(1) Answer each of the following questions in the space allotted.

4 (a) Consider switching in an R-C circuit at \( t = 0 \). At what instant is the magnitude of the capacitor current a maximum? Is your answer valid independent of whether the capacitor is being charged or discharged after switching? Justify.

\[
V_c(t) = V_c(\infty) + \left[ V_c(0) - V_c(\infty) \right] e^{-t/RC}
\]

\[
I_c = \frac{1}{RC} \left[ V_c(0) - V_c(\infty) \right] e^{-t/RC}
\]

\[
|I_c| \text{ is maximum at } t = 0^+.
\]

4 (b) Two inductors are in parallel. Derive current divider formula and state clearly under what conditions, if any, it is applicable.

\[
\frac{I_1}{I} = \frac{L_2}{L_1}
\]

\[
i = i_1(t_0) + \frac{1}{L_1} \int_{t_0}^{t} v \, dt
\]

4 (c) In the table below, list typical values of the three parameters used to characterize an op amp.

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(d) A voltage pulse $v_s(t)$ shown below is applied to the circuit:

Sketch the capacitor voltage for following two cases:

(i) $RC \gg t_0$

(ii) $RC \ll t_0$.

(e) Which quantity has to be continuous in a capacitor and why?

\[ i_C = C \frac{dv_C}{dt} \]

$v_C$ must be continuous for $i_C$ to be finite.
Consider an ideal op amp circuit shown.

(a) Find $V_p$.

\[
\frac{V_p - 4}{20} + \frac{V_p}{30} + \frac{V_p}{60} = 0
\]

\[
V_p = 2 \text{ V}
\]

\[
\Rightarrow V_n = 2 \text{ V}
\]

(b) Find $V_0$ in terms of $V_1$.

\[
\frac{2 - (-V_1)}{40} + \frac{2 - V_0}{20} = 0
\]

\[
2 + V_1 + 4 - 2V_0 = 0
\]

\[
2V_0 = V_1 + 6
\]

\[
V_0 = \frac{1}{2} V_1 + 3
\]

(c) What is the range of values of $V_1$ for linear operation?

\[
V_o = 12 \quad \Rightarrow \quad V_1 = 18 \text{ V}
\]

\[
V_o = -12 \quad \Rightarrow \quad V_1 = -30
\]

\[
-30 \leq V_1 \leq 18 \text{ V}
\]

(d) If $V_1 = 3 \text{ V}$, find the power delivered by this voltage source.

\[
I_s = \frac{-3 - 2}{40 \text{ k}} = -0.125 \text{ mA}
\]

\[
P = V_1 I_s = -0.375 \text{ mW absorbed}
\]

\[
P = +0.375 \text{ W} \text{ delivered}
\]
(3) The switch in the circuit shown below opens at \( t = 0 \).

Given: \( v_0(t) = 2000e^{-20t} \text{ V} \) for \( t > 0 \), \( i_1(0) = 20 \text{ A} \), \( i_2(0) = 10 \text{ A} \), find the following quantities:

5. (a) \( i_0(t) \) for \( t > 0 \).

\[
\begin{align*}
  i_0(t) & = 10 + \frac{1}{10} \int_0^t -2000e^{-20t} \, dt \\
        & = 10 - \left( \frac{2000}{10 \times -20} e^{-20t} \right)_0^n \\
        & = 10 e^{-20t} \text{ A}
\end{align*}
\]

5. (b) \( v_1(t) \) for \( t > 0 \).

\[
\begin{align*}
  v_2 & = 6 \frac{d}{dt} (10 e^{-20t}) dt \\
  v_2 & = -1200 \times -20t e^{-20t} \\
  v_1 & = v_2 + v_0 = 800 e^{-20t}
\end{align*}
\]

5. (c) \( i_1(t) \) for \( t > 0 \).

\[
\begin{align*}
  i_1(t) & = 20 + \frac{1}{20} \int_0^t -800 e^{-20t} \, dt \\
         & = 20 - \frac{800}{20 \times (-20)} (e^{-20t})_0^n \\
         & = 2 e^{-20t} + 18 \text{ A}
\end{align*}
\]
(d) \( i_2(t) \) for \( t > 0 \).

\[
1' \ (t) = 1(t) - 0 (t) \\
= 18 - 8e^{-20t} \ \ \text{A}
\]

(e) Total initial energy stored.

\[
W(0) = \frac{1}{2} \cdot 20 \cdot (20)^2 + \frac{1}{2} \cdot 5 \cdot (10)^2 + \frac{1}{2} \cdot 6 \cdot (10)^2 \\
= 4550 \ \text{J}
\]

(f) Total final energy stored.

\[
W(\infty) = \frac{1}{2} \cdot 20 \cdot (18)^2 + \frac{1}{2} \cdot 5 \cdot (18)^2 \\
= 4052 \ \text{J}
\]

(g) Energy transferred to the box by using results of parts (e) and (f).

\[
\Delta W = W(0) - W(\infty) \\
= 500 \ \text{J}
\]

(h) Energy transferred to the box by integrating the power absorbed by the box.

\[
\Delta W = \int_{0}^{\infty} v_0 (t) \cdot i(t) \, dt = \int_{0}^{\infty} 20000 \cdot e^{-40t} \, dt \\
= 500 \ \text{J}.
\]
(4) The initial voltage on the capacitor circuit shown below was $v_c(0) = -3 \text{ V}$. The switch closes at $t = 0$.

(a) Was there a DC steady state at $t = 0^-$?

In a DC steady state, since the circuit is source-free, all voltages and current must be zero. Since $v_c(0) \neq 0$, there was no DC steady state.

(b) Find $v_c(\infty)$.

The switch is closed at $t = 0$. Compute

$V_x = \frac{9}{6+9} V_L = \frac{3}{5} V_L$

$V_x = \frac{9}{6+9} V_L = \frac{3}{5} V_L$

$V_1 - 64 + \frac{V_1 - 2V_x}{30} + \frac{V_1 - V_c}{6} = 0$

$v_c = 24 \text{ V}$

CONTINUED......
(c) Determine the time constant $\tau$ for $t > 0$.

\[
V_4 = 2V_x, \quad V_2 - V_3 = 1, \quad V_x = V_2
\]

\[
\frac{V_1 - 2V_x}{30} + \frac{V_1}{10} + \frac{V_1 - V_2}{6} = 0
\]

\[
\frac{V_2 - V_1}{6} + \frac{V_3}{60} + \frac{V_2}{a} = 0
\]

Solution: \hspace{1cm} \begin{align*}
V_1 &= 0.07865 \text{ V} \quad V_2 = 0.10112 \text{ V} \\
I_S &= \frac{V_3}{60} = 0.01498 \text{ A} \Rightarrow R_m &= 66.75 \Omega \\
\tau &= 0.10 \text{ ms}
\end{align*}

(d) At what time does the energy stored go to zero?

\[
V_c(t) = 24 + (-3 - 24) e^{-100t} \text{ V}
\]

\[W_c = 0 \text{ when } V_c(t) = 0\]

\[
24 = 27 e^{-100t}
\]

\[
t = 0.00118 \text{ s} = 1.18 \text{ ms}
\]

(e) Find the expression for $i_C(t)$ for $t > 0$.

\[
i_C = 150 \times 10^{-6} (27)(100) e^{-100t} \text{ A}
\]

\[
i_C = 40.5 e^{-100t} \text{ mA}
\]

CONTINUED ---
(f) Determine $v_x(t)$ for $t > 0$.

\[
\begin{align*}
v_x &= v_c + 60t_c \\
v_x &= 24 - 27e^{-kt} + 2.43e^{-100t} \\
v_x &= 24 - 2.7e^{-100t} \text{ m/s}
\end{align*}
\]

(g) Of the following quantities, which ones are not continuous at $t = 0$?

(i) $v_x$ \text{ not, zero at } t = 0

(ii) $i_0$ \text{ not, zero at } t = 0

(iii) $i_s$ \text{ not, zero at } t = 0