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المديرية العامة للتربية | فرع العلوم العامة
دائرة الامتحانات

مسابقة في الفيزياء | الاسم :
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This exam is formed of four obligatory exercises in four pages
The use of non-programmable calculators is allowed

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
Δ t (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
Δ t (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.

Second Exercise (6 points) Energy levels of the hydrogen atom

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

$$E_n = -\frac{13.6}{n^2} \text{ (in eV)}$$ where n 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.

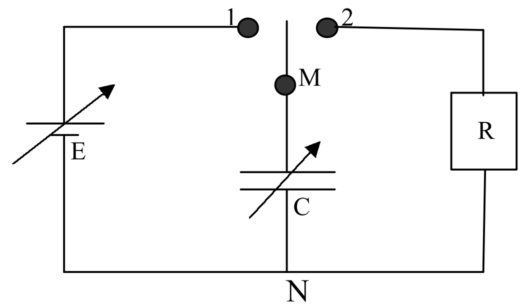
C - Interaction photon - hydrogen atom

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.

<u>Third Exercise</u> (7 points) <u>Saving life capacitor</u>

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.

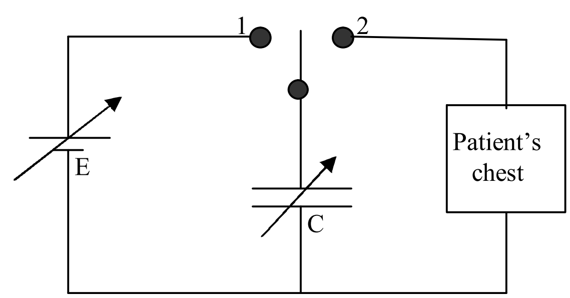
b) The expression $u_C = A\,e^{-\frac{t}{\tau}}$, where A and τ are constants , is a solution of that equation. Determine the expressions of A and τ in terms of E, R and C.

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.

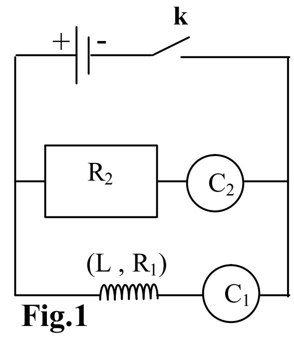


Fig.1

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.

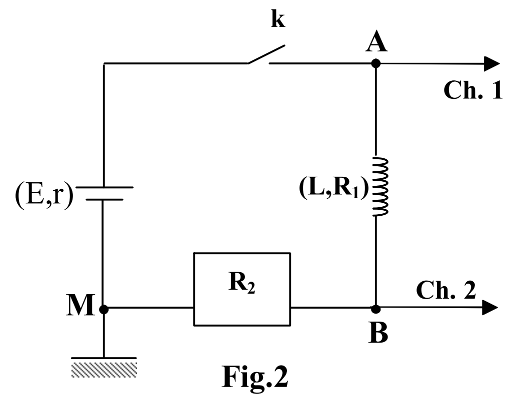


Fig.2

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.

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

5) Calculate L.

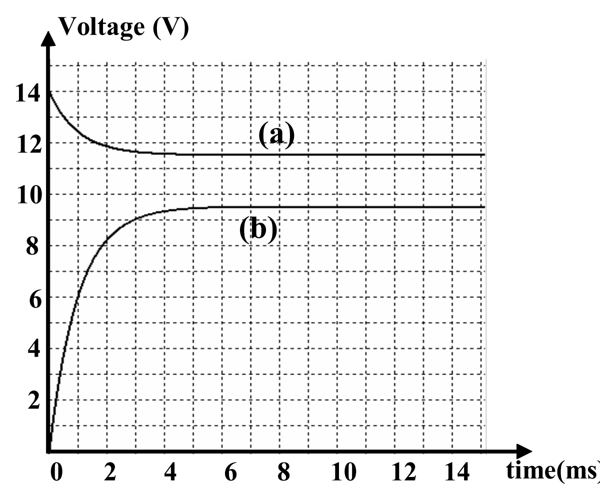


Fig.3

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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

$\Rightarrow$ The values of energies are discontinous.

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

b) Second excited state corresponding to n = 3 $\Rightarrow$ E_3 = -1.51 eV.

3 – Ionize state

B) 1 – a) $E = \frac{hc}{\lambda}$ or E is inversely prop. to $\lambda \Rightarrow \lambda_1$= 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 $\Rightarrow$ 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 $\Rightarrow$ not absorbed

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

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

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

<u>Third exercise :</u>

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 ;

$u_C = Ee^{-\frac{t}{\tau}} \Rightarrow t = 6.2$ 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 – $u_{AM} = u_{AB} + u_{BM} \Rightarrow E - ri = R_1\, i + L\frac{di}{dt} + R_2\, i \Rightarrow E = Ri + L\frac{di}{dt}$

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

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

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

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

B) II – 1 – a) $u_1 = u_{AM}$

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

2 – a) $u_2 = u_{BM}$

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

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 $I_{max} = \frac{u_{2\max}}{R_2} = \frac{9.5}{100} = 95\times10^{-3}$ A

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

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

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