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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.

Second Exercise (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.

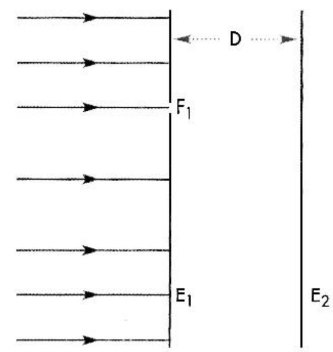


fig. 1

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.

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.

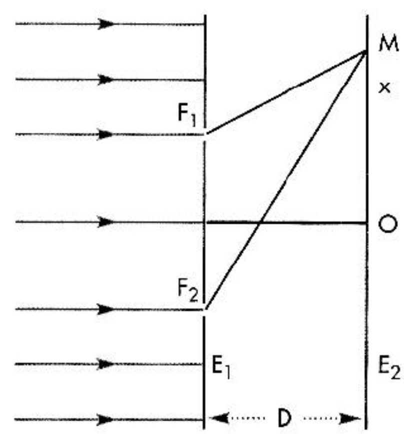


fig. 2

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.

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

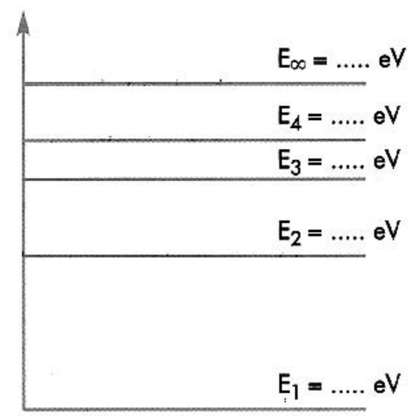
Given:

- 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.

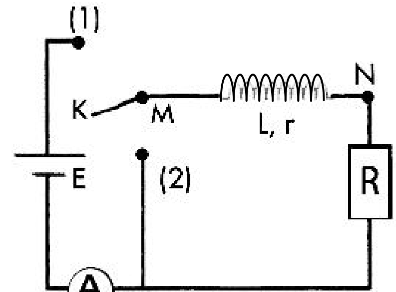


fig. 1

A- We place the coil in a circuit formed of: a resistor of resistance R = 50 Ω, 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 = τ.

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.

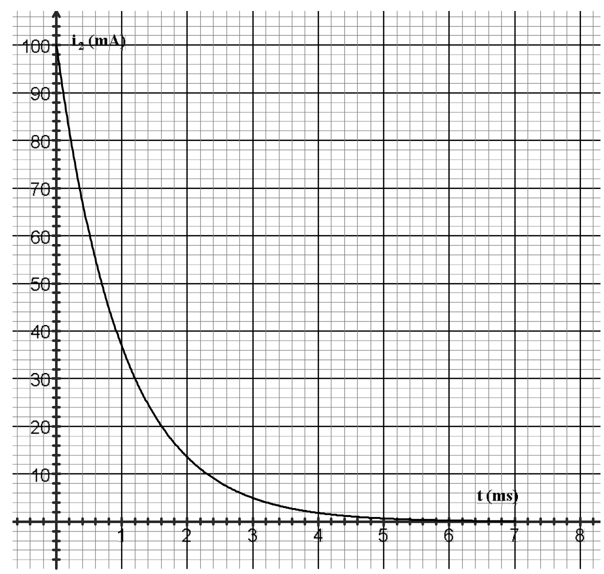


fig. 2

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 μF all in series across the terminals of a low frequency generator delivering a sinusoidal voltage of frequency f (fig. 3)

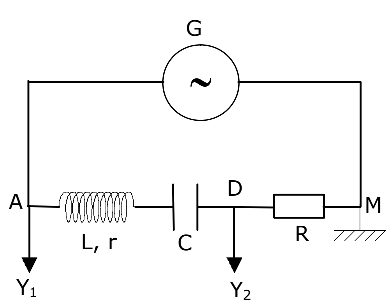


fig. 3

Horizontal sensitivity: 2 ms/div.

Vertical sensitivity on channel Y_1: 2 V/div.

Vertical sensitivity on channel Y_2: 5 V/div.

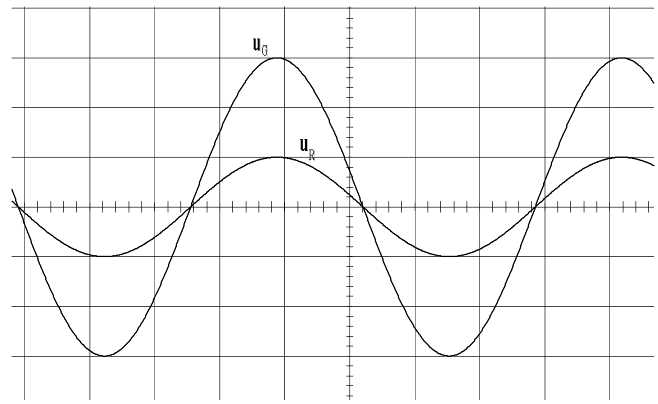


fig. 4

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)

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

(1.5 pts)

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

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

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

(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, $\theta_1 = \frac{1\times\lambda}{a_1}$.

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

(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)

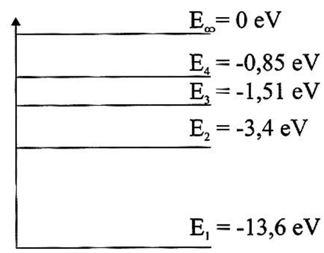
Third Exercise (6 ½ points)

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)