q}{dt^2} = -q''$ $\frac{q}{C} = -\ L\,q''$, then : $q'' + \frac{1}{LC}q = 0$	1
	2.2	The differential equation is of the form of : $q'' + \omega_0^2\,q = 0$, then $\omega_0 = \frac{1}{\sqrt{LC}}$ $T_0 = \frac{2\pi}{\omega_0}$, then $T_o = 2\pi\sqrt{LC}$	0.5
	2.3	Graphically, $T_E = 0.5\,\pi$ ms, then $T_0 = 2T_E = 2 \times 0.5\,\pi$, so $T_o = \pi$ ms	0.5
	2.4	$T_0^2 = 4\,\pi^2\,L\,C$, then $(\pi \times 10^{-3})^2 = 4\,\pi^2\,L\,(10^{-6})$, so $L = 0.25$ H	0.5

Exercise 3 (5 pts) **Self induction**

Part		Answer	Mark
1		**Statement 1 corresponds to circuit 2; The resistance R opposes the electric of current** **Statement 2 corresponds to circuit 1; The inductance L opposes the variation of electric current**	0.25 0.25
2	2.1	$u_{DA} = u_{DB} + u_{BA}$ $E = u_R + ri + L\frac{di}{dt}$ $u_{BD} = u_R = R\,i$, then $i = \frac{u_R}{R}$, hence $\frac{di}{dt} = \frac{1}{R}\frac{du_R}{dt}$ Then, $E = u_R + r\frac{u_R}{R} + \frac{L}{R}\frac{du_R}{dt}$ So: $\frac{L}{R}\frac{du_R}{dt} + \left(\frac{R+r}{R}\right)u_R = E$	1.25
	2.2	In the steady state: i = constant; then, $\frac{du_R}{dt} = 0$, and i is maximum , then $u_R = U_{Rmax}$ Substituting in the differential equation gives : $0 + \left(\frac{R+r}{R}\right)U_{R\,max} = E$, thus $U_{R\,max} = E\frac{R}{R+r}$	1
	2.3.1	$U_{R\,max} = 8$ V	0.25
	2.3.2	$U_{R\,max} = E\frac{R}{R+r}$, so $8 = 10\frac{8}{8+r}$, hence $r = 2\ \Omega$	0.75
	2.3.3	At $t = \tau$: $u_R = 63\ \%\ U_{Rmax} = 0.63 \times 8 = 5.04$ V Graphically : for $u_R = 0.63\ U_{Rmax} = 5.04$ V , $t = \tau = 50$ ms	0.25 0.5
	2.3.4	$\tau = \frac{L}{R+r}$, thus $L = \tau(R+r) = 0.05 \times (8+2)$, so $L = 0.5$ H	0.5

Exercise 4 (6 pts) **Stray bullets**

Part		Answer	Mark
1	1.1	$\vec{P}_o = m\vec{V}_0 = 7\times10^{-3}\times 610\ \vec{j}$, then $\vec{P}_o = 4.27\ \vec{j}$ (kg.m/s) $\vec{P}_1 = m\vec{V}_1 = \vec{0}$, since $\vec{V}_1 = \vec{0}$	0.5 0.25
	1.2	$\Delta\vec{P} = \vec{P}_1 - \vec{P}_0 = \vec{0} - 4.27\ \vec{j}$, so $\Delta\vec{P} = -4.27\ \vec{j}$ (kg.m/s)	0.5
	1.3	$m\vec{g} + \vec{f} = \frac{\Delta\vec{P}}{\Delta t}$ Projecting the vectors along the y-axis gives : $-mg - f = \frac{\Delta P}{\Delta t}$ Then, $-7\times10^{-3}\times10 - f = \frac{-4.27}{9.84}$, thus $f \cong 0.364$ N	0.75
	1.4	$ME_0 = KE_0 + PE_{g0} = \frac{1}{2} m V_o^2 + m g h_o = \frac{1}{2}\times(7\times10^{-3})\times 610^2 + 0$ Then , $ME_o = 1302.35$ J	0.5
	1.5	$ME_1 = KE_1 + PE_{g1} = \frac{1}{2} m V_1^2 + mgh = 0 + 7\times10^{-3}\times 10\ h = 0.07\ h$ $\Delta ME = W_{\vec{f}}$, then $ME_1 - ME_0 = -f\times h$ $0.07\ h - 1302.35 = -0.364\ h$; therefore , $h \cong 3000$ m	0.75
	1.6	$\Delta ME = W_{\vec{f}} = -f\ h = -0.364\times3000 = -1092$ J $W_{th1} = \|\Delta ME\| = 1092$ J	0.25
2	2.1	$W_{th2} = \|W_{\vec{f_1}}\|$, and $W_{\vec{f}} = -f_1\times BO$ BO = AO – AB = 3000 – 352 = 2648 m $W_{\vec{f}} = -0.07\times2648 = -185.36J \cong -185$ J , then $W_{th2} \cong 185$ J	0.75
	2.2	$W_{thermal} = 18 + 185 = 203$ J	0.25
3		For S : $V_{ground} = 44$ m/s < 61 m/s For S' : $V_{ground} = 90$ m/s > 61 m/s Therefore, S' is more dangerous than S	0.5

	مسابقة في مادة الفيزياء	الاسم:
	المدة: ساعتان ونصف	الرقم:

This exam is formed of four obligatory exercises in four pages.
The use of non-programmable calculator is recommended.

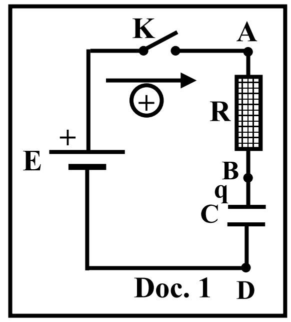
Exercise 1 (5 pts)

Charging a capacitor

The aim of this exercise is to determine the capacitance C of a capacitor and the average electric power consumed by this capacitor during a certain time interval.

For this purpose, consider the series circuit of document 1 that includes a resistor of resistance R = 1 kΩ, an initially uncharged capacitor of capacitance C, an ideal battery of electromotive force E, and a switch K.

The switch K is closed at $t_0 = 0$.



Doc. 1

1) Name the physical phenomenon that takes place in the circuit.

2) Determine the differential equation that governs the variation of the voltage $u_{BD} = u_C$ across the capacitor.

3) The solution of this differential equation is:

$u_C = A + B e^{\frac{-t}{\tau}}$.

Determine the expressions of the constants A, B and τ in terms of E, R and C.

4) The curve of document 2 represents u_C as a function of time.

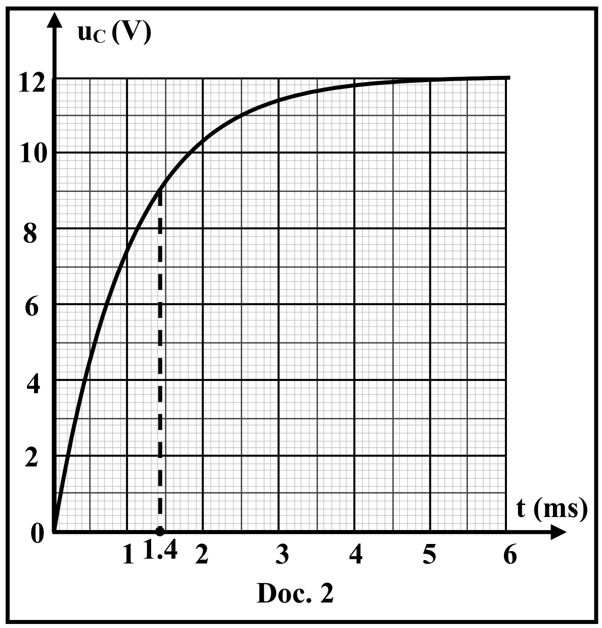
4.1) Referring to document 2 indicate the value of E.

4.2) Use document 2 to determine the time constant τ of the circuit.

4.3) Deduce the value of C.

4.4) Use document 2 to determine the electric energy stored in the capacitor at t = 1.4 ms.

4.5) Deduce the average electric power consumed by the capacitor between $t_0 = 0$ and t = 1.4 ms.



Doc. 2

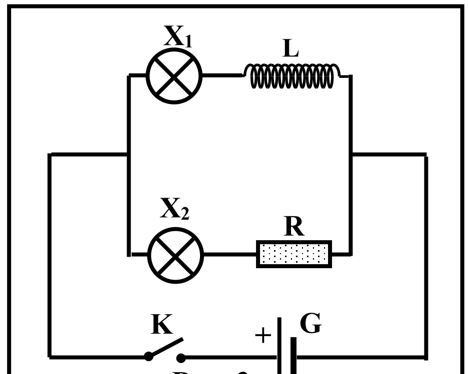
Exercise 2 (5 pts)

Self-induction

Consider an ideal battery G of electromotive force (emf) E, a coil of inductance L and negligible resistance, a resistor of resistance R, two lamps X_1 and X_2, an oscilloscope, and a switch K.
The aim of this exercise is to study the effect of the inductance of a coil on the growth of the current and to determine the value of this inductance.
Two experiments are set up for this purpose:

1) First experiment

Consider the circuit of document 3. When we close the switch K, we observe that X_2 glows instantly whereas X_1 glows with some time delay.
Explain the cause of this time delay.

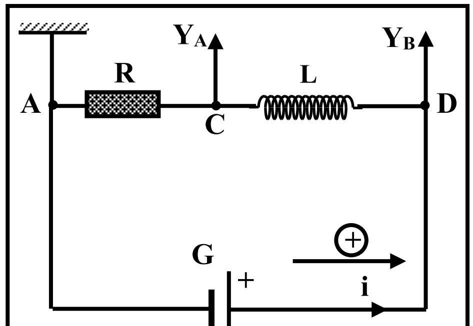


Doc. 3

2) Second experiment

Consider the circuit of document 4. Given that R = 100 Ω.

2.1) An oscilloscope is connected as indicated in document 4 in order to display two voltages as functions of time. Indicate the voltage displayed by channel Y_A and that displayed by channel Y_B.



Doc. 4

2.2) Determine the differential equation that governs the variation of the voltage $u_{CA} = u_R$ across the resistor.

2.3) The solution of this differential equation is:

$$u_R = A\,(1 - e^{\frac{-t}{\tau}}).$$

Determine the expressions of the constants A and τ in terms of E, L and R.

2.4) Show that the voltage across the resistor in the steady state is $u_R = E$.

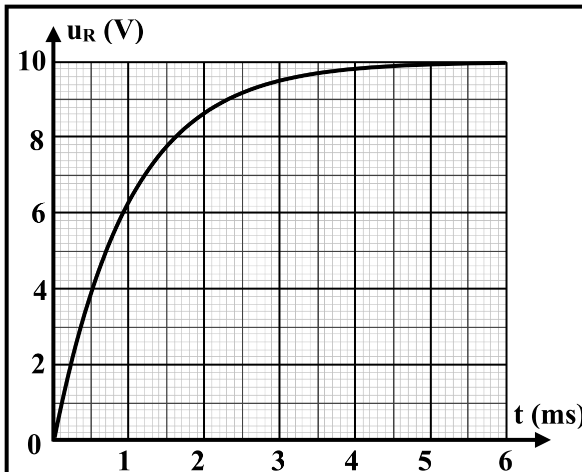
2.5) The curve of document 5 represents u_R as a function of time.

2.5.1) Referring to document 5 indicate the value of E.

2.5.2) Define the time constant τ of the series (RL) circuit.

2.5.3) Use document 5 to determine the value of τ.

2.5.4) Deduce the value of L.



Doc. 5

Exercise 3 (5 pts)

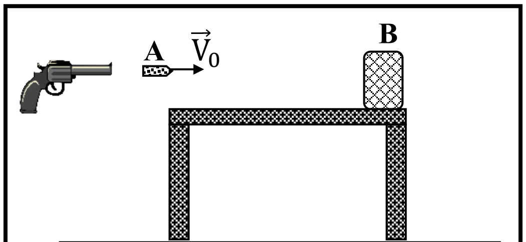
Motion of a block in a vertical plane

A gun shoots a bullet (A) of mass $m_1 = 10$ g towards a block (B), considered as a particle of mass $m_2 = 240$ g, initially at rest on the edge of a horizontal table (Doc. 6).

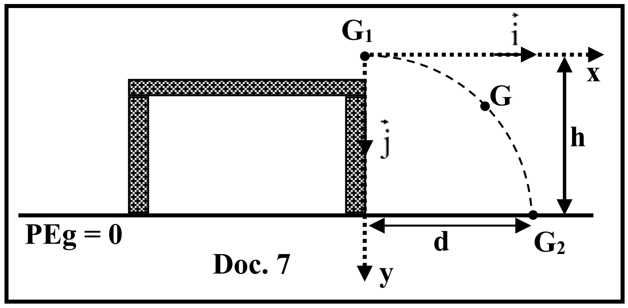
The bullet (A) hits the block (B) with a horizontal velocity $\vec{V}_0$ of magnitude $V_0 = 125$ m/s and becomes embedded in it.

The system [(A) - (B)] is taken as a particle G of mass $M = m_1 + m_2$. Just after the collision, G leaves the table at position G_1 of height h = 80 m with a horizontal velocity $\vec{V}_1$. G moves in the vertical plane G_1xy containing $\vec{V}_1$ and then it reaches the ground at position G_2 (Doc. 7).

Neglect air resistance.



Doc. 6



Doc. 7

Take:

- the horizontal plane containing G_2 as a reference level for gravitational potential energy;
- $g = 10$ m/s^2.

1) During the collision between (A) and (B), the linear momentum of the system [(A) - (B)] is conserved. Why?

2) Deduce that the magnitude of $\vec{V}_1$ is $V_1 = 5$ m/s.

3) Show that the collision between (A) and (B) is inelastic.

4) G leaves the table at G_1 at an instant $t_0 = 0$ taken as an initial time.

4.1) During the motion of G between G_1 and G_2, the mechanical energy of the system [(A) - (B) - Earth] is conserved. Why?

4.2) Deduce the value of the speed V_2 with which G reaches the ground at G_2.

4.3) Apply Newton's second law to show that the expression of the linear momentum of the system [(A) - (B)] is: $\vec{P} = 1.25\,\vec{i} + 2.5\,t\,\vec{j}$ (SI).

4.4) Deduce the parametric equations x(t) and y(t) of G in the plane G_1xy.

4.5) Given that the coordinates of G_2 are ($x_{G2} = d$, $y_{G2} = 80$ m). Deduce:

4.5.1) the time taken by G to pass from G_1 to G_2;

4.5.2) the value of the distance $d = x_{G2}$.

Exercise 4 (5 pts)

Compound pendulum

Consider a uniform rigid thin rod AB of mass $M = 0.5$ kg and length $L = AB = 2$ m.

This rod may rotate about a horizontal axis (Δ) passing through its upper end A (Doc. 8).

The aim of this exercise is to determine the moment of inertia I_1 of the rod about (Δ).

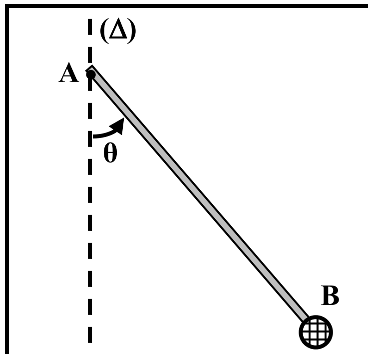
For this purpose, we fix a particle of mass $m = 0.1$ kg at the lower end B of the rod.

The system (S), formed by the rod and the particle, constitutes a compound pendulum whose center of mass is G.

(S) is shifted from its stable equilibrium position ($\theta_0 = 0$) by a small angle and then it is released without initial velocity at the instant $t_0 = 0$.

(S) oscillates without friction about (Δ).

At an instant t, the angular abscissa of the pendulum is θ and its angular velocity is $\theta' = \dfrac{d\theta}{dt}$.



Doc. 8

Take:

- the horizontal plane containing A as a reference level for gravitational potential energy;
- $\sin\theta \approx \theta$ and $\cos\theta \approx 1 - \dfrac{\theta^2}{2}$ for $\theta \leq 10^0$ (θ in rad);
- $g = 10\ m/s^2$; $\pi^2 = 10$.

1) Write the expression of the moment of inertia I of (S) about (Δ) in terms of I_1, m and L.

2) Show that the position of G relative to A is: $AG = a = \dfrac{L(M+2m)}{2(M+m)}$.

3) (S) undergoes free un-damped oscillations. Why?

4) Write the expression of the mechanical energy of the system [(S) - Earth] in terms of m, M, g, θ, θ' and I.

5) Determine the differential equation in θ that governs the motion of (S).

6) Deduce that the expression of the proper period (natural) of the pendulum is $T_0 = 2\pi\sqrt{\dfrac{2I}{(M+2m)gL}}$.

7) The pendulum performs 20 oscillations during 49 seconds.

7.1) Determine the value of I.

7.2) Deduce the value of I_1.

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Exercise 1 (5 pts) **Charging a capacitor**

Part		Answer	Mark
1		Charging the capacitor	0.25
2		$u_{AD} = u_{AB} + u_{BD}$ $E = Ri + u_C$ $i = \frac{dq}{dt}$ and $q = C u_C$, then $i = C\frac{du_C}{dt}$ Substituting in the above equation gives : $E = RC\frac{du_C}{dt} + u_C$	1
3		$u_C = A + Be^{-t/\tau}$, then $\frac{du_C}{dt} = -\frac{B}{\tau}e^{-t/\tau}$ Substituting u_C and $\frac{du_C}{dt}$ into the differential equation gives: $E = -RC\frac{B}{\tau}e^{-t/\tau} + A + Be^{-t/\tau}$ $E = Be^{-t/\tau}(-RC\frac{1}{\tau} + 1) + A$ This equation is valid at any instant, then : $E = A$ and $Be^{-t/\tau}(-RC\frac{1}{\tau} + 1) = 0$ $Be^{-t/\tau} = 0$ is rejected , so $(-RC\frac{1}{\tau} + 1) = 0$; therefore, $\tau = RC$	1
4	4.1	$E = 12$ V	0.25
	4.2	At $t = \tau$: $u_C = 0.63 E = 0.63 \times 12 = 7.56$ V Graphically, for $u_C = 7.56$ V , $t = \tau = 1$ ms	1
	4.3	$\tau = RC$, then $1 \times 10^{-3} = 1000 \times C$, hence $C = 1 \times 10^{-6}$ F	0.5
	4.4	Graphically: At t = 1.4 ms , $u_C = 9$ V $W_C = \frac{1}{2} C u_C^2 = \frac{1}{2} \times 1 \times 10^{-6} \times 9^2$, then $W_C = 4.05 \times 10^{-5}$ J	0.5
	4.5	$P = \frac{W_C}{\Delta t} = \frac{4.05 \times 10^{-5}}{1.4 \times 10^{-3}} = 0.029$ W	0.5

Exercise 2 (5 pts) **Self-induction**

Part		Answer	Mark
1		When we close the switch the electric current in the circuit increases, then the coil is crossed by a variable self-flux; therefore, the coil becomes the seat of self-induced electromotive force which according to Lenz's law tends to oppose the increase in the current (delays its growth). X_1 is connected in series with the coil, thus it glows with some time delay.	0.75
2	2.1	Channel Y_A displays the voltage u_{CA} Channel Y_B displays the voltage u_{DA}	0.25 0.25
	2.2	$u_{DA} = u_{DC} + u_{CA}$ $E = L\frac{di}{dt} + u_R$; $i = \frac{u_R}{R}$, so $\frac{di}{dt} = \frac{1}{R}\frac{du_R}{dt}$ Substituting $\frac{di}{dt}$ into the above equation gives: $E = \frac{L}{R}(\frac{du_R}{dt}) + u_R$	1
	2.3	$u_R = A(1 - e^{-t/\tau}) = A - A\,e^{-t/\tau}$, then $\frac{du_R}{dt} = \frac{A}{\tau}e^{-t/\tau}$ Substituting u_R and $\frac{du_R}{dt}$ into the differential equation gives: $E = \frac{LA}{R\tau}e^{-t/\tau} + A - A\,e^{-t/\tau}$ This equation is valid at any instant, then $E = A$ $Ae^{-t/\tau}(\frac{L}{R\tau} - 1) = 0$, but $A\,e^{-t/\tau} = 0$ is rejected Hence, $(\frac{L}{R\tau} - 1) = 0$, then $\tau = \frac{L}{R}$	1
	2.4	In the steady state $t = 5\tau$, then $u_R = E(1 - e^{-5}) \cong E$	0.25
	2.5.1	$E = 10V$	0.25
	2.5.2	τ is the time needed by the current flowing in the coil to grow or to decay 63% of its maximum value.	0.5
	2.5.3	At $t = \tau$: $u_R = 0.63E = 0.63\times 10 = 6.3$ V Graphically : for $u_R = 6.3$ V , $t = \tau = 1$ ms	0.25
	2.5.4	$\tau = \frac{L}{R}$, then $1\times10^{-3} = \frac{L}{100}$, hence $L = 0.1$ H	0.5

Exercise 3 (5 pts) Motion of a block in a vertical plane

Part		Answer	Mark
1		During the collision the internal forces are much stronger than the external forces acting on the system, then the external forces can be considered neglected relative to the internal forces. Therefore, the system of the two colliding objects is considered isolated during the collision : $\sum \vec{F}_{ext} = \frac{d\vec{P}}{dt} = \vec{0}$, then $\vec{P}$ is constant.	0.25
2		$\vec{P}_{befor} = \vec{P}_{after}$ $m\ \vec{V}_0 = (m_1 + m_2)\ \vec{V}_1$ Then, $0.01 \times 125\ \vec{i} = (0.01 + 0.24)\ \vec{V}_1$, so $V_1 = 5$ m/s	0.75
3		$KE_{before} = \frac{1}{2} m_1 V_0^2 = \frac{1}{2} \times 0.01 \times 125^2$, then $KE_{before} = 78.125$ J $KE_{after} = \frac{1}{2} (m_1 + m_2) V_1^2 = \frac{1}{2} (0.01 + 0.24) \times 5^2$, then $KE_{after} = 3.125$ J $KE_{after} < KE_{before}$, then this collision is non-elastic	0.5
4	4.1	Since air resistance is neglected Or : The sum of the works done by the non-conservative forces is zero; therefore, the mechanical energy of the system is conserved.	0.25
	4.2	$ME_{G1} = ME_{G2}$ $KE_{G1} + GPE_{G1} = KE_{G2} + GPE_{G2}$ ($GPE_{G2} = 0$ since G is at the reference level of GPE) $KE_{G1} + (m_1 + m_2)\ g\ h = \frac{1}{2} (m_1 + m_2) V_2^2 + 0$ $3.125 + (0.25 \times 10 \times 80) = \frac{1}{2} \times 0.25 \times V_2^2$ Then $V_2 = 40.3$ m/s	0.75
	4.3	$\sum \vec{F}_{ext} = \frac{d\vec{P}}{dt}$, then $M\ \vec{g} = Mg\ \vec{j} = \frac{d\vec{P}}{dt}$, hence $d\vec{p} = Mg\ \vec{j}\ dt$ $\vec{p} = Mg\ t\ \vec{j} + \vec{P}_1$, but $\vec{P}_1 = M\ \vec{V}_1 = 0.25 \times 5\ \vec{i}$, so $\vec{P}_1 = 1.25\ \vec{i}$ (kg.m/s) $\vec{p} = (0.25 \times 10)\ t\ \vec{j} + 1.25\ \vec{i}$; therefore, $\vec{P} = 1.25\ \vec{i} + 2.5t\ \vec{j}$	0.75
	4.4	$\vec{V} = \frac{\vec{P}}{M} = \frac{1,25\ \vec{i} + 2,5t\ \vec{j}}{0,25} = 5\ \vec{i} + 10\ t\ \vec{j}$ (SI) $\vec{r} = \int \vec{V}\ dt = 5t\ \vec{i} + 5\ t^2\ \vec{j} + \vec{r}_1$, but $\vec{r}_1 = \vec{0}$, so $\vec{r} = 5t\ \vec{i} + 5\ t^2\ \vec{j}$ $x = 5\ t$ (SI) and $y = 5\ t^2$ (SI)	0.5 0.5
	4.5.1	G reaches G_2 when $y = 80$ m $80 = 5t^2$, so $t = 4$ s	0.5
	4.5.2	Substituting $t = 4$ into $x(t)$ gives : $x_{G2} = d = 5 \times 4$, then $d = 20$ m	0.25

Exercise 4 (5 pts) **Compound pendulum**

Part		Answer	Mark
1		$I = I_{rod/(\Delta)} + I_{p/(\Delta)}$, then $I = I_1 + mL^2$	0.5
2		$\overrightarrow{AG} = \frac{M\,\overrightarrow{AO} + m\,\overrightarrow{AB}}{M+m}$, then $a = AG = \frac{M\frac{L}{2} + m\,L}{M+m}$, hence $a = AG = \frac{L(M+2m)}{2(M+m)}$	0.75
3		Since (S) oscillates about (Δ) without friction.	0.25
4		$ME = KE + GPE = \frac{1}{2} I (\theta')^2 + (m + M)g\,Z$ with $Z = - a \cos \theta$ $ME = \frac{1}{2} I (\theta')^2 - (m + M)g\, a \cos\theta$ $ME = \frac{1}{2} I (\theta')^2 - (m + M)g \left(\frac{L\,(M+2m)}{2\,(M+m)}\right) \cos\theta$ $ME = \frac{1}{2} I (\theta')^2 - \frac{g\,L\,(M+2m)}{2} \cos\theta$	1
5		Friction is neglected, then the mechanical energy is conserved, hence $\frac{dME}{dt} = 0$ $I\theta'\,\theta'' + \frac{g\,L\,(M+2m)}{2}\,\theta' \sin\theta = 0$, then $\theta' \left(I\theta'' + \frac{g\,L\,(M+2m)}{2} \sin\theta\right) = 0$ $\theta' = 0$ is rejected , then $I\theta'' + \frac{g\,L\,(M+2m)}{2} \sin\theta = 0$ θ is small, so $\sin\theta \approx \theta$, hence $\theta'' + \frac{(M+2\,m)\,g\,L}{2I}\,\theta = 0$	0.5
6		The differential equation is of the form $\theta'' + \omega_o^2\,\theta = 0$, then $\omega_o^2 = \frac{(M+2\,m)\,g\,L}{2I}$ Then, $\omega_o = \sqrt{\frac{(M+2m)\,g\,L}{2I}}$ But, $\omega_o = \frac{2\pi}{T_0}$, hence $T_o = 2\pi \sqrt{\frac{2I}{(M+2m)gL}}$	1
7	7.1	$T_0 = \frac{49}{20} = 2.45$ s $T_o^2 = \frac{8\,\pi^2\,I}{(M+2m)gL}$ $2.45^2 = \frac{8\,(10)\,I}{(0.5+0.2)\times 10 \times 2}$, then $I = 1.05$ kgm^2	0.5
	7.2	$I = I_1 + m\,L^2$ $I_1 = 1.05 - (0.1 \times 2^2)$, then $I_1 = 0.65$ kg.m^2	0.5

مسابقة في مادة الفيزياء
المدة: ساعتان ونصف

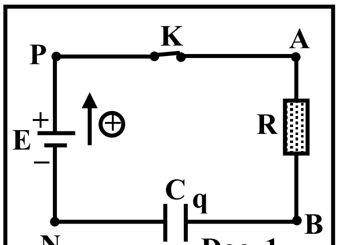
الاسم:
الرقم:

This exam is formed of four obligatory exercises in four pages.
The use of non-programmable calculator is recommended.

Exercise 1 (4.5 pts)

Charging a capacitor

The aim of this exercise is to determine the minimum duration needed for a capacitor to store the electric energy needed to feed an electronic flash later.
For this purpose, we set up the circuit represented in document 1.
This series circuit is composed of: a resistor of resistance R = 100 Ω, a capacitor, initially uncharged, of capacitance C = 10 mF, a switch K and an ideal battery of emf $E = u_{PN} = 12$ V.
Switch K is closed at the instant $t_0 = 0$, thus a current i flows in the circuit.



Doc. 1

1) Redraw the circuit of document 1 and show on it the direction of i.

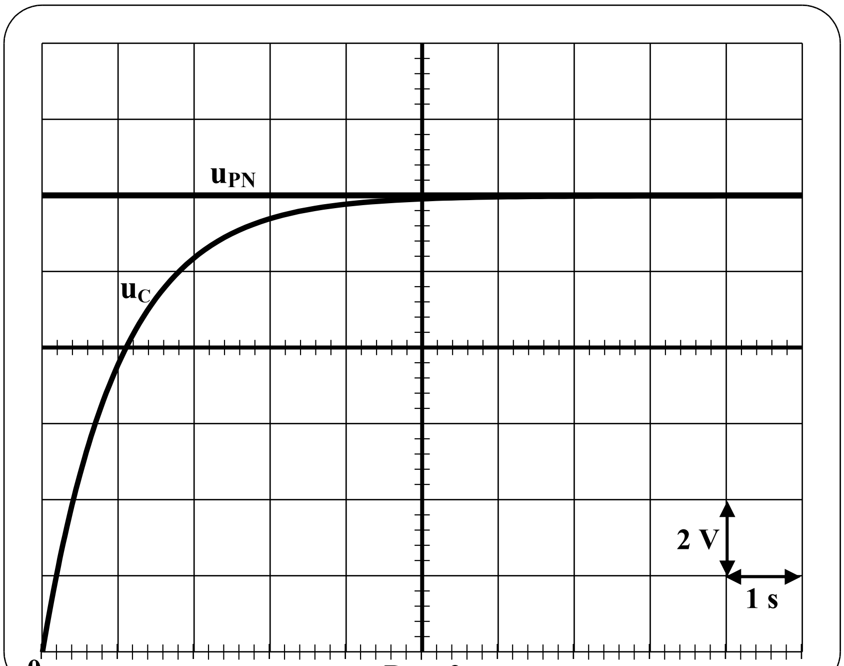
2) Determine the differential equation that governs the variation of the voltage $u_C = u_{BN}$ across the capacitor.

3) The solution of this differential equation is of the form: $u_C = E\,(1 - e^{\frac{-t}{\tau}})$, where τ is constant.

3.1) Determine the expression of τ in terms of R and C.

3.2) Calculate the value of τ.

4) An oscilloscope is used to display on channel Y_1 the voltage $u_C = u_{BN}$ across the capacitor, and on channel Y_2 the voltage u_{PN} across the battery.
The obtained curves are displayed on the screen of the oscilloscope (Doc. 2).



Doc. 2

4.1) Show on the redrawn circuit, of document 1, the connections of the oscilloscope.

4.2) Referring to document 2, determine again the value of τ.

5) During the charging process, the minimum electric energy needed to be stored in the capacitor in order to feed the flash later is W = 0.18 J.

5.1) Calculate the value U_1 of u_C when the energy stored in the capacitor becomes 0.18 J.

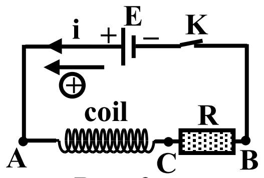
5.2) Deduce, graphically, the minimum duration taken by the capacitor to store the electric energy needed to feed the flash.

Exercise 2 (5 pts)

Sparks due to switching off a circuit of large inductance

Consider a circuit consisting of a coil of inductance L and resistance r connected in series with a resistor of resistance $R = 10^4\ \Omega$ and a switch K, across an ideal battery of constant voltage $u_{AB} = E = 20$ V.

Switch K is closed at $t_0 = 0$, thus a current i flows in the circuit (Doc. 3).



Doc. 3

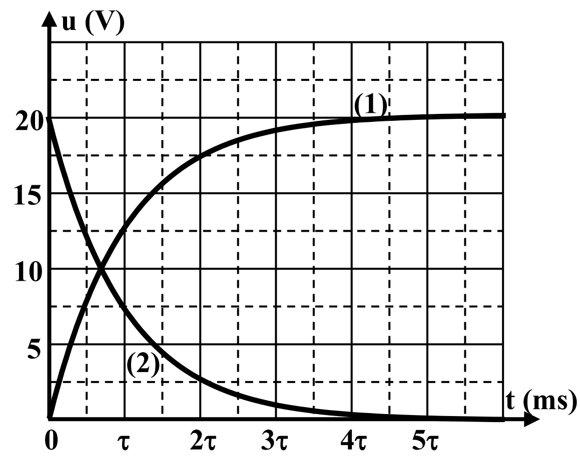
1) Theoretical study

1.1) Determine the differential equation that governs the variation of i.

1.2) The solution of this differential equation is of the form $i = I_m\left(1 - e^{\frac{-t}{\tau}}\right)$, where I_m and τ are constants. Determine the expressions of I_m and τ in terms of E, R, r and L.

2) Experimental study

Curves (1) and (2) in document 4 represent the voltages u_{AC} across the coil and u_{CB} across the resistor as functions of time t.



Doc. 4

2.1) Curve (1) represents $u_{CB} = u_R$. Why?

2.2) Use curve (2) to prove that the resistance r of the coil can be neglected.

2.3) The steady state is practically attained at t = 0.25 ms. Calculate the value of the time constant τ of the circuit.

2.4) Deduce that L = 0.5 H.

2.5) Determine the maximum magnetic energy stored in the coil in steady state.

3) Switching off the circuit

The circuit is switched off abruptly. Assume that the current decreases linearly with time and has the following expression $i = -2000\,t + 0.002$ (SI units).

3.1) Calculate the self-induced emf "e" in the coil during the decay of the current.

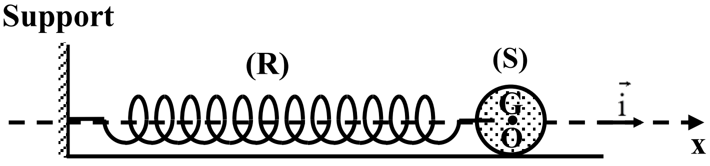
3.2) Deduce that sparks appear at the switch contacts during the decay of the current.

3.3) Propose a method used to protect the switch from sparks.

Exercise 3 (5 pts)

Determination of the force exerted by a wall on a ball

The aim of this exercise is to determine the magnitude of the force exerted by a wall on a ball during the collision between them.
For this purpose, we use a massless spring (R) of force constant k = 51 N/m.
The spring is placed horizontally connected from one of its ends to a fixed support.

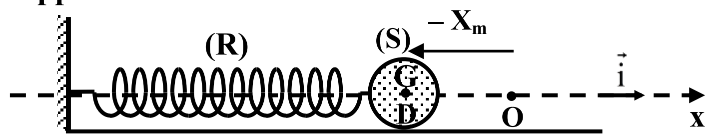


Doc. 5

A ball (S) of mass m = 1 kg is attached to the other end of the spring. (S) may slide without friction on a horizontal surface and its center of mass G can move along a horizontal x-axis of unit vector $\vec{i}$.
At equilibrium, G coincides with the origin O of the x-axis (Doc. 5).

1) Oscillatory motion of (S)

(S) is shifted from the equilibrium position to the left, in the negative direction, by a displacement $\overline{OD} = -X_m$ and then it is released from rest at $t_0 = 0$ as shown in document 6.



Doc. 6

Thus, the elastic pendulum formed by the spring and the ball oscillates without friction with a proper (natural) period T_0.

At an instant t, the abscissa of G is $x = \overline{OG}$ and the algebraic value of its velocity is $v = \frac{dx}{dt}$.

G reaches point O for the first time at an instant t_1 with a velocity $\overrightarrow{V_1} = 1\,\vec{i}$ (m/s).
Take the horizontal plane containing G as a reference level for gravitational potential energy.

1.1) By applying the principle of conservation of mechanical energy of the system [(S)-Spring-Earth], determine the value of X_m.

1.2) Write the expression of the mechanical energy ME of this system at an instant t in terms of m, k, x and v.

1.3) Determine the second order differential equation that governs the variation of x.

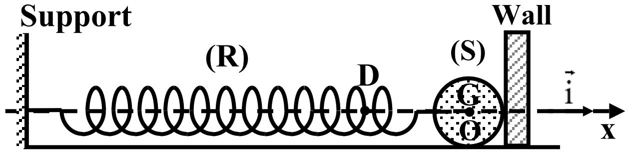
1.4) Deduce the value of T_0.

1.5) Choose from the table below the correct relation between t_1 and T_0.

Relation 1	Relation 2	Relation 3	Relation 4
$t_1 = \frac{T_0}{4}$	$t_1 = \frac{T_0}{2}$	$t_1 = \frac{3T_0}{4}$	$t_1 = T_0$

2) Collision of (S) with a wall

As G reaches point O at the instant t_1, ball (S) makes a head-on elastic collision with the wall (Doc.7).
At an instant t_2, just after the collision, (S) rebounds with a velocity $\overrightarrow{V_2} = -1\,\vec{i}$ (m/s).
The duration of this collision is Δt. G continues its oscillation with the same proper (natural) period T_0 and returns back to point D at an instant t_3.



Doc. 7

2.1) Show that $t_3 = \frac{T_0}{2} + \Delta t$.

2.2) Calculate Δt knowing that $t_3 = 0.5$ s.

2.3) Determine the variation $\Delta\vec{P}$ in the linear momentum of (S), during its collision with the wall, between t_1 and t_2.

2.4) Apply Newton's second law $\Sigma\vec{F}_{ext} = \frac{d\vec{P}}{dt} \cong \frac{\Delta\vec{P}}{\Delta t}$ on (S) to determine the magnitude of the force $\vec{F}_{wall/(S)}$ (supposed constant) exerted by the wall on (S) during the collision. Neglect the magnitude of the spring force exerted by the spring on (S) during the collision.

Exercise 4 (5.5 pts)

Oscillation of a rigid rod

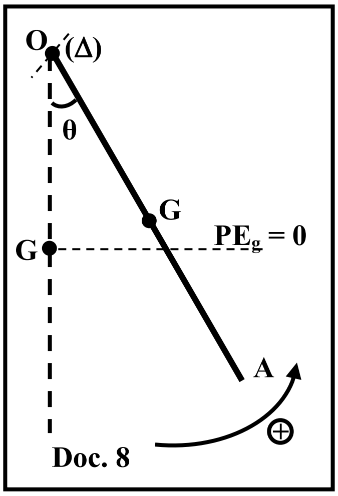
A compound pendulum consists of a thin uniform metallic rod of length ℓ = OA and mass m = 0.5 kg. The rod of center of mass G can rotate without friction in the vertical plane about a horizontal axis (Δ) passing through its upper end O.

The moment of inertia of the rod about (Δ) is $I = \frac{m\ell^2}{3}$.

The pendulum is shifted in the vertical plane by a small angle θ_m from its stable equilibrium position, and then it is released from rest.

At the instant $t_0 = 0$, the pendulum passes through the equilibrium position ($\theta_0 = 0$) in the positive sense (Counterclockwise).

At an instant t, the angular abscissa of the pendulum is θ and its angular velocity is $\theta' = \frac{d\theta}{dt}$ (Doc. 8).



Doc. 8

Take:

- the horizontal plane passing through the lowest position of G as a reference level for gravitational potential energy;
- $\sin\theta \cong \theta$ and $\cos\theta \cong 1 - \frac{\theta^2}{2}$ for small angles measured in radians (rad);
- $g = 10\ m/s^2$;
- $\pi^2 = 10$.

1) Time equation of motion of the pendulum

1.1) Determine the expression of the mechanical energy of the system (Pendulum-Earth) in terms of m, g , I, θ , θ' and a = OG.

1.2) Prove that the differential equation that governs the variation of θ is: $\theta'' + \frac{3g}{2\ell}\theta = 0$.

1.3) The solution of the obtained differential equation is $\theta = \theta_m \sin(\omega_0 t + \varphi)$, where ω_0 and φ are constants. Determine:

1.3.1) the expression of the proper (natural) angular frequency ω_0 in terms of g and ℓ;

1.3.2) the value of φ.

1.4) The rod completes 10 oscillations during 16 s.

1.4.1) Deduce the value of ω_0.

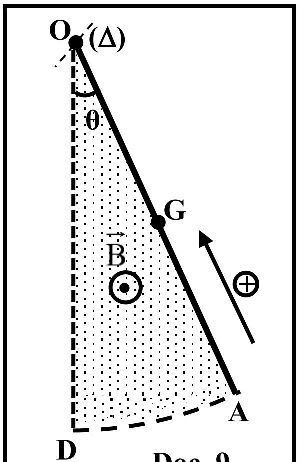
1.4.2) Calculate the value of ℓ.

2) Electromagnetic induction

The above experiment is repeated in a horizontal uniform magnetic field $\vec{B}$, of magnitude B = 0.19 T, parallel to (Δ) as shown in document 9.

An emf "e" is induced in the rod and no current passes through the rod since the circuit is open.

During the motion of the rod from its equilibrium position ($\theta_0 = 0$) to the extreme position ($\theta = \theta_m$), the magnetic flux crossing the shaded area ODA at an instant t is given by: $\phi = \frac{B\ell^2}{2}\theta$, where $\theta = \theta_m \sin(\omega_0 t)$ and $t \in [0, \frac{T_0}{4}]$. T_0 is the proper period of the pendulum.



Doc. 9

During the time interval $[0, \frac{T_0}{4}]$:

2.1) Determine the expression of "e" in terms of B, θ_m, ℓ, ω_0 and t.

2.2) The voltage across the rod is $u_{AO} = ri - e$. Prove that $u_{AO} = \frac{B\ell^2\omega_0\theta_m}{2}\cos(\omega_0 t)$.

2.3) Given that $u_{AO} = 0.06\cos(\omega_0 t)$ in SI units. Deduce the value of θ_m.

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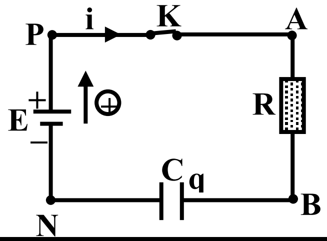
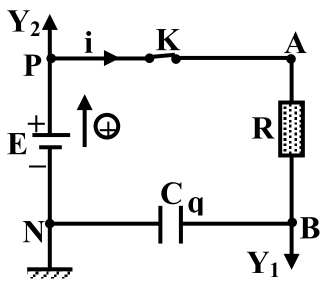
Exercise 1 (4.5pts) **Charging a capacitor**

Part		Answer	Note
1			0.25
2		$u_{PN} = u_{PA} + u_{AB} + u_{BN}$, then $E = R\,i + u_C$ But, $i = \frac{dq}{dt}$ and $q = C\,u_C$, so $i = C\frac{du_C}{dt}$; therefore, $E = RC\frac{du_C}{dt} + u_C$	1
3	3.1	$u_C = E(1 - e^{\frac{-t}{\tau}}) = E - E e^{\frac{-t}{\tau}}$, so $\frac{du_C}{dt} = \frac{E}{\tau}e^{\frac{-t}{\tau}}$ Substituting the expressions of u_C and $\frac{du_C}{dt}$ into the differential equation, gives: $E = RC\frac{E}{\tau}e^{\frac{-t}{\tau}} + E - E\,e^{\frac{-t}{\tau}}$, then $E e^{\frac{-t}{\tau}}[\frac{RC}{\tau} - 1] = 0$ The equation is valid at any instant: $E e^{\frac{-t}{\tau}} = 0$ is rejected. Then, $\frac{RC}{\tau} - 1 = 0$, hence $\tau = RC$	1
	3.2	$\tau = RC = 100 \times 10^{-2} = 1$ s	0.25
4	4.1		0.25
	4.2	At $t = \tau$, $u_C = 0.63 \times 12 = 7.56$ V ; Graphically: $u_C = 7.56$ V at $t = 1$ s , so $\tau = 1$ s	0.75
5	5.1	$W = \frac{1}{2}C\,u_C^2$, then $0.18 = \frac{1}{2}10^{-2}\,U_1^2$, so $U_1 = 6$ V	0.75
	5.2	Graphically: $U_1 = 6$ V at $t = 0.7$ s	0.25

Exercise 2 (5pts)

Sparks due to switching off a circuit of large inductance

Part		Answer	Note
1	**1.1**	$u_{AB} = u_{AC} + u_{CB}$, then $E = r\,i + L\frac{di}{dt} + R\,i$, then $E = (R+r)\,i + L\frac{di}{dt}$	0.75
	1.2	$i = I_m\left(1 - e^{\frac{-t}{\tau}}\right) = I_m - I_m e^{-\frac{t}{\tau}}$, then $\frac{di}{dt} = \frac{I_m}{\tau} e^{\frac{-t}{\tau}}$ Substituting the expressions of i and $\frac{di}{dt}$ into the differential equation, gives: $E = (R+r)(I_m - I_m e^{-\frac{t}{\tau}}) + L\frac{I_m}{\tau} e^{\frac{-t}{\tau}} = I_m(R+r) - I_m(R+r)e^{-\frac{t}{\tau}} + L\frac{I_m}{\tau} e^{\frac{-t}{\tau}}$ Then, $I_m e^{\frac{-t}{\tau}} [\frac{L}{\tau} - (R+r)] + (R+r) I_m = E$ This equation is true for any instant, by comparison: $\frac{L}{\tau} - (R+r) = 0$, then $\tau = \frac{L}{R+r}$, and $(R+r) I_m = E$, then $I_m = \frac{E}{R+r}$	1
2	**2.1**	$u_{CB} = u_R = R\,i$. The current increases during its growth and R is a positive constant, therefore, u_R increases with time.	0.25
	2.2	<u>In steady state</u>: $i = I_m$ = constant , so $\frac{di}{dt} = 0$; Graphically $u_{AC} = 0$ But, $u_{AC} = r\,i + L\frac{di}{dt}$, then $0 = r\,I_m + 0$. But, $I_m \neq 0$; therefore, $r = 0$	0.5
	2.3	Steady state is attained at t = 0.25 ms = 5 τ , so $\tau = \frac{0.25}{5} = 0.05$ ms	0.25
	2.4	$\tau = \frac{L}{R+r}$, then $L = \tau(R+r) = 0.05\times10^{-3}\left(10^4 + 0\right)$ so L = 0.5 H	0.5
	2.5	$W_{magnetic} = \frac{1}{2} L\, I_m^2$, but $I_m = \frac{E}{R+r} = \frac{20}{10^4} = 2\times10^{-3}$ A $W_{magnetic} = \frac{1}{2}\times 0.5\times(2\times10^{-3})^2 = 1\times10^{-6}$ J	0.75
3	**3.1**	$e = -L\frac{di}{dt} = -0.5\,(-2000)$, so e = 1000 V	0.5
	3.2	e = 1000 V which is a very large value. Then, the voltage across the switch would be very large; therefore, sparks appear at the switch contacts.	0.25
	3.3	We connect a capacitor across the switch. Or: We connect a diode and a resistor in parallel across the coil.	0.25

Exercise 3 (5pts)

Determination of the force exerted by a wall on a ball

Part		Answer	Note
1	1.1	$ME_D = ME_O$, then $GPE_D + KE_D + EPE_D = GPE_O + KE_O + EPE_O$ $GPE_D = GPE_O = 0$ since G is at the reference level; $KE_D = 0$ since $V_D = 0$ $EPE_O = 0$ since the spring is not deformed at O. $\frac{1}{2} k\ X_m^2 = \frac{1}{2} m\ V_1^2$, then $\frac{1}{2} \times 51 \times X_m^2 = \frac{1}{2} \times 1 \times 1$, so $X_m = 0.14$ m	0.5
	1.2	$ME = KE + EPE + GPE$, then $ME = \frac{1}{2} k\ x^2 + \frac{1}{2} m\ v^2$	0.5
	1.3	Friction is neglected, so ME is conserved. Or: The sum of the works done by the nonconservative forces is zero, then ME is constant. Therefore, $\frac{dME}{dt} = 0$ $k\,x\,x' + m\,v\,v' = 0$, but $x' = v$ and $v' = x''$, then $v\,(k\,x + m\,x'') = 0$ $v = 0$ is rejected , then $k\,x + m\,x'' = 0$ Therefore, $x'' + \frac{k}{m} x = 0$	0.75
	1.4	This differential equation is of the form: $x'' + \omega_0^2 x = 0$, with $\omega_0^2 = \frac{k}{m}$. $T_0 = \frac{2\pi}{\omega_0}$, then $T_0 = 2\pi\sqrt{\frac{m}{k}}$; $T_0 = 2\pi\sqrt{\frac{1}{51}}$, so $T_0 = 0.88$ s	0.75
	1.5	$t_1 = \frac{T_0}{4}$	0.25
2	2.1	G moves from D to O during a time $\frac{T_0}{4}$. The duration of the collision is Δt. G moves from O to D during a time $\frac{T_0}{4}$. Then, $t_3 = \frac{T_0}{4} + \Delta t + \frac{T_0}{4}$; therefore, $t_3 = \frac{T_0}{2} + \Delta t$	0.5
	2.2	$t_3 = \frac{T_0}{2} + \Delta t$, then $0.5 = \frac{0.88}{2} + \Delta t$, so $\Delta t = 0.06$ s	0.25
	2.3	$\Delta\vec{P} = \vec{P}_{t_2} - \vec{P}_{t_1} = m\vec{V}_2 - m\vec{V}_1$, then $\Delta\vec{P} = -1\,\vec{i} - 1\,\vec{i} = -2\,\vec{i}$ (kg.m/s)	0.5
	2.4	Newton's 2nd law on (S): $\Sigma\,\vec{F}_{ext} = \frac{d\vec{P}}{dt}$, then $m\,\vec{g} + \vec{N} + \vec{F}_{wall/S} = \frac{\Delta\vec{P}}{\Delta t}$, but $m\,\vec{g} + \vec{N} = \vec{0}$ $\vec{F}_{wall/S} = \frac{-2\,\vec{i}}{0.06} = -33.3\,\vec{i}$ (N)	1

Exercise 4 (5.5pts)

Oscillations of a rigid rod

Part			Answer	Note
1	1.1		$ME = KE + GPE = \frac{1}{2}\, I\, \theta'^2 + m\, g\, Z_G$, where $Z_G = a\,(1 - \cos\theta)$ So, $ME = \frac{1}{2}\, I\, \theta'^2 + mg\, a\,(1 - \cos\theta)$	0.75
	1.2		Friction is neglected, or the sum of the works done by the non-conservative forces is zero, therefore the mechanical energy is conserved. Therefore, $\frac{dME}{dt} = 0$ $I\, \theta'\, \theta'' + mg\, a\, \theta' \sin\theta = 0$, then $\theta'\,(I\, \theta'' + mg\, a \sin\theta) = 0$; $\sin\theta \cong \theta$ So, $\theta'\,(I\, \theta'' + mg\, a\, \theta) = 0$; $\theta' = 0$ is rejected , then $I\, \theta'' + mg\, a\, \theta = 0$ $\frac{m\ell^2}{3}\, \theta'' + mg\frac{\ell}{2}\, \theta = 0$, so $\frac{\ell}{3}\, \theta'' + \frac{1}{2}\, g\, \theta = 0$, hence $\theta'' + \frac{3g}{2\ell}\, \theta = 0$	0.75
	1.3	1.3.1	$\theta = \theta_m \sin(\omega_0 t + \varphi)$; $\theta' = \omega_0\theta_m \cos(\omega_0 t + \varphi)$; $\theta'' = -\omega_0^2\theta_m \sin(\omega_0 t + \varphi)$ Then, $\theta'' = -\omega_0^2\theta$. Replace θ'' by its expression in the differential equation: $-\omega_0^2\theta + \frac{3\,g}{2\,\ell}\, \theta = 0$, then $\theta\,(-\omega_0^2 + \frac{3\,g}{2\,\ell}) = 0$ $\theta = 0$ is rejected , then $-\omega_0^2 + \frac{3\,g}{2\,\ell} = 0$, so $\omega_0 = \sqrt{\frac{3\,g}{2\,\ell}}$	1
		1.3.2	$\theta = \theta_m \sin(\omega_0 t + \varphi)$: At $t_o = 0$: $\theta_o = 0 = \theta_m \sin\varphi$ $\theta_m \neq 0$, then $\sin\varphi = 0$, hence $\varphi = 0$ or $\varphi = \pi$ rad $\theta' = \omega_0\theta_m \cos(\omega_0 t + \varphi)$: At $t_o = 0$: $\theta'_0 = \omega_0\theta_m \cos(\varphi)$ $\theta'_0 > 0$, so $\cos(\varphi) > 0$; therefore, $\varphi = 0$	0.5
	1.4	1.4.1	$10\, T_0 = 16$ s , then $T_0 = 1.6$ s ; $\omega_0 = \frac{2\pi}{T_0} = \frac{2\pi}{1.6} = 1.25\,\pi$ rad/s $= 3.9$ rad/s	0.5
		1.4.2	$\omega_0 = \sqrt{\frac{3\,g}{2\,\ell}}$, then $\ell = \frac{3\,g}{2\,\omega_0^2} = \frac{3\,(10)}{2 \times 1.25^2 \times 10}$, so $\ell = 0.96$ m	0.5
2	2.1		$e = -\frac{d\phi}{dt} = -\,(\frac{B\ell^2}{2}\theta')$, then $e = -\frac{B\ell^2}{2}\theta_m\, \omega_0 \cos(\omega_0 t)$	0.5
	2.2		The circuit is open, then $i = 0$; $u_{AO} = ir - e = -e$ Therefore, $u_{AO} = \frac{B\ell^2\omega_0\theta_m}{2} \cos(\omega_0 t)$	0.5
	2.3		$u_{AO} = 0.06 \cos(\omega_0 t) = \frac{B\ell^2\omega_0\theta_m}{2} \cos(\omega_0 t)$, then $0.06 = \frac{B\ell^2\omega_0\theta_m}{2}$ $0.06 = \frac{(0.19)(0.96)^2\,(1.25\,\pi)\,\theta_m}{2}$, then $\theta_m = 0.17$ rad	0.5

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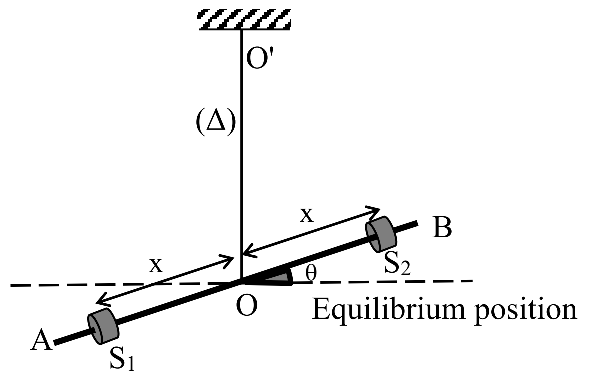
This exam is formed of four obligatory exercises in four pages.
The use of non-programmable calculator is recommended.

Exercise 1 (5 pts) Torsion pendulum

Consider a torsion pendulum (P) formed by:

- a uniform rod AB suspended from its center of mass O to a vertical torsion wire fixed from its upper end to a point O';
- two identical objects, (S_1) and (S_2), taken as particles of same mass m = 200 g. The two particles are fixed on the rod on opposite sides of O at the same adjustable distance « x » from it (Doc. 1).



Doc. 1

Neglect the mass of the torsion wire. The wire has a torsion constant C, and the rod AB has a moment of inertia I_0 about an axis (Δ) confounded with (OO').

The rod is rotated from its equilibrium position by an angle θ_m in the horizontal plane, and then it is released from rest.

The rod starts oscillating without friction in a horizontal plane about (Δ). At time t, the angular abscissa of the rod is θ and its angular velocity is $\theta' = \dfrac{d\theta}{dt}$.

The horizontal plane containing the rod is taken as a reference level for gravitational potential energy.

Given: $\pi^2 = 10$

1) Write the expression of the moment of inertia I of (P) about (Δ) in terms of I_0, m, and x.

2) Write the expression of the mechanical energy ME of the system [(P) , Earth] in terms of I, θ, C, and θ′.

3) Determine the differential equation that governs the variation of θ.

4) Deduce the expression of the proper (natural) period T_0 in terms of I and C.

5) Show that: $T_0^2 = \dfrac{4\pi^2 I_0}{C} + \dfrac{8\pi^2 m\,x^2}{C}$

6) We vary the distance x, and we measure the duration of 10 complete oscillations for each value of x. We record the measured values in the table of document 2.

x (cm)	10	15	20	25
Duration of 10 oscillations (s)	5.83	6.24	6.78	7.41
T_0 (s)				
T_0^2 (s^2)				
x^2 (m^2)				

Doc. 2

6.1) Copy and complete the table of document 2.

6.2) Draw on the graph paper the curve that represents T_0^2 as a function of x^2 using the following drawing scale: On the axis of abscissa: 1 cm ↔ 0.01 m^2
On the axis of ordinate: 1 cm ↔ 0.1 s^2

6.3) The shape of this curve can be considered in agreement with the expression of T_0^2 in part (5). Justify.

7) Deduce the values of I_0 and C.

Exercise 2 (5 pts)

Period of a simple pendulum

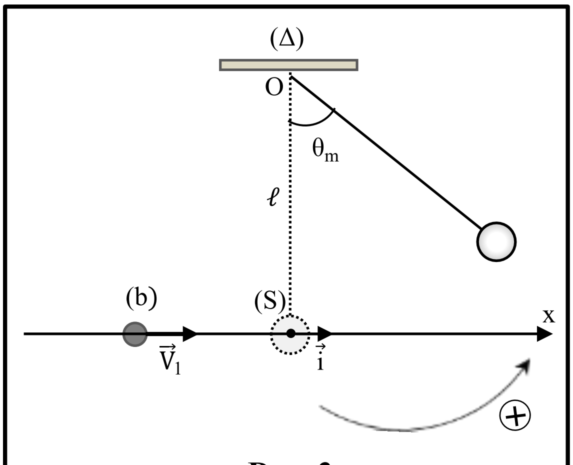
A simple pendulum is formed of a sphere (S), taken as a particle of mass m_s = 2 kg, suspended from a light inextensible cord of length ℓ = 1 m.

A marble (b) of mass m_b = 50 g is launched with a velocity $\vec{V}_1 = 11\,\vec{i}$ (m/s) along a horizontal x-axis of unit vector $\vec{i}$, and it makes a head-on collision with (S) initially at rest.

Just after the collision, marble (b) recoils horizontally with a velocity $\vec{V}'_1 = -10.46\,\vec{i}$ (m/s) and (S) starts moving with a horizontal velocity of magnitude V_0.

The pendulum [Cord , (S)] oscillates without friction in a vertical plane about a horizontal axis (Δ) passing through the upper end O of the cord (Doc. 3).

The purpose of this exercise is to determine the oscillation period of the pendulum for different values of the marble's launch speed.



Doc. 3

Take:

- the horizontal plane passing through the lowest position of (S) as a reference level for gravitational potential energy;
- $\sin\theta \cong \theta$ in radians, for $\theta \leq 0.175$ rad;
- $g = 10$ m/s^2.

1) Collision between (S) and (b)

1.1) Prove that $V_0 = 0.537$ m/s by applying the principle of conservation of linear momentum to the system [(S) , (b)].

1.2) Show that this collision is elastic.

2) Maximum deflection of the pendulum

After the collision, the pendulum is deflected by a maximum angle θ_m. Show that θ_m= 0.17 rad.

3) Oscillation of the pendulum

After the collision, the pendulum [Cord, (S)] oscillates in the vertical plane about (Δ). At an instant t, the angular abscissa of the pendulum is θ and its angular velocity is $\theta' = \dfrac{d\theta}{dt}$.

The differential equation the governs the variation of θ is: $\theta'' + \dfrac{g}{\ell}\sin\theta = 0$.

3.1) Deduce that the motion of the pendulum is simple harmonic.

3.2) Deduce the expression of the proper (natural) period T_0 of the oscillations in terms of ℓ and g.

3.3) Calculate the value of T_0.

4) The same experiment is repeated by lunching the marble horizontally with a velocity $\vec{V}_1 = V_1\,\vec{i}$, where $V_1 < 11$ m/s. Specify whether the value of the oscillation period of the pendulum increases, decreases or remains the same.

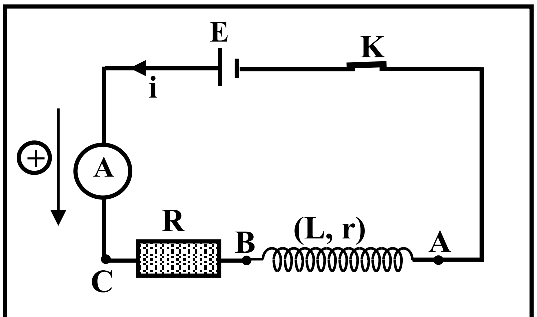
Exercise 3 (5 pts)

Characteristics of a coil

The circuit of document 4 consists of:

- an ideal battery of emf $E = 12$ V;
- an ohmic conductor of resistance $R = 15\ \Omega$;
- a coil of inductance L and resistance r;
- an ammeter (A) of negligible resistance;
- a switch K.

The purpose of this exercise is to determine the values of L and r.
At the instant $t_0 = 0$, switch K is closed and the current i in the circuit starts increasing gradually.
At the instant t_1 steady state is attained in the circuit, and ammeter (A) reads a current $I_1 = 0.5$ A.



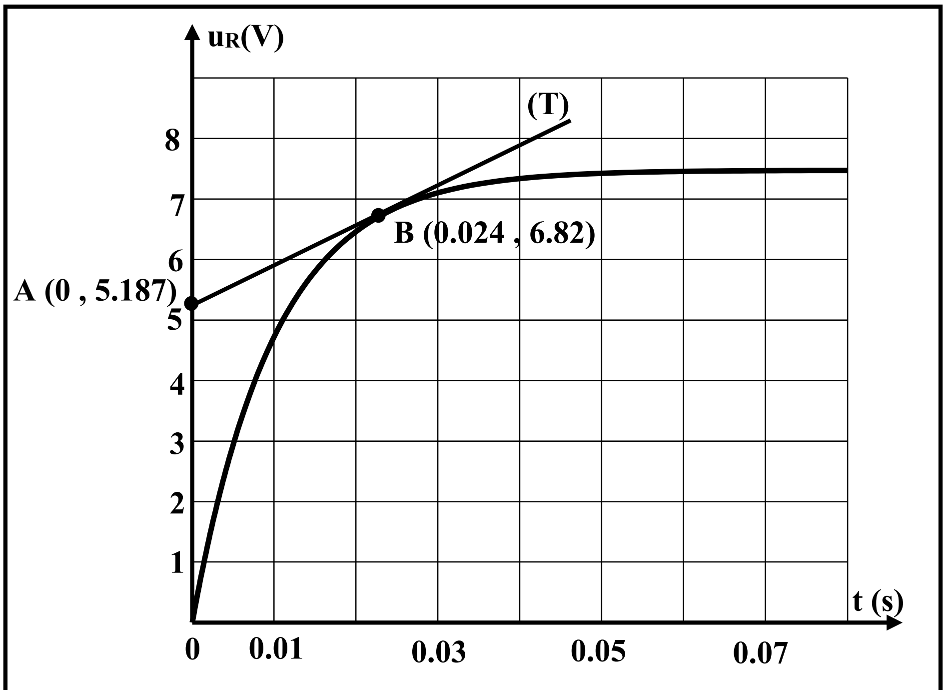
Doc. 4

1) The phenomenon of self-induction takes place in the coil between t_0 and t_1. Explain this phenomenon.
2) In steady state, the coil acts as a resistor of resistance r. Justify.
3) Show that the resistance of the coil is $r = 9\ \Omega$.
4) Show that the differential equation that governs the variation of the voltage $u_{CB} = u_R$ is:

$$\frac{RE}{L} = \left(\frac{r+R}{L}\right)u_R + \frac{du_R}{dt}$$

5) Verify that $u_R = \frac{RE}{r+R}\left(1 - e^{-\frac{t}{\tau}}\right)$ is a solution of this differential equation where $\tau = \frac{L}{r+R}$.

6) Deduce the expression of the instant t_1 in terms of L, r, and R.
7) The curve of document 5 represents u_R as a function of time.
(T) is the tangent to the curve u_R at point B (0.024s , 6.82V).
7.1) Calculate the slope of the tangent (T).
7.2) Use document 5 and the differential equation in order to deduce the value of L.



Doc. 5

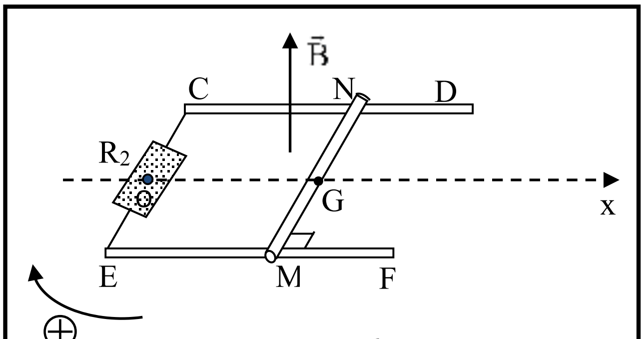
Exercise 4 (5 pts)

Electromagnetic induction

Two parallel conducting rails, CD and EF, of negligible resistance and separated by a distance $\ell = 15$ cm, are placed in a horizontal plane.

A rigid conducting rod MN, of length ℓ and perpendicular to the rails, may move without friction on the rails. The center of mass G of the rod moves along an x-axis which is parallel to the rails. The resistance of the rod is $R_1 = 0.5\ \Omega$. The ends C and E of the rails are connected to a resistor of resistance $R_2 = 0.5\ \Omega$.

The circuit formed by the two rails and the rod is placed in a vertical uniform magnetic field $\vec{B}$ perpendicular to the plane of the rails and of magnitude B = 0.5 T (Doc. 6).



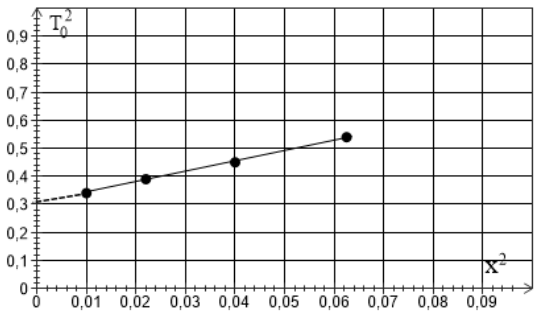
Doc. 6

At the instant $t_0 = 0$, G coincides with the origin O of the x-axis, and the rod is displaced at a constant velocity $\vec{V}$ in the positive x-direction.

At an instant t, the abscissa of G is $x = \overline{OG} = 2\ t$ (x in m and t in s).

1) The magnetic flux crossing the closed circuit CNME changes.
   - **1.1)** Indicate the reason behind the change in the magnetic flux crossing this circuit.
   - **1.2)** Explain this statement « The circuit CNME carries an electric current as long as the rod MN is moving ».
2) Show that the expression of the magnetic flux crossing the area CNME is $\phi = -0.15\ t$ (SI).
3) Determine the value of the electromotive force « e » induced in the rod.
4) Knowing that $u_{NM} = R_1 i - e$, show that the expression of the induced electric current in the circuit CNME is: $i = \dfrac{e}{R_1 + R_2}$
5) Deduce the value and the direction of i.
6) An electromagnetic force (Laplace's force) $\vec{F}$ is acting on the moving rod MN.
   - **6.1)** Indicate the direction of this force.
   - **6.2)** Calculate the magnitude F of $\vec{F}$.
7) We move the rod with a constant velocity having the same magnitude as that of $\vec{V}$ but of opposite direction. Indicate in this case the direction and the magnitude of the Laplace force acting on the rod.

مسابقة في مادة الفيزياء
المدة: ساعتان ونصف

<table>
<tr><th colspan="3">Exercise 1 (5 pts) Torsion pendulum</th></tr>
<tr><th>Part</th><th>Answer</th><th>Mark</th></tr>
<tr><td>1</td><td>$I_{[P]/\Delta} = I_{rod/\Delta} + I_{S1/\Delta} + I_{S2/\Delta} = I_0 + mx^2 + mx^2 = I_0 + 2mx^2$</td><td>0.25</td></tr>
<tr><td>2</td><td>$ME = \frac{1}{2}I\theta'^2 + \frac{1}{2}C\theta^2$</td><td>0.5</td></tr>
<tr><td>3</td><td>ME= const , so $\frac{dE_m}{dt} = 0$, then
$I\theta'\theta'' + C\theta\theta' = 0$ then $\theta'' + \frac{C}{I}\theta = 0$</td><td>0.5</td></tr>
<tr><td>4</td><td>The differential equation is of the form : $\theta'' + \omega_0^2\theta = 0$, where $\omega_0 = \sqrt{\frac{C}{I}}$
So, $T_0 = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{I}{C}}$</td><td>0.25
0.25</td></tr>
<tr><td>5</td><td>$T_0 = 2\pi\sqrt{\frac{I}{C}} = 2\pi\sqrt{\frac{I_0 + 2mx^2}{C}}$
$T_0^2 = \frac{4\pi^2 I_0}{C} + \frac{8\pi^2 m x^2}{C}$</td><td>0.25</td></tr>
<tr><td>6.1</td><td><table>
<tr><td>x (cm)</td><td>10</td><td>15</td><td>20</td><td>25</td></tr>
<tr><td>Duration of 10 oscillations</td><td>5.83</td><td>6.24</td><td>6.78</td><td>7.41</td></tr>
<tr><td>T_0 (s)</td><td>0.583</td><td>0.624</td><td>0.678</td><td>0.741</td></tr>
<tr><td>T_0^2 (s^2)</td><td>0.34</td><td>0.39</td><td>0.46</td><td>0.55</td></tr>
<tr><td>x^2 (m^2)</td><td>0.01</td><td>0.022</td><td>0.04</td><td>0.06</td></tr>
</table></td><td>0.75</td></tr>
<tr><td>6.2</td><td>
</td><td>0.75</td></tr>
<tr><td>6.3</td><td>The curve is a straight line not passing through the origin with a positive slope, so its equation is of the form : $T_0^2 = A x^2 + B$ (A and B are two positive constants).
Therefore, the curve is an agreement with the relation $T_0^2 = \frac{4\pi^2 I_0}{C} + \frac{8\pi^2 m x^2}{C}$</td><td>0.5</td></tr>
<tr><td>7</td><td>Slop of the curve $= \frac{8\pi^2 m}{C} = \frac{80 \times 0.02}{C} = \frac{0.55 - 0.34}{0.06 - 0.01} = 4.2$, then $C \cong 4$ N.m/rad
By choosing a point on the curve : $I_0 \cong 0.03$ kg .m^2</td><td>0.5
0.5</td></tr>
</table>

Exercise 2 (5 pts)	Period of a simple pendulum	
Part	**Answer**	**Mark**
1.1	$\vec{P}_{before} = \vec{P}_{after}$; $m_b\vec{v}_1 = m_b\vec{v'}_1 + m_s\vec{v}_0$ $m_b\vec{v}_1 - m_b\vec{v'}_1 = m_s\vec{v}_0$; $m_b(\vec{v}_1 - \vec{v'}_1) = m_s\vec{v}_0$ $0.05\,(11\,\vec{i} + 10.46\,\vec{i}) = 2\,\vec{v}_0$; $\vec{v}_0 = 0.537\,\vec{i}$ (m/s)	**1**
1.2	$KE_{before} = \frac{1}{2}m_b v_1^2 = \frac{1}{2}\times 0.05\times 11^2 = 3.02$ J $KE_{after} = \frac{1}{2}m_b v_1'^2 + \frac{1}{2}m_S v_0^2 = \frac{1}{2}\times 0.05\times 10.46^2 + \frac{1}{2}\times 2\times 0.537^2 = 3.02$ J $KE_{before} = KE_{after}$, then the collision is elastic.	**1**
2	ME is constant, then : $\frac{1}{2}m_s v_0^2 = m_s g\,\ell\,(1 - \cos\theta_m)$ $\frac{1}{2}(0.537^2) = 10 \times 1 \times (1 - \cos\theta_m)$, then $\cos\theta_m = 0.986$, so $\theta_m = 0.17$ rad	**1**
3.1	$\theta m \leq 0.175$ rad , then $\sin\theta \approx \theta$, so $\theta'' + \frac{g}{\ell}\sin\theta = 0$. The differential equation is of the form : $\theta'' + \omega_0^2\theta = 0$ with $\omega_0 = \sqrt{\frac{g}{\ell}}$. Then the motion is simple harmonic.	**0.5**
3.2	$T_0 = \frac{2\pi}{\omega_0} = 2\pi\sqrt{\frac{\ell}{g}}$	**0.5**
3.3	$T_0 = 2\pi\sqrt{\frac{1}{10}} = 1.99 \cong 2$ s	**0.5**
4	$V_1 < 11$ m/s, then $\theta m \leq 0.175$ rad, therefore the motion is still simple harmonic, hence $T_0 = 2\pi\sqrt{\frac{\ell}{g}}$ which is independent of V_1. Then T_0 remains the same.	**0.5**

Exercise 3 (5 pts)	Characteristics of a coil	
Part	**Answer**	**Mark**
1	Between t_0 and t_1, the current increases, then the magnitude of the magnetic field produced inside the coil increases; hence, the coil is crossed by a variable self-flux. Therefore, the coil becomes the seat of induced emf.	0.5
2	$u_{BA} = ri + L\frac{di}{dt}$ In steady state, $i = I_1$ = constant, then $\frac{di}{dt} = 0$ Then, $u_{BA} = ri$; therefore, the coil acts as a resistor.	0.5
3	$u_{CA} = u_{CB} + u_{BA}$, then $E = Ri + ri + L\frac{di}{dt}$ In steady state : $E = RI_1 + rI_1$ $I_1 = \frac{E}{R+r} = \frac{12}{15+r} = 0.5$, then $15 + r = \frac{12}{0.5} = 24$, so $r = 9\Omega$	0.5
4	$E = Ri + +ri + L\frac{di}{dt}$, then $E = L\frac{di}{dt} + (R+r)i$ $u_R = Ri$; then $i = \frac{u_R}{R}$ and $\frac{di}{dt} = \frac{1}{R}\frac{du_R}{dt}$ So : $E = \frac{L}{R}\frac{du_R}{dt} + (R+r)\frac{u_R}{R}$ Therefore : $\frac{RE}{L} = \left(\frac{r+R}{L}\right)u_R + \frac{du_R}{dt}$	1
5	$u_R = \frac{RE}{r+R}(1 - e^{\frac{-t}{\tau}})$ $\frac{du_R}{dt} = \frac{RE}{r+R} \times \frac{1}{\tau} \times e^{\frac{-t}{\tau}} = \frac{RE}{r+R} \times \frac{r+R}{L} \times e^{\frac{-t}{\tau}} = \frac{RE}{L} e^{\frac{-t}{\tau}}$ Replace in the differential equation : $\frac{RE}{L} = \left(\frac{r+R}{L}\right)\left(\frac{RE}{r+R} - \frac{RE}{r+R}e^{\frac{-t}{\tau}}\right) + \frac{RE}{L}e^{\frac{-t}{\tau}}$, then $\frac{RE}{L} = \frac{RE}{L} - \frac{RE}{L}e^{\frac{-t}{\tau}} + \frac{RE}{L}e^{\frac{-t}{\tau}}$ Then, $0 = 0$ So, this is a solution for the differential equation .	0.75
6	$t_1 = 5\,\tau = \frac{5L}{r+R}$	0.25
7.1	$\text{slope} = \frac{\Delta u_R}{\Delta t} = \frac{6.82\ -\ 5.187}{0.024\ -\ 0} = 68\ \text{V/s}$	0.5
7.2	$\frac{RE}{L} = \left(\frac{r+R}{L}\right)u_R + \frac{du_R}{dt}$ At $t = 0.024$ s , $u_R = 6.82$V and $\frac{du_R}{dt} = \text{slope} = 68\text{V/s}$ Replace in the differential equation: $\frac{15\times12}{L} = \left(\frac{24}{L}\right)6.82 + 68$, *then* $L = 0.24\text{H} = 240\text{mH}$	1

Exercise 4 (5 pts)		Electromagnetic induction	
Part		**Answer**	**Mark**
1	**1.1**	During its motion, the area swept by the rod changes, then the circuit is crossed by a variable magnetic flux.	**0.5**
	1.2	During the motion of the rod, the magnetic flux changes, then the rod becomes the seat of emf and the closed circuit carries an induced current.	**0.5**
2		$\phi = B.S.\cos(\vec{B}, \vec{n}) = B.(\ell x).\cos(\pi) = 0{,}5 \times 0{,}15 \times 2\,t = -0.15\,t.$	**0.5**
3		$e = -\frac{d\phi}{dt} = 0.15\ V$	**0.75**
4		$u_{NM} = R_1 i - e = u_{CE} = -R_2\, i$, then $e = (R_1 + R_2)\, i$, so $i = \frac{e}{R_1 + R_2}$ **<u>or</u>** : $u_{NM} + u_{CB} + u_{EC} + u_{CN} = 0$ $R_1\, i - e + 0 + R_2\, i + 0 = 0$, then $i = \frac{e}{R_1 + R_2}$	**0.5**
5		$i = \frac{e}{R_1 + R_2} = \frac{0.15}{1} = 0.15A$ $i > 0$, then the circuit carries a current in the chosen positive sense (clockwise)	**0.5** **0.5**
6	**6.1**	direction : to the left	**0.25**
	6.2	$F = i\,B\,\ell\,\sin(\pi/2) = 0.15 \times 0.5 \times 0.15 \times 1 = 0.011\ N$	**0.5**
7		Direction: to the right Value : F = 0.011 N	**0.25** **0.25**

وزارة التّربية والتعليم العالي
المديريّة العامّة للتّربية
دائرة الامتحانات الرّسميّة

امتحانات الشهادة الثانويّة العامّة
فرع العلوم العامّة

دورة العام ٢٠٢٣ العاديّة
الثلاثاء ١١ تموز ٢٠٢٣

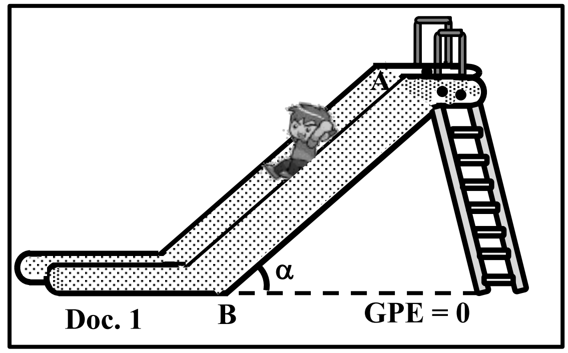
مسابقة في مادّة الفيزياء	الاسم:
المدّة: ساعتان ونصف	الرّقم:

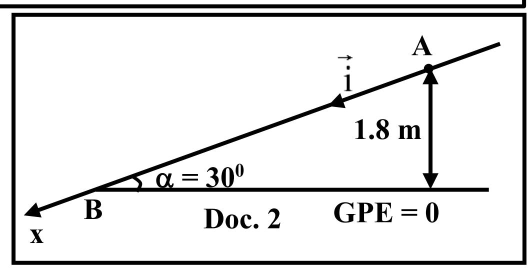
This exam is formed of four obligatory exercises in four pages.
The use of non-programmable calculator is recommended.

Exercise 1 (5 pts)

Motion on a slide

In a park, a child plays on a slide.
The child, considered as a particle, has a mass M = 20 kg.
He climbs to point A the top of the slide, and then slides down without initial velocity to point B at the bottom of the slide at the ground level (Doc. 1).
The part AB of the slide is straight and inclined by an angle $\alpha = 30^o$ with respect to the horizontal. The top A of the slide is situated at a height $h_A = 1.8$ m above the ground.
Point A is taken as the origin of the x-axis, passing through AB, and of unit vector $\vec{i}$ (Doc. 2).





The aim of this exercise is to determine the duration of motion of the child from A to B in two cases: without friction and with friction.
Take:

- the horizontal plane passing through B as a reference level for gravitational potential energy;
- $g = 10$ m/s^2.

1) The child climbs from the ground to point A.

1.1) Calculate the variation of the gravitational potential ΔGPE of the system (Child, Earth) between the ground and A.

1.2) Calculate the work W done by the weight of the child, when he climbs from the ground to A, knowing that $W = M\,g\,(h_i - h_f)$ where h_i and h_f are the initial and final heights above the ground.

1.3) Compare W and ΔGPE.

2) Suppose that the child slides without friction from A to B.

2.1) Determine the speed V_B of the child when he reaches the ground at B.

2.2) Show that the variation of the linear momentum of the child between A and B is $\Delta\vec{P} = 120\,\vec{i}$ (kg.m/s).

2.3) Show that the sum of the external forces exerted on the child, during the downward motion from A to B is $\Sigma\vec{F}_{ext.} = 100\,\vec{i}$ (N).

2.4) Deduce, by applying Newton's second law, the duration Δt_1 along AB, knowing that $\frac{\Delta\vec{P}}{\Delta t} = \frac{d\vec{P}}{dt}$.

3) In reality, the child is submitted to a force of friction $\vec{f}$, supposed constant and parallel to the displacement. During the motion from A to B, the system (Child, Slide, Earth, Atmosphere) loses 25% of its mechanical energy at A.

3.1) Show that during the downward motion of the child from A to B, the variation in the internal energy of the system (Child, Slide, Earth, Atmosphere) is ΔU = 90 J.

3.2) Deduce that the magnitude of the friction force $\vec{f}$ is f = 25 N.

3.3) The variation of the linear momentum of the child between A and B, in this case, is $\Delta\vec{P} = 60\sqrt{3}\,\vec{i}$ (kg.m/s).
Determine, by applying Newton's second law, the duration Δt_2 along AB, knowing that $\frac{\Delta\vec{P}}{\Delta t} = \frac{d\vec{P}}{dt}$.

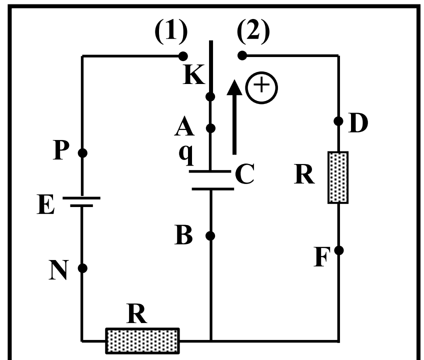
Exercise 2 (5.5 pts)

Effect of the capacitance on the duration of discharging of a capacitor

The aim of this exercise is to study the effect of the capacitance of a capacitor on the duration of discharging of a capacitor.

For this aim, we set-up the circuit of document 3 that includes:

- a capacitor, initially uncharged, of adjustable capacitance C;
- two identical resistors of resistance $R = 100\ \Omega$;
- an ideal battery of voltage $u_{PN} = E$;
- a double switch K.



Doc. 3

1) Charging the capacitor

At $t_0 = 0$, K is turned to position (1) and the charging process of the capacitor starts. At an instant t_1, the capacitor is completely charged.

1.1) Indicate the value of the current i carried by the circuit at t_1.

1.2) Write, at t_1, the charge Q in the capacitor in terms of E and C.

2) Discharging the capacitor

The capacitor is completely charged.

At an instant $t_0 = 0$, taken as an initial time, the switch K is turned to position (2); the phenomenon of discharging of the capacitor thus starts.

2.1) Show that the differential equation that describes the variation of the charge q of plate A of the capacitor is: $R\frac{dq}{dt} + \frac{q}{C} = 0$.

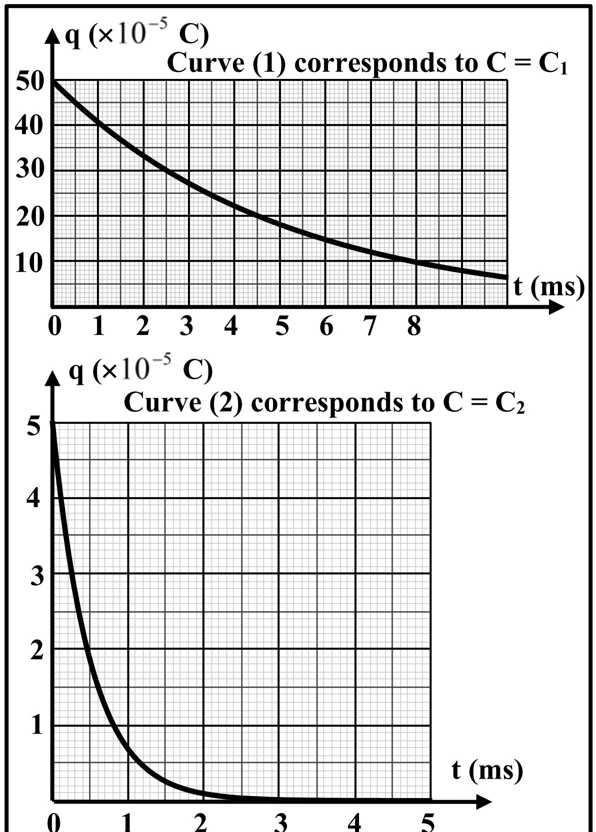
2.2) The solution of this differential equation is of the form: $q = Q\ e^{\frac{-t}{\tau}}$ where τ is a constant.
Determine the expression of τ in terms of R and C.

2.3) Calculate the ratio $\frac{q}{Q}$ at $t = \tau$.

2.4) Verify that the capacitor is practically completely discharged at $t_2 = 5\ \tau$.

3) Duration of discharging a capacitor

We repeat the charging and the discharging of the capacitor by giving C two different values C_1 and C_2. The curves of document 4 show the charge q during the discharging process of the capacitor for each value of C as funcrions of time.



Doc. 4

3.1) Using document 4, copy and complete the below table:

	The charge Q (in C) at $t_0 = 0$	The time constant τ (in ms)
Curve (1) corresponds to $C = C_1$	$Q_1 =$	$\tau_1 =$
Curve (2) corresponds to $C = C_2$	$Q_2 =$	$\tau_2 =$

3.2) Calculate the values C_1 and C_2.

3.3) Deduce the effect of the capacitance of the capaitor on the duration of the discharging process.

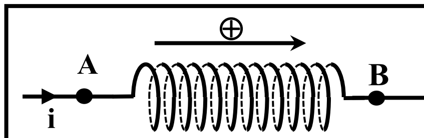
Exercise 3 (5.5 pts)

Inductance and resistance of a coil

Consider a coil of inductance L and internal resistance r.
The aim of this exercise is to determine L and r by two different methods.

1) First method

A portion of a circuit is formed of the coil, that carries a current « i ».
The coil is oriented positively from A to B (Doc. 5).



Doc. 5

1.1) Write the expression of the self-induced electromotive force « e » in the coil in terms of L, i and time t.

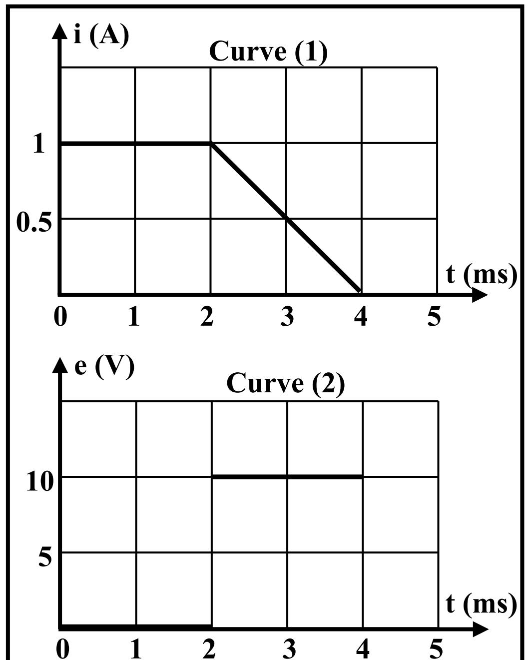
1.2) The curves (1) and (2) of document 6 show respectively « i » and « e » as functions of time, between 0 and 4 ms.
Using document 6:

1.2.1) Justify each of the following statements:

- **Statement 1**: between 0 and 2 ms, the coil acts as a resistor of resistance r.
- **Statement 2**: between 2 ms and 4 ms, a phenomenon of self-induction takes place in the coil.
- **Statement 3**: between 2 ms and 4 ms the coil supplies the circuit with the stored magnetic energy.

1.2.2) Determine the value of L.

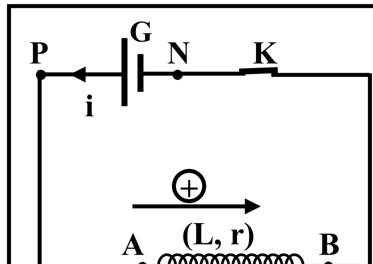
1.2.3) Determine the value of r, knowing that $u_{AB} = -5$ V at t = 3 ms.



Doc. 6

2) Second method

We connect the coil in series with an ideal battery (G) of electromotive force (e.m.f) E = 20 V (Doc.7).
At $t_0 = 0$, we close the switch K.
At an instant t, the circuit carries a current i.
Document 8 shows the current i as a function of time and the tangent (T) to the curve i(t) at $t_0 = 0$.



Doc. 7

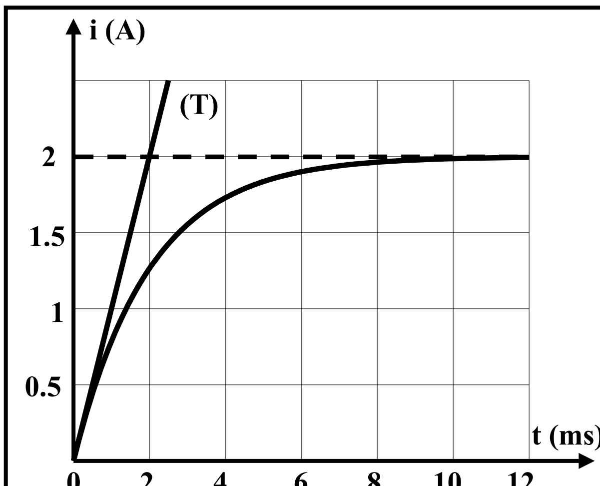
2.1) Establish the first order differential equation that describes the variation of the current i as a function of time.

2.2) Determine the expression of the maximum current I_m, at the steady state, in terms of E and r.

2.3) Calculate r using document 8.

2.4) Determine, using the differential equation, the expression of $\frac{di}{dt}$ at $t_0 = 0$ in terms of E and L.

2.5) Calculate the slope of the tangent (T). Deduce L.

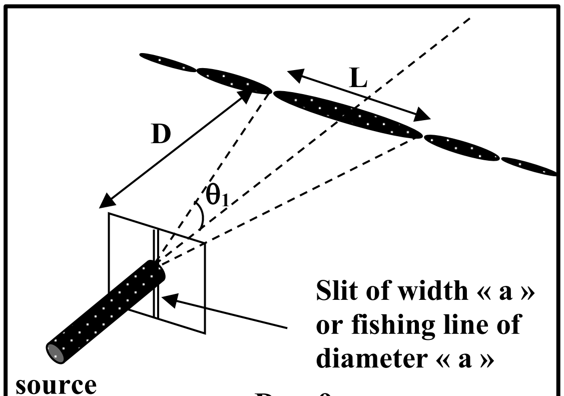


Doc. 8

Exercise 4 (4 pts)

Diameter of a fishing line

The aim of this exercise is to determine whether the fishing line chosen by a fisherman is suitable to catch the trout fish of a specific size using the phenomenon of diffraction.



Doc. 9

1) Set-up of diffraction

A monochromatic light, of wavelength λ, falls normally on a vertical narrow slit of width « a ». The diffraction pattern is observed on a screen placed perpendicularly to the incident light beam at a distance D from the slit.
Let «L» be the linear width of the central bright fringe (Doc. 9).
The diffraction angles in this exercise are small.
For small angle, take $\tan\theta \approx \sin\theta \approx \theta$ in radian.

1.1) Describe the diffraction pattern observed on the screen.
1.2) Write, in terms of λ and « a », the expression of the angle of diffraction θ_1 corresponding to the center of the first dark fringe.
1.3) Show that $L = \frac{2\lambda D}{a}$.

2) Diameter of fishing line

A fisherman wants to catch a trout fish of size 50 cm to 55 cm. He bought a thin fishing line made up of 100% copolymer, but the strength of a fishing line also depends on its diameter « a ».
To find out if the chosen fishing line is suitable for such a type of fish, he uses the diffraction set-up of document 9 by replacing the slit of width « a » by the fishing line of diameter « a », so he obtains a diffraction pattern similar to that shown in document 9.
The screen is placed at a distance D from the fishing line, the linear width of the central bright fringe is $L_1 = 13$ mm. The screen is displaced by 50 cm away from the fishing line, the linear width of the central bright fringe becomes $L_2 = 19.5$ mm.

2.1) Show that D = 1 m.
2.2) Calculate the diameter « a » of the chosen fishing line, knowing that the wavelength of the used light is $\lambda = 650$ nm.
2.3) Referring to the table in document 10, specify if the chosen fishing line is suitable for fishing trout fish of size 50 to 55 cm.

Fishing line (100 % copolymer)	Diameter	Use
Fishing line (1)	0.10 mm	It is suitable to fishing a trout fish of size 35 cm to 40 cm.
Fishing line (2)	0.18 mm	It is suitable to fishing a trout fish of size 50 cm to 55 cm.
Fishing line (3)	0.25 mm	It is suitable to fishing a trout fish of size 65 cm to 70 cm.

https://www.truitesaquaponiques.com/

Doc. 10

مسابقة الفيزياء
أسس التصحيح

Exercise 1 (5 pts)	Motion on a slide	
Part	**Answer**	**Mark**
1.1	The gravitational potential energy of the system at B $GPE_{ground} = 0$ and at A, $GPE_A = M\,g\,h_A = 360$ J $\Delta GPE = GPE_A - GPE_B = 360 - 0 = 360$ J	**0.75**
1.2	The work done by the weight of the child, when he moves from the ground to the top A: $W = M\,g\,(h_i - h_f) = 20\times10\times(0 - 1.8) = -360$ J	**0.25**
1.3	$W_{weight} = -\Delta GPE$	**0.25**
2.1	$ME_A = GPE_A + KE_A = 360$ J ($KE_A = 0$ since $V_A = 0$) In the absence of friction, (or the work done by the nonconsevative forces is zero) the mechanical energy of the system is conserved, then $ME_B = ME_A = 360$ J But $ME_B = KE_B + GPE_B$; $GPE_B = 0$ (on reference) So $\frac{1}{2} M V_B^2 = 360$ therefore $V_B = 6$ m/s	**0.75**
2.2	$\Delta\vec{P} = \vec{P_B} - \vec{P_A}$; $\Delta\vec{P} = M\vec{V_B} - M\,\vec{V_A}$, therefore $\Delta\vec{P} = 20\times6\,\vec{i} - \vec{0}$, then $\Delta\vec{P} = 120\,\vec{i}$	**0.5**
2.3	$\Sigma\vec{F}_{ext} = M\vec{g} + \vec{N}$, along $\vec{i}$: $\Sigma\vec{F}_{ext} = Mg.\sin\alpha\,\vec{i} + \vec{0} = 100\,\vec{i}$	**0.5**
2.4	$\Delta\vec{P} = \Sigma\vec{F}_{Ext}\times\Delta t_1$, so $120\,\vec{i} = 100\,\vec{i}\times\Delta t_1$, then $\Delta t_1 = 1.2$ s	**0.25**
3.1	The system (Child, Slide, Earth, Atmosphere) is energetically isolated, So its total energy $E = ME + U =$ constant So, $\Delta U = -\Delta(ME)$ There is a loss of 25 % of ME; so $\Delta(ME) = -0.25\times ME_A = -0.25(360) = -90$ J: Hence, $\Delta U = 90$ J	**0.75**
3.2	The variation in mechanical energy equals the work of friction: $\Delta ME = W_{\vec{f}}$ so $\Delta(ME) = -90 = -f\times AB = -f\times\frac{h_A}{\sin(\alpha)}$ $-90 = -f\times3.6$, thus $f = 25$ N	**0.5**
3.3	$\Delta\vec{P} = \Sigma\vec{F}_{ext}\times\Delta t_2$, $\Sigma\vec{F}_{Ext} = (Mg.\sin\alpha - f)\,\vec{i} + \vec{0}$ so $60\sqrt{3}\,\vec{i} = (100 - 25)\,\vec{i}\times\Delta t_2$, then $\Delta t_2 = 1.385$ s	**0.5**

Exercise 2 (5.5 pts) Effect of the capacitance on the discharging of a capacitor		
Part	**Answer**	**Mark**
1.1	At instant t_1 : $i = 0$	**0.25**
1.2	$Q = C\,E$	**0.25**
2.1	$u_C = u_{DF} = u_R$; $\frac{q}{C} = R\,i$; But $i = -\frac{dq}{dt}$ so we get : $R\frac{dq}{dt} + \frac{q}{C} = 0$	**0.5**
2.2	$q = Q\,e^{\frac{-t}{\tau}}$; $\frac{dq}{dt} = -\frac{Q}{\tau}\,e^{\frac{-t}{\tau}}$ we substitute q and $\frac{dq}{dt}$ in the differential equation $-R\frac{Q}{\tau}e^{\frac{-t}{\tau}} + \frac{Qe^{\frac{-t}{\tau}}}{C} = 0$; $Qe^{\frac{-t}{\tau}}[-\frac{R}{\tau} + \frac{1}{C}] = 0$; But $Qe^{\frac{-t}{\tau}} \neq 0$; so $-\frac{R}{\tau} + \frac{1}{C} = 0$; therefore $\frac{R}{\tau} = \frac{1}{C}$ thus $\tau = RC$	**1**
2.3	the ratio: $\frac{q}{Q} = \frac{Qe^{\frac{-t}{\tau}}}{Q}$ at $t = \tau$: $\frac{q}{Q} = e^{-1} = 0.37$	**0.5**
2.4	$q = Q\,e^{\frac{-t}{\tau}}$; à $t_2 = 5\,RC$: $q = Q\,e^{-5} = 0.006\,Q \approx 0$	**0.5**
3.1	Curve (1): At $t_0 = 0$: $Q_1 = 50 \times 10^{-5}$ C at $t = \tau_1$: $q = 0.37\times50\times10^{-5} = 18.5\times10^{-5}$ C. From the graph: $q = 18.5\times10^{-5}$ C at t = 5 ms ; so $\tau_1 = 5$ ms Curve (2): at $t_0 = 0$: $Q_2 = 5 \times 10^{-5}$ C at $t = \tau_2$: $q = 0.37\times5\times10^{-5} = 1.85\times10^{-5}$ C. From the graph: $q = 1.85\times10^{-5}$ C at t = 0.5 ms ; so $\tau_1 = 0.5$ ms | | Charge Q at $t_0 = 0$ | The time constant τ | | Curve (1) for $C = C_1$ | $Q_1 = 50\times10^{-5}$ C | $\tau_1 = 5$ ms | | Curve (2) for $C = C_2$ | $Q_2 = 5\times10^{-5}$ C | $\tau_2 = 0.5$ ms |	**1**
3.2	$\tau_1 = R\,C_1$, so $C_1 = \frac{\tau_1}{R}$: $C_1 = \frac{5\times10^{-3}}{100}$ thus $C_1 = 5\times10^{-5}$ F = 50 µF $\tau_2 = R\,C_2$, so $C_2 = \frac{\tau_2}{R}$; $C_2 = \frac{0.5\times10^{-3}}{100}$ thus $C_2 = 0.5\times10^{-5}$ F = 5 µF	**1**
3.3	As the capacitance increases , the duration of discharging increases	**0.5**

Exercise 3 (5.5 pts)	Characteristics of a coil	
Part	**Answer**	**Mark**
1.1	$e = -L\frac{di}{dt}$	**0.25**
1.2.1	• Statement 1 : During this interval i = constant, so $\frac{di}{dt} = 0$ thus e = 0, The voltage across the coil $u_{AB} = ri - e = ri$ The coil acts as a resistor of resistance r. • Statement 2 : i varies with time so $e \neq 0$ therefore e exists this implies that a phenomenon of self-induction appears in the circuit. • Statement 3 : i decreases, then $W_{mag} = \frac{1}{2}Li^2$ decreases Or $e.i > 0$, then it acts as a generator	**1.5**
1.2.2	Between 2 ms and 4 ms : e = 10 V $\frac{di}{dt} = \text{slope} = \frac{0-1}{4\times10^{-3}-2\times10^{-3}} = -500$ A/s $e = -L\frac{di}{dt}$ so : $10 = -L(-500)$, thus L = 0.02 H = 20 mH	**0.75**
1.2.3	$u_{AB} = ri - e$; at t = 3 ms : $-5 = r(0.5) - 10$ $0{,}5\,r = 10 - 5 = 5$, then r = 10 Ω	**0.5**
2.1	$u_g = u_L$; $E = ri + L\frac{di}{dt}$;	**0.5**
2.2	in steady state : $i = I_m$; and $\frac{di}{dt} = 0$ so $E = r\,I_m$, thus $I_m = \frac{E}{r}$	**0.5**
2.3	$I_m = 2$ A ; $2 = \frac{20}{r}$, then r = 10 Ω	**0.25**
2.4	$E = r\,i + L\frac{di}{dt}$, then $\frac{di}{dt} = E - r\,i$; At $t_0 = 0$: i = 0 then $\left.\frac{di}{dt}\right)_{t_0=0} = \frac{E}{L}$	**0.5**
2.5	Slope of the tangent $= \frac{2}{2\times10^{-3}} = 1000$ A/s But, slope of the tangent = $\left.\frac{di}{dt}\right)_{t_0=0} = \frac{E}{L}$; So, $1000 = \frac{20}{L}$, then L = 0.02 H = 20 mH	**0.75**

Exercise 4 (4 pts)	Diameter of a fishing line	
Part	**Answer**	**Mark**
1.1	We observe on the screen: ✓ Alternating bright and dark fringes; ✓ The central bright fringe is the most intense and has a width double that of the other bright fringes; ✓ The direction of the fringes is perpendicular to the direction of the slit.	**0.75**
1.2	$\sin\theta_1 \approx \theta_1 = \dfrac{\lambda}{a}$	**0.25**
1.3	$\tan\theta_1 = \dfrac{L/2}{D}$, then $\theta_1 = \dfrac{L}{2D}$; $\dfrac{\lambda}{a} = \dfrac{L}{2D}$; thus, $L = \dfrac{2\lambda D}{a}$	**1**
2.1	$\dfrac{\lambda}{a} = \dfrac{L_1}{2D_1} = \dfrac{L_2}{2D_2}$; $\dfrac{L_2}{L_1} = \dfrac{D_2}{D_1} = \dfrac{D+0.5}{D}$ $\dfrac{L_2}{L_1} = \dfrac{D+0.5}{D}$, so $\dfrac{19.5}{13} = \dfrac{D+0.5}{D}$ then 19.5 D = 13 D + 6.5 ; thus D = 1 m	**1**
2.2	$a = \dfrac{2\lambda D}{L_1}$ then $a = \dfrac{2\times 650\times 10^{-9}\times 1}{1.3\times 10^{-2}}$; a = 0.1 mm	**0.5**
2.3	The chosen line is not suitable to catch the trout fish of size 50 to 55 cm. Because the diameter of the line is less than 0.18 mm.	**0.5**

مسابقة في مادة الفيزياء	الاسم:
المدة: ساعتان ونصف	الرقم:

<u>This exam is formed of four obligatory exercises in four pages.</u>
<u>The use of non-programmable calculator is recommended.</u>

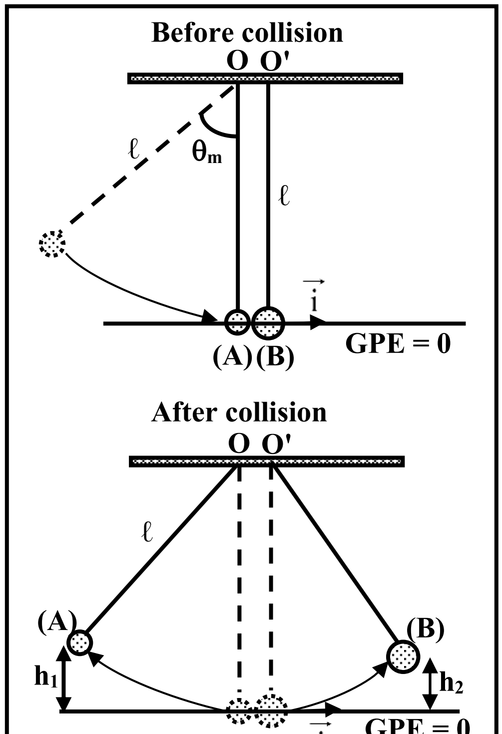
Exercise 1 (5.5 pts)

Collision

Consider two simple pendulums (S_1) and (S_2):

- pendulum (S_1) is formed of a sphere (A), taken as a particle of mass m_1, suspended to the lower extremity of a light inextensible string of length ℓ. The upper extremity of the string is fixed, at O, to a support;
- pendulum (S_2) is formed of a sphere (B), taken as a particle of mass $m_2 > m_1$, suspended to the lower extremity of a light inextensible string of same length ℓ. The upper extremity of the string is fixed, at O', to the same support of (S_1).

The two strings are vertical and the two particles touching each other (Doc. 1).



Doc. 1

Neglect air resistance and friction around O and O'.

Take:

- the horizontal plane passing through the lowest positions of (A) and (B) as a reference level for gravitational potential energy;
- $g = 10\ m/s^2$.

1) The pendulum (S_1) is shifted in the vertical plane by an angle θ_m from its stable equilibrium position, the string remains taut, and then (A) is released from rest. Determine, in terms of g, ℓ and θ_m, the expression of the speed v_1 of (A) when the pendulum (S_1) passes through the equilibrium position.

2) When (S_1) passes through the equilibrium position, (A) makes a head-on elastic collision with (B). Determine, in terms of m_1, m_2 and v_1, the expressions v'_1 and v'_2 of the algebraic values of the velocities $\vec{v'_1}$ and $\vec{v'_2}$ of (A) and (B) respectively just after this collision.

3) Specify the signs of v'_1 and v'_2.

4) P'_1 and P'_2 are respectively the algebraic values of the linear momentum of (A) and (B) just after this collision:

$P'_1 = \frac{-2}{75}$ kg.m/s and $P'_2 = \frac{1}{15}$ kg.m/s.

4.1) Determine the algebraic value of the linear momentum P_1 of (A) just before this collision.

4.2) Deduce the value of the angle θ_m if $\ell = 40$ cm and $m_1 = 20$ g.

5) The maximum heights attained by (A) and (B) after this collision are h_1 and h_2 respectively (Doc. 1).

5.1) Determine the expression of h_1 in terms of v'_1 and g.

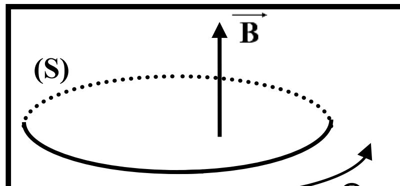
5.2) Write the expression of h_2 in terms of v'_2 and g.

5.3) Determine the ratio $\frac{m_1}{m_2}$ such that: $h_1 = h_2$.

Exercise 2 (5 pts)

Induction plate

Consider a circular closed loop (S), of diameter d = 4 cm and of resistance R = 1 mΩ. The plane of the loop, placed horizontally, is perpendicular to a uniform magnetic field $\vec{B}$ (Doc. 2).



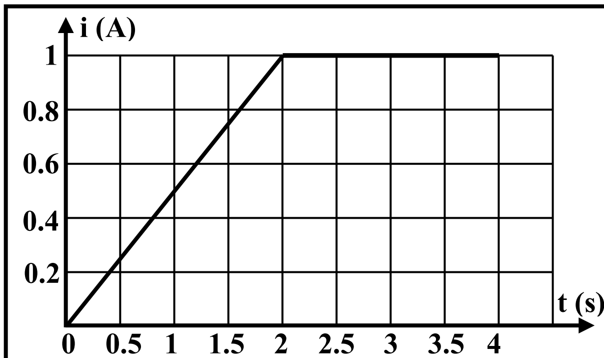
Doc. 2

The magnetic field $\vec{B}$ is created by a current « i ».
Document 3 shows « i » as a function of time.
The magnitude of the magnetic field is given by: B = 0.01 i (B in T and i in A)

1) Show that, taking into consideration the positive direction shown in document 2, the expression of the magnetic flux that crosses (S) is:

1.1) $\phi = 2\pi \times 10^{-6}\, t$ (ϕ in Wb and t in s) for $t \in [0 ; 2\text{ s}]$;

1.2) $\phi = 4\pi \times 10^{-6}$ Wb for $t \in \,]2\text{ s} ; 4\text{ s}]$.



Doc. 3

2) Deduce the value of the induced electromotive force « e » that appears in (S) during each of the two intervals: [0; 2 s[and]2 s; 4 s].

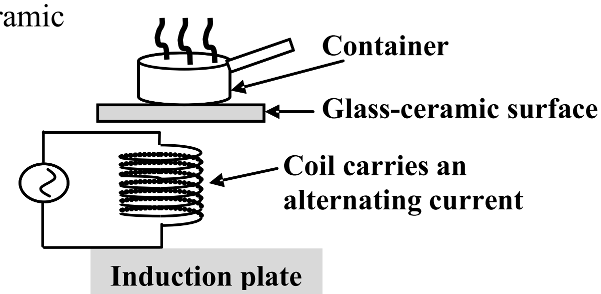
3) The electric energy produced in (S) is totally converted into thermal energy « E ».

3.1) Specify the time interval during which there is release of thermal energy in (S).

3.2) Determine, during this interval, the value of the released thermal energy « E », knowing that the induced current in (S) is given by: $i_1 = \dfrac{e}{R}$.

4) The induction plates are one of the applications for the production of thermal energy based on the principle of electromagnetic induction (Doc. 4).

In this type of plates, a coil is placed under a glass ceramic surface. When the coil carries a variable alternating current of an adjustable frequency f between 50 Hz and 50 kHz, it generates a variable magnetic field which, in turn, induces electric currents in the metallic bottom of the container, which produces thermal energy (heat) by Joule's effect.



Doc. 4

4.1) Referring to document 4, indicate the part that acts as the inducing source and the one that acts as the induced circuit.

4.2) The bottom of the container is modeled by a circular loop similar to (S). Explain the existence of an induced current in the bottom of the container.

4.3) The average total power produced in the bottom of the container is given by :

$$P = k\,(2\pi f)^2 \text{ (k is a positive constant).}$$

Determine the factor by which the power P will be multiplied if the frequency f becomes 100 times greater.

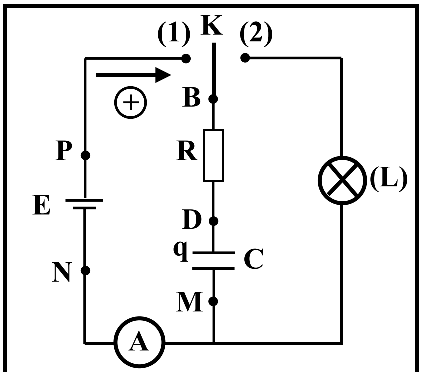
Exercise 3 (5 pts)

Duration of the brightness of a lamp

The aim of this exercise is to study the duration of brightness of a lamp on the ceiling of a car.

For this purpose, we set up the circuit of document 5 that includes:

- an ideal battery of electromotive force E = 12 V;
- a resistor of resistance R;
- a capacitor, initially uncharged, of capacitance C;
- an ammeter (A) of negligible resistance;
- a lamp (L) of negligible resistance;
- a double switch K.



Doc. 5

1) Charging the capacitor

At instant $t_0 = 0$, K is in position (1) and the charging process of the capacitor starts.

At an instant t, the plate D of the capacitor carries a charge q and the circuit carries a current i.

The differential equation that describes the variation of the current i is: $R\frac{di}{dt} + \frac{1}{C}i = 0$.

1.1) Verify that $i = \frac{E}{R}e^{\frac{-t}{RC}}$ is a solution of the differential equation.

1.2) Deduce the expression of i at $t_0 = 0$.

1.3) Calculate the value of R, knowing that at $t_0 = 0$, the ammeter indicates 1.2 mA.

1.4) Apply the law of addition of voltages to prove that $q = EC - EC\,e^{\frac{-t}{RC}}$.

1.5) When the capacitor is fully charged, the charge of plate D is $Q = 12\times10^{-4}$ coulomb.
Show that C = 100 μF.

1.6) Calculate the value of the time constant τ of the circuit during charging the capacitor, knowing that τ = RC.

2) Discharging the capacitor

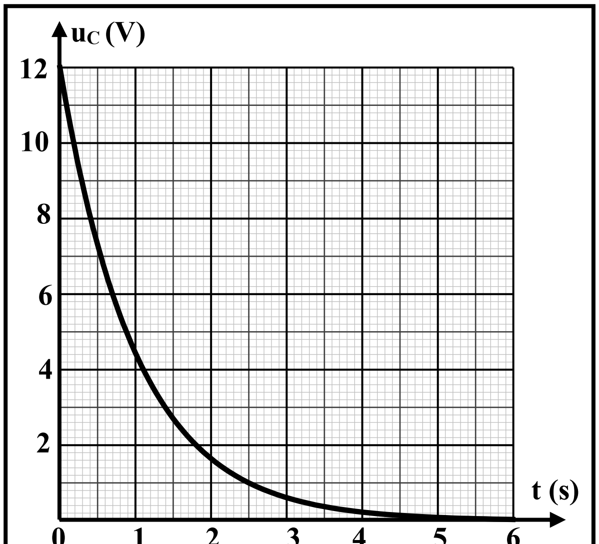
The circuit in document 5 represents a model circuit, used to turn on a lamp in the ceiling of a car.

Initially the switch is in position (1) and the capacitor is fully charged, when the door of the car is opened and then closed, the switch is turned to position (2).

Thus the capacitor discharges through the resistor and the lamp.

During discharging the brightness of the lamp decreases gradually.

Document 6, shows the voltage $u_{DM} = u_C = E\,e^{\frac{-t}{\tau'}}$ as a function of time.



Doc. 6

2.1) Using document 6, determine the value of the time constant τ' of the circuit during the discharging of the capacitor.

2.2) τ = τ'. Why?

2.3) The lamp glows as long as $u_C \geq 1$ V.
Referring to document 6, indicate how long the lamp glows during the dicharging of the capacitor.

2.4) Specify how the value of C should be varied in order to increase this duration.

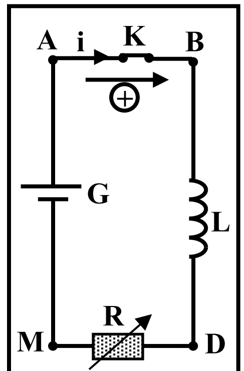
Exercise 4 (4.5 pts)

Inductance of a coil

The aim of this exercise is to determine the inductance L of a coil. For this purpose, we set up the series circuit represented in document 7.

This series circuit is composed of: an ideal battery (G) of electromotive force $E = 6$ V, a switch K, a resistor of adjustable resistance R, and a coil of inductance L and of negligible resistance.

Switch K is closed at $t_0 = 0$. At an instant t, the circuit carries a current i.

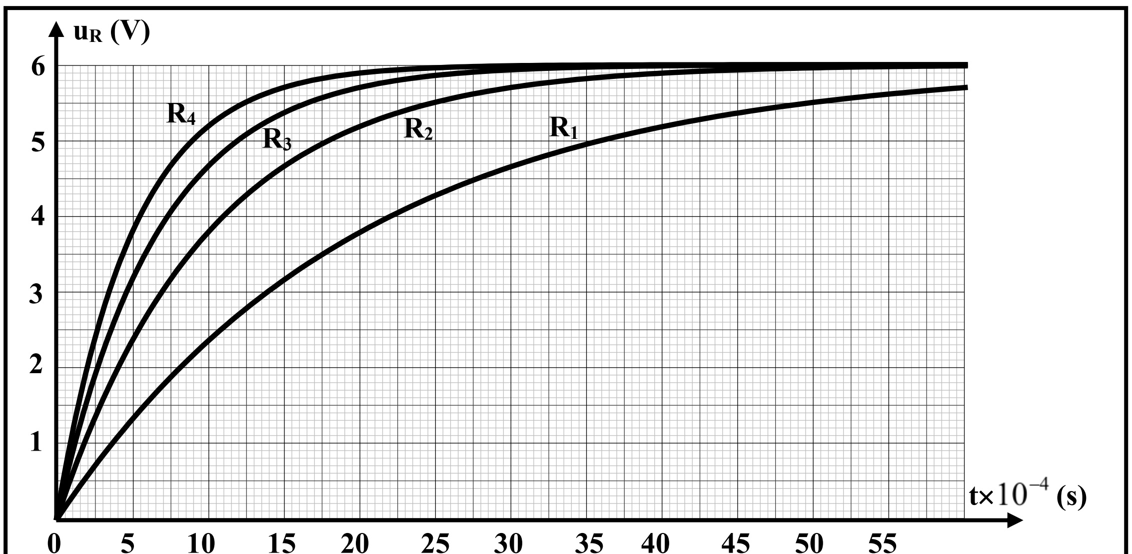


Doc. 7

1) Show that the first order differential equation that describes the variation of the voltage $u_R = u_{DM}$ across the resistor is given by: $E = \frac{L}{R}\frac{du_R}{dt} + u_R$.

2) The solution of this differential equation has the form: $u_R = a + b\, e^{\frac{-t}{\tau}}$ where a, b and τ are constants. Determine the expressions of a, b and τ in terms of R, E and L.

3) Document 8 shows u_R as a function of time for four different values of R:
$R_1 = 50\ \Omega$, $R_2 = 100\ \Omega$, $R_3 = 150\ \Omega$ and $R_4 = 200\ \Omega$



Doc. 8

3.1) Using document 8, determine, for each value of R, the value of the time constant τ of the R-L circuit.

Value of R	$R_1 = 50\ \Omega$	$R_2 = 100\ \Omega$	$R_3 = 150\ \Omega$	$R_4 = 200\ \Omega$
Time constant τ (s)	$\tau_1 =$	$\tau_2 =$	$\tau_3 =$	$\tau_4 =$

3.2) Verify that $R_1\tau_1 = R_2\tau_2 = R_3\tau_3 = R_4\tau_4$.

3.3) Deduce the value of L.

مسابقة في مادة الفيزياء
أسس التصحيح

Exercise 1 (5.5 pts)	Collision	
Part	**Answer**	**Note**
1	No friction (or the work done by the nonconservative force is zero), the mechanical energy of the system [(S_1), Earth] is conserved. $(ME)_{\theta=\theta m} = (ME)_{\theta=0}$, So, $(KE + GPE)_{\theta=\theta m} = (KE + GPE)_{\theta=0}$ then $(GPE)_{\theta=\theta m} = (KE)_{\theta=0}$ $m_1 g\ell(1-\cos\theta) = \frac{1}{2} m_1 v_1^2$, this implies $v_1 = \sqrt{2g\ell(1-\cos\theta_m)}$	0.75
2	During collision, linear momentum is conserved. $\vec{P}_{\text{just before collision}} = \vec{P}_{\text{just after collision}}$; $m_1 \vec{v}_1 = m_1 \vec{v'}_1 + m_2 \vec{v'}_2$ Collinear velocities, Project along $\vec{i}$ (algebraic values): $m_1 v_1 = m_1 v'_1 + m_2 v'_2$, so $m_1 (v_1 - v'_1) = m_2 v'_2$ ….. Eq. (1) Elastic collision, kinetic energy is conserved: $KE_{\text{before collision}} = KE_{\text{after collision}}$ $\frac{1}{2} m_1 v_1^2 = \frac{1}{2} m_1 v_1'^2 + \frac{1}{2} m_2 v_2'^2$, so $m_1 (v_1^2 - v_1'^2) = m_2 v_2'^2$ ….. Eq. (2) Divide Eq. (2) by Eq. (1): $\frac{m_1(v_1^2 - v_1'^2)}{m_1(v_1 - v'_1)} = \frac{m_2 v_2'^2}{m_2 v'_2}$, we get: $v'_2 = v_1 + v'_1$ ….. Eq. (3) Solve Eq. (1) and Eq. (3) to find v'_1 and v'_2: $v'_1 = \frac{(m_1 - m_2)v_1}{m_1 + m_2}$ and $v'_2 = \frac{2 m_1 v_1}{m_1 + m_2}$	1.25
3	$v'_1 < 0$ since $m_1 < m_2$ and v_1 is positive; so (A) moves in the negative sense (rebounds) $v'_2 > 0$ since m_1 and v_1 are positive; so, (B) moves in the positive direction	0.25 0.25
4.1	During collision, linear momentum is conserved $\vec{P}_{\text{just before collision}} = \vec{P}_{\text{just after collision}}$ Algebraic values : $P_{\text{just before collision}} = P'_1 + P'_2 = 0.04$ kg.m/s $= \frac{1}{25}$ kg. m/s	0.5
4.2	$P_{\text{just before collision}} = m_1 v_1$, so $0.04 = 0.02 \times v_1$ this implies $= 2$ m/s But $v_1 = \sqrt{2g\ell(1-\cos\theta_m)}$, so $2 = \sqrt{2\times 10\times 0.4(1-\cos\theta_m)}$ this implies $\theta_m = 60^o = 1.04$ rad	0.25 0.5
5.1	System [(S_1), Earth] ; $ME_{h=0} = ME_{h=h1}$ $(KE)_{h=0} = (GPE)_{h=h1}$; then $\frac{1}{2} m_1 v_1'^2 = m_1 g h_1$ this implies $h_1 = \frac{v_1'^2}{2g}$	0.5
5.2	$h_2 = \frac{v_2'^2}{2g}$	0.25
5.3	$h_1 = h_2$ then $v_1'^2 = v_2'^2$. But after collision, (A) and (B) moves in opposite directions. Hence $\frac{2 m_1 v_1}{m_1 + m_2} = -\frac{(m_1 - m_2)v_1}{m_1 + m_2}$. This implies, $2 m_1 v_1 = - m_1 v_1 + m_2 v_1$, So, $3 m_1 v_1 = m_2 v_1$, thus: $\frac{m_1}{m_2} = \frac{1}{3}$	1

Exercise 2 (5 points) Induction plate		
Part	**Answer**	**Note**
1.1	For $t \in [0 ; 2\ s]$: $i = 0.5\ t$ $\phi = B\times S \times \cos(\vec{B}, \vec{n}) = 0.01\ i \times\pi \times r^2\times \cos(0^o) = 0.01\times 0.5\ t \times\pi \times 0.02^2 = 2\pi \times10^{-6}\ t$ Wb	**0.25** **0.75**
1.2	For $t \in]2\ s ; 4\ s]$: $i = 1$ A $\phi = B\times S\times \cos(\vec{B}, \vec{n}) = 0.01\ i \times \pi \times r^2\times \cos(0^o) = 0.01\times 1 \times \pi \times 0.02^2 = 4\ \pi \times 10^{-6}$ Wb	**0.25** **0.5**
2	$e = -\dfrac{d\phi}{dt}$ For $t \in [0 ; 2s[$: $e = -6.3 \times10^{-6}$ V $= -2\pi \times10^{-6}$ V For $t \in]2s ; 4s]$: $e = 0$ V	**0.25** **0.25** **0.25**
3.1	There is release of thermal energy when (S) carries an induced current, that is when we have induced e.m.f , hence thermal energy is released in the interval [0 ; 2s[	**0.25**
3.2	$i_1 = \dfrac{e}{R} = \dfrac{-6.3\times10^{-6}}{0.001} = -6.3\times10^{-3}$ A $= -2\pi \times10^{-3}$ A $E = R\ i_1^2 \times t = 0.001 \times (6.3\times10^{-3})^2 \times 2 = 7.9\times10^{-8}$ J	**0.25** **0.5**
4.1	Source of induction: the coil Induction circuit : Bottom of the container	**0.25** **0.25**
4.2	When the coil carries a variable alternating current, it creates a variable magnetic field, so we have a variable flux through the bottom of the container, which induces electric current in the bottom of the metal of the container.	**0.5**
4.3	$f' = 100\ f$ $P = k\ (2\pi\ f)^2$; $P' = k\ (200\ \pi\ f)^2 = 10^4\ k\ (2\pi\ f)^2 = 10^4\ P$	**0.5**

Exercise 3 (5 points)	Duration of the brightness of a lamp	
Part	**Answer**	**Note**
1.1	$R\frac{di}{dt} + \frac{1}{C}i = 0$; $\frac{di}{dt} = -\frac{E}{R}\frac{1}{RC}e^{\frac{-t}{RC}}$, replace i and $\frac{di}{dt}$ in the differential equation $-R\frac{E}{R}\frac{1}{RC}e^{\frac{-t}{RC}} + \frac{1}{C}\frac{E}{R}e^{\frac{-t}{RC}} = 0$ thus $-\frac{E}{RC}e^{\frac{-t}{RC}} + \frac{1}{C}\frac{E}{R}e^{\frac{-t}{RC}} = 0$; $0 = 0$ (verified)	**1**
1.2	At $t_0 = 0$; $i_0 = \frac{E}{R}$	**0.25**
1.3	$1.2 \times 10^{-3} = \frac{12}{R}$ so $R = 10\,000\ \Omega = 10\ k\Omega$	**0.25**
1.4	$E = u_R + u_C$; $E = Ri + \frac{q}{C}$; $E = E\,e^{\frac{-t}{RC}} + \frac{q}{C}$; $E - E\,e^{\frac{-t}{RC}} = \frac{q}{C}$; thus, $q = EC - EC\,e^{\frac{-t}{RC}}$	**1**
1.5	$Q = EC = 12\times10^{-4}$ C so $C = 1 \times 10^{-4}$ F = 100 μF.	**0.25**
1.6	$\tau = RC = 10\,000 \times 1 \times 10^{-4} = 1$ s	**0.25**
2.1	At $t = \tau'$, we have $u_C = 0.37\times12 = 4.44$ V which corresponds for $\tau' = 1$s	**0.75**
2.2	Since $\tau = RC$, C is the same and R is the same; while the lamp has negligible resistance, Then, $\tau = \tau'$.	**0.5**
2.3	$U_C = 1$ V for t = 2.5 s	**0.25**
2.4	To increase t, C must be increased because when C increases, τ increases. The capacitor takes more time to reach the voltage of 1 V.	**0.5**

Exercise 4 (4.5 pts) **Inductance of a coil**		
Part	**Answer**	**Note**
1	$u_{AM} = u_{AB} + u_{BD} + u_{DM}$ $E = L\frac{di}{dt} + u_R$; $u_R = Ri$ and $\frac{di}{dt} = \frac{1}{R}\frac{du_R}{dt}$ so $E = \frac{L}{R}\frac{du_R}{dt} + u_R$	**0.75**
2	$u_R = a + b\,e^{\frac{-t}{\tau}}$; $\frac{du_R}{dt} = -\frac{b}{\tau}\,e^{\frac{-t}{\tau}}$ Replace in the differential equation : $E = \frac{-Lb}{R\tau}\,e^{\frac{-t}{\tau}} + a + b\,e^{\frac{-t}{\tau}}$ $b\,e^{\frac{-t}{\tau}}\,[\frac{-L}{R\tau} + 1] + a = E$ By comparison: $a = E$ and $\tau = \frac{L}{R}$ At $t = 0$, $i = 0$, so $u_R = 0$ and $a = -b$ thus $b = -E$	**1**
3.1	Graphical method to determine the time constant τ. At $t = \tau$ we have $u_R = 0.63\times6 = 3.78 \cong 3.8$ V ; From the graph for each value of R we get τ : R: $R_1 = 50\ \Omega$; $R_2 = 100\ \Omega$; $R_3 = 150\ \Omega$; $R_4 = 200\ \Omega$ τ (s): $\tau_1 = 20\times10^{-4} = 0.002$ s; $\tau_2 = 0.001$ s; $\tau_3 = 0.0006$ s; $\tau_4 = 0.0005$ s	**0.5** **1**
3.2	Since, $R_1\tau_1 = 0.1$; $R_2\tau_2 = 0.1$; $R_3\tau_3 = 0.09 \cong 0.1$; and $R_4\tau_4 = 0.1$ (SI unit) Thus, $R_1\tau_1 = R_2\tau_2 = R_3\tau_3 = R_4\tau_4 \cong 0.1$ (S.I.)	**0.5**
3.3	Since $\tau = \frac{L}{R}$ so $R\,\tau = L$ this implies $L = 0.002\times50 = 0.1$ H	**0.75**

These files have been meticulously arranged by the 'Together We Can' team,

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