This is a Class 1 exam

Lebanon Evangelical School for Boys and Girls

Lebanon Evangelical School
for Boys and Girls Loueizeh - Baabda

Stage Exam 03

16MAY2025

Do NOT write in this box. Your MARK will be placed here.

Subject :	Physics
Class :	12M
Teacher :	Mr. Ali Moukalled
Duration :	1 hour

You are to answer the questions to this exam on : Squared paper

Your name :		*Time taken to complete exam*
Your Class :		
Exam Room :		
How many sheets, including cover sheet :		

- Do not open this paper until the teacher in charge instructs you to do so.
- The most important thing to remember in taking an exam is NEVER PANIC.
- If you are caught cheating in this exam, you will be awarded zero for ALL exams that are taken on this day.

EXERCISE 1 (10 points)

Radioactivity of potassium-40

The object of this exercise is to study the decay of the potassium isotope $^{40}_{19}\mathbf{K}$, and to measure the age of a rock. For this purpose, we consider the decay of this potassium isotope into the daughter nucleus argon $^{M}_{N}\mathbf{Ar}$. This daughter nucleus could be produced in an excited state or in the ground state.
Given: mass of $^{40}_{19}\mathbf{K} = 39.953577\mathbf{u}$; $^{A}_{Z}\mathbf{X} = 5.486 \times 10^{-4}\mathbf{u}$; $1\mathbf{u} = 931.5\,\mathrm{MeV/c^2}$.

A. Decay of $^{40}_{19}\mathbf{K}$

The decay equation of potassium $^{40}_{19}\mathbf{K}$ into argon is represented as follows:

$$^{40}_{19}\mathbf{K} \longrightarrow ^{M}_{N}\mathbf{Ar} + ^{A}_{Z}\mathbf{X} + ^{0}_{0}\nu$$

1. The particle **X** is a positron. Why?
2. Determine **M** and **N** and then write the complete equation of this decay.
3. The energy liberated due to the disintegration of one nucleus of potassium-40 is $\mathbf{E = 1.5MeV}$. Deduce the mass defect in u due to one decay of potassium-40 in **u**.
4. Deduce the mass of $^{M}_{N}\mathbf{Ar}$ and then prove that $\mathbf{m}_{^{40}_{19}\mathbf{K}} \approx 1.000054\,\mathbf{m}\,^{M}_{N}\mathbf{Ar}$. (Neglect the mass of the neutrino).
5. Neglect the kinetic energy of the parent and the daughter nuclei. The energies of the positron and the neutrino in this decay are **0.48MeV** and **0.44MeV** respectively. Show that the daughter nucleus is produced in an excited state. Calculate the energy of the photon emitted by this nucleus.

B. Age of a rock

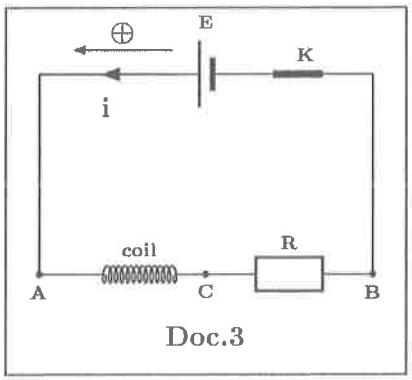
The half-life of $^{40}_{19}\mathbf{K}$ is $\mathbf{1.3 \times 10^9}$ **years**.
When a rock is formed at $\mathbf{t_0 = 0}$, it contains potassium-40 of mass $\mathbf{m_0}$ and does not contain any argon nucleus. To determine the age of the rock, it is sufficient to measure the present mass of argon and that of potassium-40 in a sample of the rock.
A sample of the rock contains **1.676007g** of potassium-40 and **1.396673g** of $^{M}_{N}\mathbf{Ar}$.

1. Use part A-4 to calculate the initial mass $\mathbf{m_0}$ of potassium-40.
2. Deduce the age of the rock.

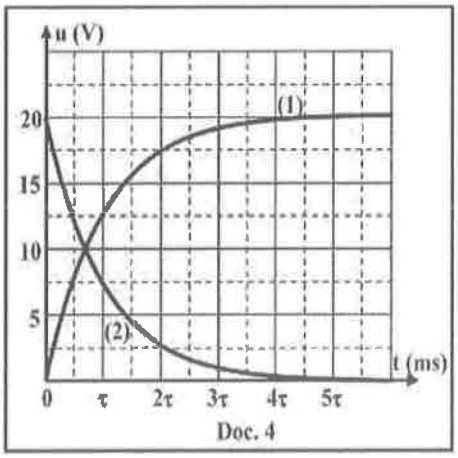
Exercise2 (10 points)

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 $\mathbf{R = 10^4\Omega}$ and a switch **K**, across an ideal battery of constant voltage $\mathbf{u_{AB} = E = 20V}$.
Switch **K** is closed at $\mathbf{t_0 = 0}$, thus a current **i** flows in the circuit (Doc.3).



Doc.3



Doc. 4

1. **Theoretical Study**
   (a) Determine the differential equation that governs the variation of **i**.
   (b) The solution of this differential equation is of the form $\mathbf{i = I_m(1 - e^{\frac{-t}{\tau}})}$, where $\mathbf{I_m}$ and τ are constants. Determine the expressions of $\mathbf{I_m}$ and τ in terms of **E**, **R**, **r** and **L**.
2. **Experimental Study**
   Curves (1) and (2) in document 4 represent the voltages $\mathbf{u_{AC}}$ across the coil and $\mathbf{u_{CB}}$ across the resistor as functions of time t.
   (a) Curve (1) represents $\mathbf{u_{CB} = u_R}$. Why?
   (b) Use curve (2) to prove that the resistance **r** of the coil can be neglected.
   (c) The steady state is practically attained at $\mathbf{t = 0.25ms}$. Calculate the value of the time constant τ of the circuit.
   (d) Deduce that $\mathbf{L = 0.5H}$.
   (e) 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 $\mathbf{i = -2000t + 0.002}$ (SI units).
   (a) Calculate the self-induced emf "**e**" in the coil during the decay of the current.
   (b) Deduce the sparks appear at the switch contacts during the decay of the current.
   (c) Propose a method used to protect the switch from sparks.

SE03/12M+12E/Solution

Exercise I

A) 1) Since the emission of a positron is accompanied by the emission of a neutrino. $^{0}_{+1}e$ (1)

2) Due to Soddy's law

$40 = M + 0 + 0 \Rightarrow M = 40$

$19 = N + 1 + 0 \Rightarrow N = 18$ (1)

$$\Rightarrow {}^{40}_{19}K \longrightarrow {}^{40}_{18}Ar + {}^{0}_{1}e + {}^{0}_{0}\nu$$

3) $E = 1.5\,MeV$

$E = \Delta m c^2$

$$\Delta m = \frac{E}{c^2} = \frac{1.5\,MeV}{c^2} = \frac{1.5}{931.5}\,u$$ (1)

$$\Delta m = 1.610306 \times 10^{-3}\,u$$

4) $\Delta m = m_K - (m_{Ar} + m_e)$ (1)

$$\Rightarrow 1.6 \times 10^{-3} = 39.953577 - (m_{Ar} + 5.485 \times 10^{-4})$$

$$\Rightarrow m_{Ar} = 39.9514184$$

$$\frac{m_K}{m_{Ar}} = \frac{39.953577}{39.9514184} = 1.000054 \Rightarrow m_K = 1.000054\, m_{Ar}$$ (1)

5) $E_\nu + E_e = 0.44 + 0.48$

$0.92\,MeV < 1.5\,MeV$ (1)

$E_\nu + E_e \neq E_{1.6} \Rightarrow$ γ rays are emitted

$E_{1.6} = E_\gamma + E_\bullet + E_\nu \Rightarrow 1.5 - 0.92 = 0.58\,MeV$ (1)

B. a) $m_K = 1.000054\, m_{Ar}$

$m = 1.67600 + (1.000054 \times 1.39643)$ (1)

$= 3.072755429$

b) $m = \frac{m_0}{2^n} \Rightarrow 1.67600 = \frac{3.072755542}{2^n}$

$\Rightarrow n = 0.8745$

$\Rightarrow t = (0.8745)(1.3 \times 10^9)$

$= 1.137 \times 10^9$ years

(2)

Exercise 2

1) a) $u_{AB} = u_{AC} + u_{CB}$

$$E = ri + L\frac{di}{dt} + Ri$$

$$E = (R+r)i + L\frac{di}{dt}$$ (1)

b) $i = I_m(1 - e^{-t/\tau})$ & $\frac{di}{dt} = \frac{I_m}{\tau} e^{-t/\tau}$

$$i = I_m - I_m e^{-t/\tau}$$

$$E = (R+r)\left(I_m - I_m e^{-t/\tau}\right) + L\frac{I_m}{\tau} e^{-t/\tau}$$

$$\frac{L}{\tau} - (R+r) = 0$$

$$\tau = \frac{L}{R+r}$$

$$(R+r) I_m = \mathcal{E}$$ (2)

$$I_m = \frac{\mathcal{E}}{R+r}$$

2) a) $u_{CB} = u_R = Ri$

The current increases (1) $\Rightarrow$ u_R increases with time

b) In steady state

$i = I_m$ = constant

so $\frac{di}{dt} = 0$ (1)

$$u_{AC} = ri + L\frac{di}{dt} \Rightarrow 0 = rI_m + 0$$

$$r = 0$$

c) $t = 0.25\,ms$

$5\tau = 0.25$ (1)

$\boxed{\tau = 0.05\,ms}$

d) $\tau = \frac{L}{R+r}$ $\quad L = \tau(R+r)$

$= 0.05 \times 10^{-3}(10^4 + 0)$

$\boxed{L = 0.5\,H}$ (0.5)

c) $W_{mag} = \frac{1}{2} L I_m^2$ $\quad I_m = \frac{E}{R+r} = \frac{20}{10^4} = 2 \times 10^{-3} A$

$= \frac{1}{2} \times 0.5 \times (2 \times 10^{-3})^2$ (0.5)

$= 10^{-6} J$

3) a) $e = -\frac{L di}{dt} = -0.5(-2000)$ (1)

$\boxed{e = 1000V}$

b) $e = 1000V$ is a very large value (1)
so a spark appears.

c) Connect a capacitor across the switch (1)