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مسابقة في مادة الفيزياء
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الرقم:

This exam is formed of three exercises in four pages numbered from 1 to 4.

<u>The use of non-programmable calculator is recommended</u>

<u>First exercise</u> (*7 ½ pts*) **Mechanical Oscillator**

Consider a mechanical oscillator formed of a solid (S) of mass m and whose center of inertia is G and a spring of negligible mass of un-jointed turns whose stiffness is k.

(S) may slide on a horizontal rail; the position of G on the horizontal axis $\overrightarrow{Ox}$ is defined relative to the origin O, the position of G when (S) is in the equilibrium position (Fig.1).

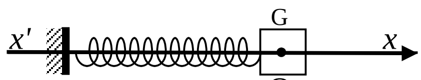

Fig.1

An apparatus is used to record the variations of the abscissa x of G and the algebraic measure v of its velocity as a function of time.

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

The object of this exercise is to compare the values of certain physical quantities associated with the motion of the oscillator in two situations.

A – First situation

The solid performs oscillations and the mechanical energy M.E of the system (oscillator, Earth) keeps a constant value M.E $= 64 \times 10^{-3}$ J.

The recording apparatus gives the curves represented in figures (2) and (3).

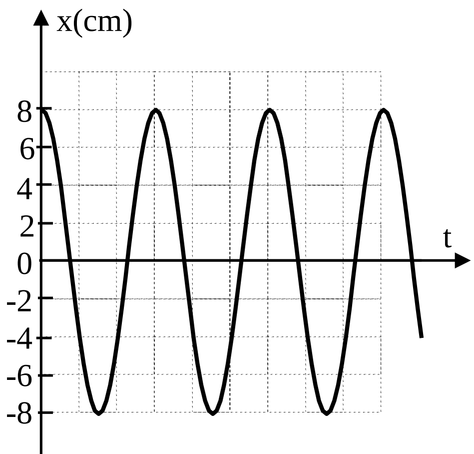

Fig.2

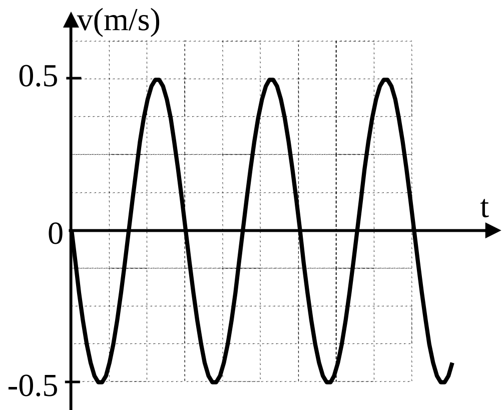

Fig.3

1) Refer to figures (2) and (3).

a) Indicate the type of oscillations of (S).

b) Specify : ***i)*** the abscissa x_0 and the value v_0 of the velocity at the instant $t_0 = 0$;

ii) the value of X_m, the amplitude of the oscillations and the maximum value V_m of the velocity;

iii) the direction of motion of G when it passes through the origin O for the first time.

2) Applying the principle of conservation of mechanical energy, show that:

a) the stiffness of the spring has a value k = 20 N/m ;

b) the mass of (S) has a value m = 512 g.

3) **a)** Write the expression of the mechanical energy of the system (oscillator, Earth) in terms of m, v, k and x.

b) Determine the second order differential equation in x which describes the motion of G.

c) Deduce the expression of the proper angular frequency ω_0 in terms of k and m.

d) The solution of the second order differential equation in this situation is $x = X_m \cos(\omega_0 t + \varphi)$ where φ is a constant. Determine the value of φ.

B- Second situation

The solid (S), now shifted by a distance x_{o1} from its equilibrium position, is launched, at the instant $t_o = 0$, in the positive direction with an initial velocity of magnitude v_{o1}. The apparatus thus records the variations of the abscissa x as a function of time (fig.4)

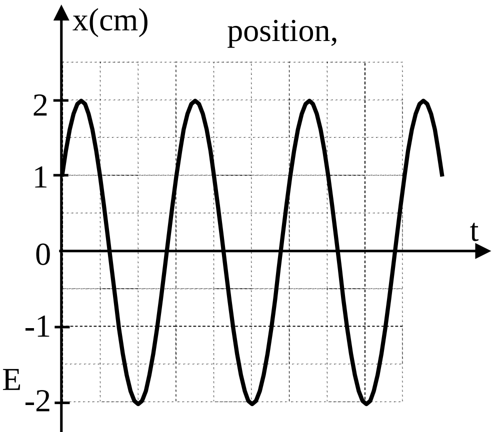

Fig.4

1) Referring to figure 4 :

a) give the value of x_{o1} of G and that of the amplitude X_{m1} of motion.

b) show that the mechanical energy $M.E_1$ of the system (oscillator, Earth) does not vary with time;

c) show that the value of $M.E_1$ is different from that of M.E given in the first situation.

2) Calculate the value of the elastic potential energy of the oscillator at $t_0 = 0$ and determine the value of v_{o1}.

3) The value of ω_0 is the same in both situations. Why?

4) The solution of the second order differential equation in this situation is $x_1 = X_{m1} \cos(\omega_0 t + \varphi_1)$. Show that the value of φ_1 is different from that of φ.

<u>Second exercise</u> (6 ½ *pts*) Usage of a Coil

A-First experiment

A bar magnet may be displaced along the axis of a coil whose terminals A and C are connected to a resistor of resistance R.

We approach the north pole of the magnet towards the face A of the coil (Fig.1). An induced current i is carried by the circuit.

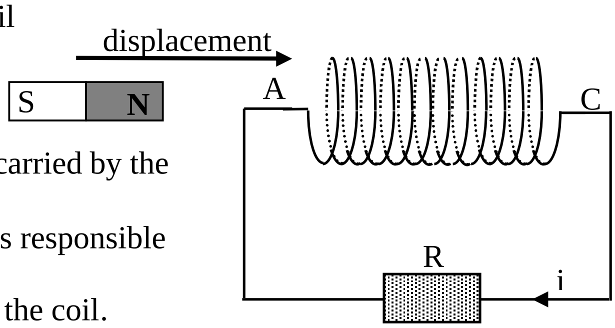

Fig.1

1) Give the name of the physical phenomenon that is responsible for the passage of this current.

2) Give, with justification, the name of each face of the coil.

3) The induced current passes from C to A through the resistor. Why?

4) Determine the sign of the voltage u_{AC}.

B- Second experiment

A coil of inductance L = 0.01H and of negligible resistance is connected in series with a resistor of resistance R across a generator G (Fig.2). The coil thus carries a current i that varies with time as shown in figure 3.

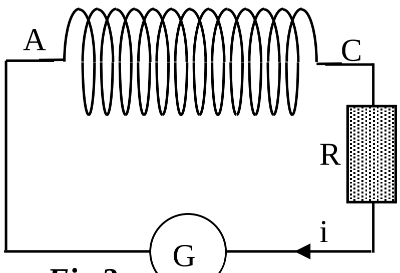

Fig.2

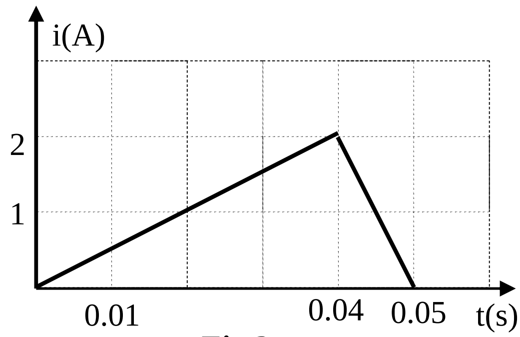

Fig.3

1) Give the name of the physical phenomenon that takes place in the coil.
2) Determine the voltage u_{AC} in each of the two intervals: [0; 0.04s] and [0.04s; 0.05s].

C- Third experiment

1) The Fig. 4 represents the diagram of a loaded transformer. The generator delivers an alternating sinusoidal voltage of frequency f .The coil (1) carries an alternating sinusoidal current i_1 of frequency f. The coil (2) thus carries an alternating sinusoidal current i_2 having the same frequency f.
Explain the existence of the current in coil (2).

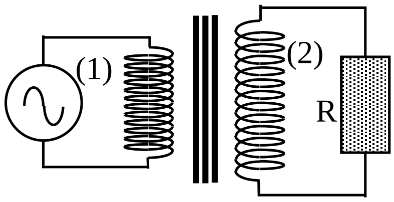

Fig.4

2) The object of this part is to show evidence of the role of a transformer in the transmission of electric energy.
An electric generator G delivers a power P = 20 kW under an alternating sinusoidal voltage of effective value U.
A transmission line of total resistance r = 1Ω feeds an electric installation (B).
Let I be the effective current that passes in the line. The power factor of the system formed of the line and the installation is $\cos\varphi = 0.95$.

a) Give the expression of the power P in terms of U, I and cosφ.

b) i) Give the expression of the power P′ lost in the line due to Joule's effect in terms of P, r, cosφ and U.

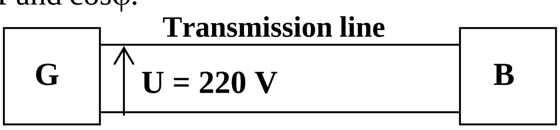

Fig.5

ii) Calculate P′ in the case when U = 220 V (Fig.5)

iii) A transformer, connected across the generator, raises the effective value of the voltage across the transmission line . The transmission of the same power P through the line thus takes place under the new effective voltage $U = 10^4$ V (Fig.6).
Calculate the new value of P′ .

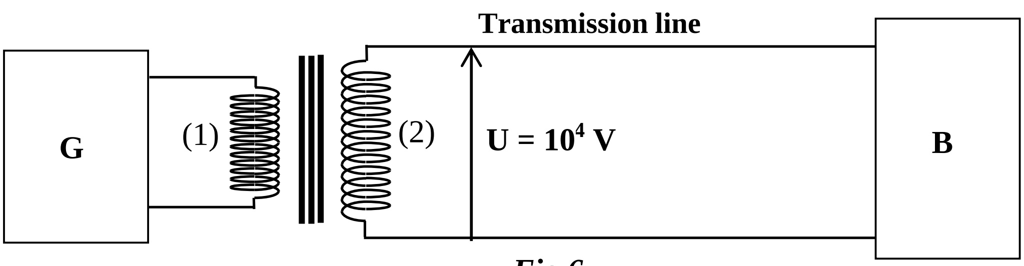

Fig.6

c) Draw a conclusion about the importance of the usage of the transformer in the transmission of electric energy over large distances.

Third exercise (6 pts) Nuclear Fusion

Given: masses of the nuclei: ${}^{2}_{1}H$: 2.0134 u ; ${}^{3}_{1}H$: 3.0160 u ; ${}^{4}_{2}He$: 4.0015 u ;

${}^{235}_{92}U$:235.12 u ; ${}^{1}_{0}n$: 1.0087 u .

1 u = 931.5 MeV/c^2 = 1.66×10^{-27} kg ; 1 MeV = 1.6×10^{-13}J.

The combustion of 1 ton of fuel oil liberates an energy of 42×10^{9}J .

The controlled nuclear fusion, if this technique is well mastered, provides enormous energetic possibilities. Nowadays, all the studies, in research centers, focus on the fusion reaction between deuterium nucleus (${}^{2}_{1}H$) and tritium nucleus (${}^{3}_{1}H$) according to the following equation:

$${}^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$$

The deuterium is abundant in nature; water is a huge reserve of this gas. The tritium is easily obtained by bombarding lithium (that exists in large quantities in minerals) by neutrons.

A - Advantages of the fusion of deuterium - tritium

1) Show that the mass defect in this reaction is: $\Delta m = 0.0192$ u.

2) Calculate, in MeV then in J, the energy liberated by this reaction.

3) Show that the energy liberated by the fusion of 1 g of a mixture formed of equal numbers of deuterium nuclei and tritium nuclei is 3.42×10^{11}J.

4) Calculate, in J, the energy liberated by the combustion of 1 g of fuel oil.

5) The fission of a uranium 235 nucleus gives, on the average, an energy of 200 MeV. Determine, in J, the energy liberated by the fission of 1 g of uranium 235.

6) Give three reasons rendering the controlled fusion a source of energy better than that of fuel oil and nuclear fission.

B - Does the fusion reaction of deuterium - tritium take place in the Sun?

The two nuclei of deuterium and tritium repel each other. In order to fuse, they must collide with very high velocities, each of the two nuclei having, before collision, a kinetic energy whose minimum value is K.E = 0.35 MeV.

1) Why do the two deuterium and tritium nuclei repel?

2) The kinetic energy of a nucleus is proportional to the temperature T of the medium in which it exists: K.E = 1.3×10^{-4} T (K.E in eV and T in K). Calculate the minimum temperature T_1 of the medium convenient for the two nuclei to undergo fusion.

3) Such fusion reaction takes place in the core of certain stars. The temperature in the core of the Sun being $T_2 = 15\times10^{6}$ K, show that this fusion reaction does not occur in the core of the Sun.

Solution

First exercise (7 ½ pts)

A- 1) a) The oscillations are **free and un-damped**. **(1/4 pt)**

b) i) At t = 0 : $x_0 = 8$ cm and $v_0 = 0$. **(1/2 pt)**

ii) $X_m = 8$ cm ; $V_m = 0.5$ m/s. **(1/2 pt)**

iii) when passes through O for the first time, v < 0

$\Rightarrow$ (S) is displaced in the negative direction. **(1/4 pt)**

2- a) $M.E = \frac{1}{2} k(X_m)^2 \Rightarrow k = 20$ N/m. **(1/2 pt)**

b) $M.E = \frac{1}{2} m (V_m)^2 \Rightarrow m = 512$ g. **(1/2 pt)**

3- a) $M.E = \frac{1}{2} m(v)^2 + \frac{1}{2}k (x)^2$. **(1/2 pt)**

b) $M.E = cte \Rightarrow (M.E)' = 0 \Rightarrow mvv' + Kxv = 0$

$\Rightarrow x'' + \frac{K}{m} x = 0$. **(1/2 pt)**

c) The differential equation has the form : $x'' + (\omega_0)^2 x = 0$

$\Rightarrow \quad (\omega_0)^2 = \frac{k}{m} \Rightarrow \omega_0 = \sqrt{\frac{k}{m}}$. **(1/2 pt)**

d) for t = 0 we have : $x = x_0 = X_m \cos\varphi \Rightarrow \cos\varphi = 1 \Rightarrow \varphi = 0$. **(1/2 pt)**

B- 1)

a) $x_{01} = 1$ cm ; $X_{max1} = 2$ cm. **(1/2 pt)**

b) because the amplitude of of the motion X_{m1} does not decrease with time. **(1/4 pt)**

c) $M.E = \frac{1}{2} k(X_m)^2$; $X_{m1} = 2$ cm and $X_m = 8$ cm $\Rightarrow M.E_1 \neq M.E$ **(1/2 pt)**

2) $P.E_0 = \frac{1}{2} k(x_{01})^2 = 10^{-3}$J **(1/4 pt);**

$\frac{1}{2} k(x_{01})^2 + \frac{1}{2} m(v_{01})^2 = \frac{1}{2} k(X_{m1})^2 = 4 \times 10^{-3}$J $\Rightarrow v_0 = 0.108$ m/s. **(3/4 pt)**

3) since the angular frequency does not depend on the initial conditions, it depends on m and k only **(1/4 pt)**

4) In situation A, we have : $\cos\varphi = \frac{x_0}{X_m} = \frac{8}{8} = 1 \quad (\varphi = 0)$

In situation B , we have : $\cos\varphi_1 = \frac{x_{01}}{X_{m1}} = \frac{1}{2} \quad (\varphi_1 = -\frac{\pi}{3}\text{rad})$

$\Rightarrow \varphi_1 \neq \varphi$ **(1/2pt)**

Second exercise (6 ½ pts)

A- 1) Electromagnetic induction. **(1/4 pt)**

2) In order to oppose , by repulsion the approach of the N-pole of the magnet. (Lenz's law), A is the North face , B is the South face. **(1/2pt)**

3) The induced magnetic field $\vec{B}_i$ opposes the increase of $\vec{B}$ of the magnet thus it has a sign opposite to that of $\vec{B}$, the induced current thus passes from C to a through the resistor **(1/2 pt)**

4) A is the negative pole of the equivalent generator $\Rightarrow u_{AC} < 0$. **(1/2pt)**

B- 1) Self-induction. **(1/4pt)**

2) $u_{AC} = L\frac{di}{dt}$ **(1/4 pt)**

for $0 \le t \le 0.040$ s, $\frac{di}{dt} = \frac{2}{0.04} = 50 A/s \Rightarrow u_{AC} = 0.01 \times 50 = 0.5V.$ **(3/4pt)**

for $0.040 \le t \le 0.050$ s, $\frac{di}{dt} = -\frac{2}{0.01} = -200 A/s \Rightarrow$

$u_{AC} = 0.01 \times -200 = -2V.$ **(3/4pt)**

C-1) i_1 is variable $\Rightarrow$ A variable magnetic field $\vec{B}$ is produced in the primary.The magnitude of $\vec{B}$ has the same value in the primary and in the secondary at any instant: The magnetic flux in the secondary is variable

=> the secondary is the seat of induced e.m.f,

the secondary being closed, an induced i_2 current will pass in it . **(1/2 pt)**

2) a) $P = UI\cos\varphi$. **(1/4 pt)**

b) i) $P' = rI^2 = r\left(\frac{P}{U\cos\varphi}\right)^2$. **(1/2 pt)**

ii) $P' = \frac{1 \times 4 \times 10^8}{0.9025 \times U^2} = \frac{4.4 \times 10^8}{U^2}$. if U = 220 V,

we get : $P' = 9 \times 10^3$ W **(1/2 pt)**

iii) if $U = 10^4$ V, we get a : P' = 4.4 W. **(1/2pt)**

c) The problem of the heat losses due to Joule's effect , has a solution in using high voltage in the transmission of electric energy thus we use step-up transformers. **(1/2 pt)**

3) $T_2 < T_1$ (180 times less) => The fusion deuterium- tritium cannot take place in the core of the Sun. **(1/2pt)**

Third exercise (6 pts)

A-

1) $\Delta m = m({}_1^2H) + m({}_1^3H) - [m({}_2^4H_e) + m({}_0^1n)] =$ 2,0134 +3.0160 – [4.0015 +1.0087] = 0.0192 u **(1pt)**

2) The energy liberated is due to the mass defect Δm. $E = \Delta m \times c^2 = 0.0192 \times 931.5 =$ 17.88 MeV
The energy liberated by the fusion of two nuclei is E = 17.88 MeV = 28.6×10^{-13}J. **(1pt)**

3) Each fusion requires 2.0134 + 3.0160 = 5.0294 u= 8.35×10^{-24}g of the mixture and liberates an energy $E = 28.6\times10^{-13}$J. 1 g of the mixture liberates $E' = \frac{28.6\times10^{-13}}{8.35\times10^{-24}} = 3.42\times10^{11}$ J **(1pt)**

4) The energy liberated by the combustion of 1 g of fuel oil is : $4.2.10^4$ **J** **(1/4 pt)**

5) The mass of one uranium 235 nucleus is 235.12 u = 3.9×10^{-22} g .
The energy liberated by the fission of 1 g of uranium 235 is : $\frac{3.2\times10^{-11}}{3.9\times10^{-22}} = 8.2\times10^{10}$ J **(1/2 pt)**

6) - the nuclear fusion is more energetic
- the nuclear fusion is not polluting
- The raw material is obtained easier an dis cheaper **(3/4pt)**

B - 1) Because the two nuclei are both positively charged. **(1/4pt)**

2) K.E > 0.35×10^6eV => 1.3×10^{-4} T > 0.35×10^6 => $T_{min} = T_1 = 2.7\times10^9$ K. **(3/4pt)**

3) $T_2 < T_1$ (180 times less) => The fusion deuterium- tritium cannot take place in the core of the Sun. **(1/2pt)**