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.

First exercise: (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.

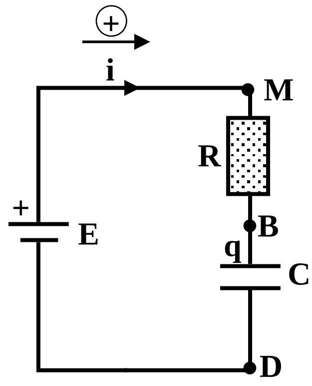


Fig. 1

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 τ = 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 ≈ 641 μF.

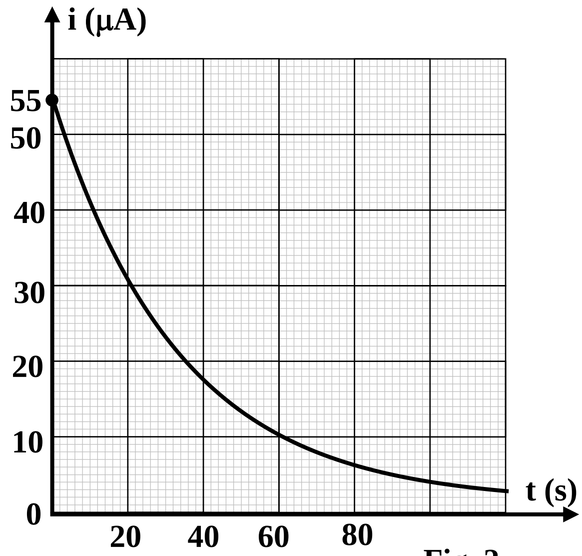


Fig. 2

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.

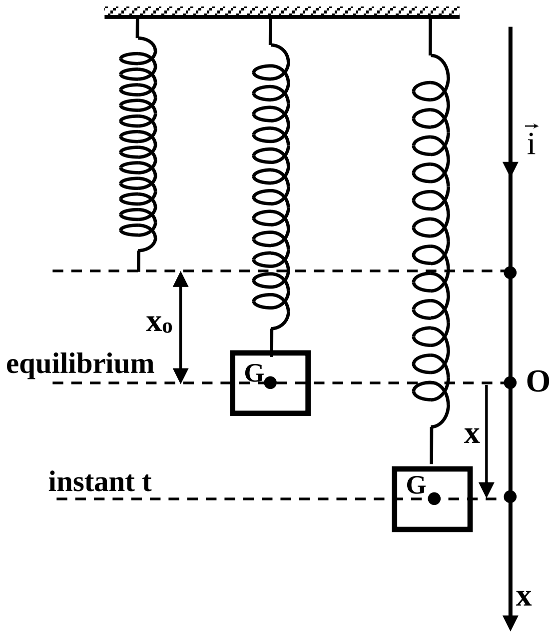
<u>Second exercise</u>: (7 points)

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.

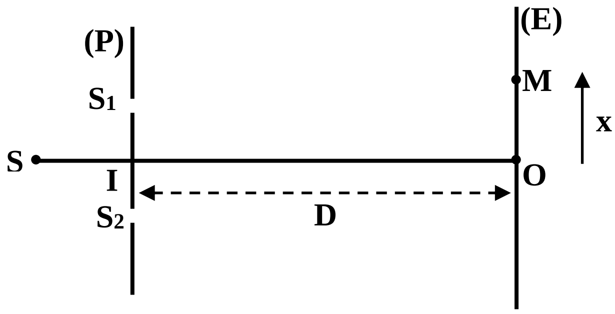
Scale : on the abscissa-axis: 1cm represents 0.16 s^2
on the ordinate –axis: 1cm represents 4 cm.

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.

Third exercise: (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)

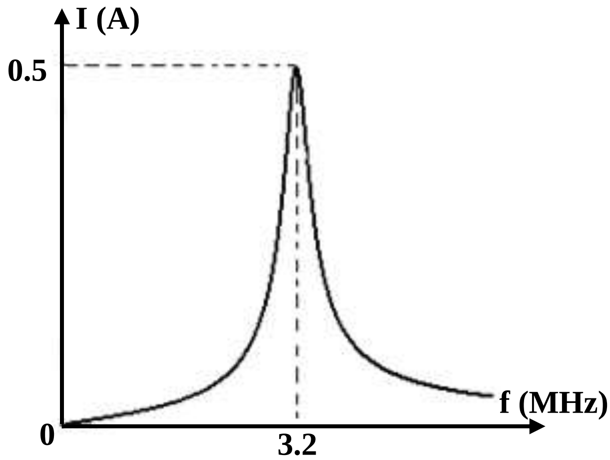
Electric resonance: danger and utilization

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 $C = 5\times10^{-10}$ 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 Ω and $L = 5\times10^{-6}$ 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 $c = 3\times10^8$ m/s.

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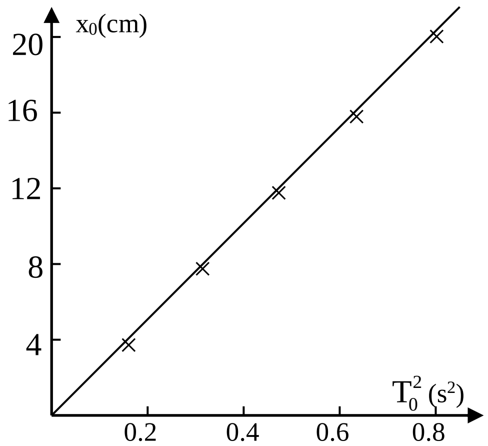
مشروع معيار التصحيح	مسابقة في مادة الفيزياء المدة ثلاث ساعات	الاسم: الرقم:

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	$W_2 = ½\ C\,U_0^2 = 28.845 J \Rightarrow P_2 = \frac{W_2}{t} = 28845$ 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: δ = (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