Department of Computer Science and Engineering (CSE)
BRAC University

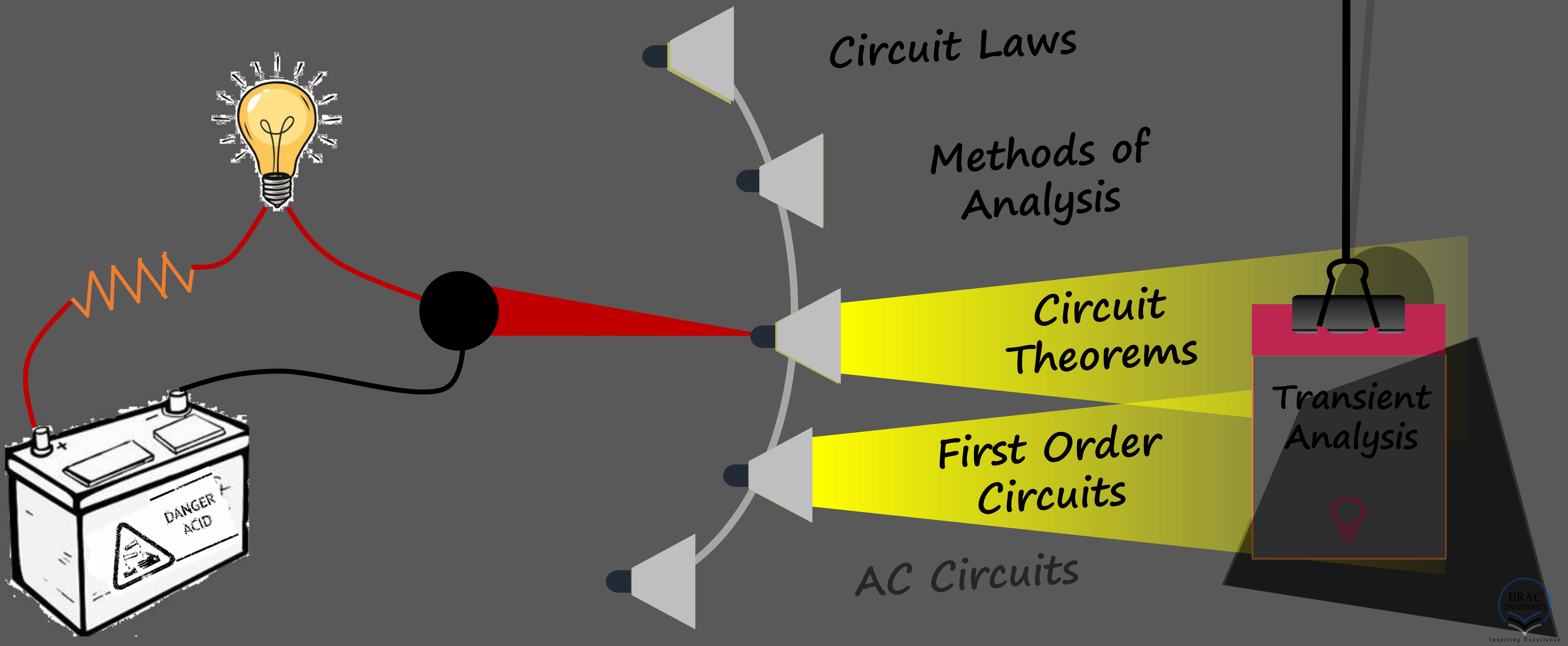
Fall 2023

CSE250 - Circuits and Electronics

First Order Circuits

Prithu mahmud, Lecturer
Department of Computer Science and Engineering (CSE)
BRAC University

Course Outline: broad themes



First Order Circuits

- A first-order circuit is characterized by a first-order differential equation.
- We shall examine two types of differential circuits: circuit comprising resistors and capacitors (RC circuit) and circuit comprising resistors and inductors (RL circuit).
- Two ways to excite the circuits: (i) by initial conditions of storage elements (source free circuits) and (ii) by independent sources (DC for this course).

First order Circuits: types

- Step response of RC Circuits
- Source-free RC Circuits
- Step response of RL Circuits
- Source-free RL Circuits

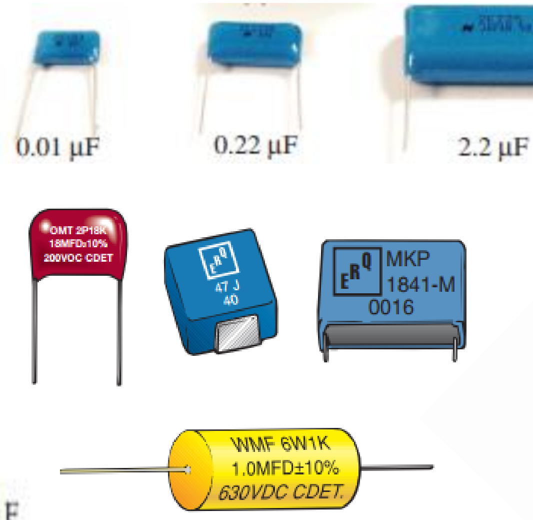
Circuit Elements

- **Active element**
  - An *active element* is capable of generating energy.
  - In other words, an element is said to be active if it can add some gain (in terms of voltage or current) to a circuit.
  - Active elements can absorb energy if they are forced to do so by other active elements.
  - Examples: *Voltage/current sources, generators, transistors, operational amplifiers.*
- **Passive element**
  - *Passive elements* cannot supply energy. They can only consume/dissipate/store energy.
  - Examples: *Resistors, capacitors, inductors, transformers.*
  - Transformers change the voltage or current levels, but the power is unchanged. This is why transformers are passive element.

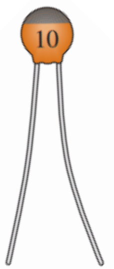
Capacitors

- A capacitor is a passive circuit element designed to store energy in its electric field.
- Unlike resistors, which dissipate energy, capacitors and inductors do not dissipate but store energy, which can be retrieved at a later time. For this reason, capacitors and inductors are called *storage* elements.

Electrolytic

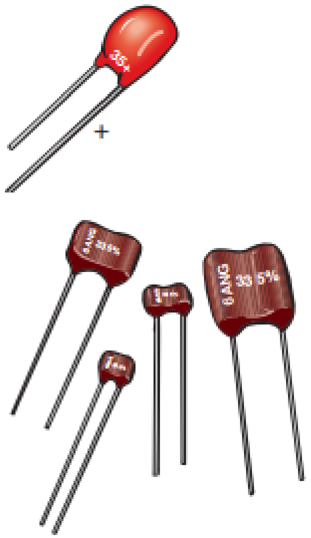


Polyester Film

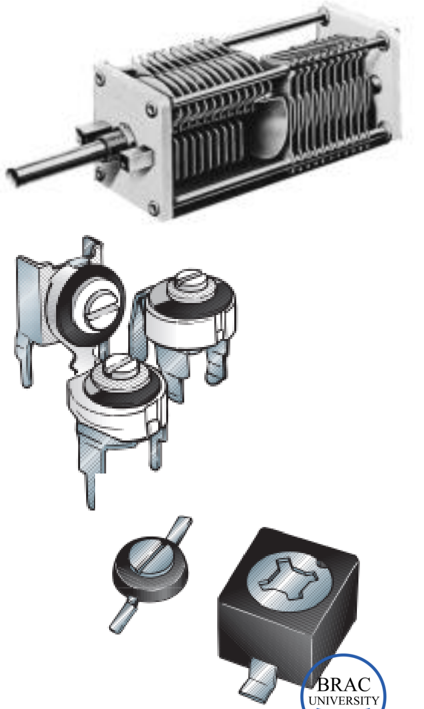


Ceramic

Mica Capacitors



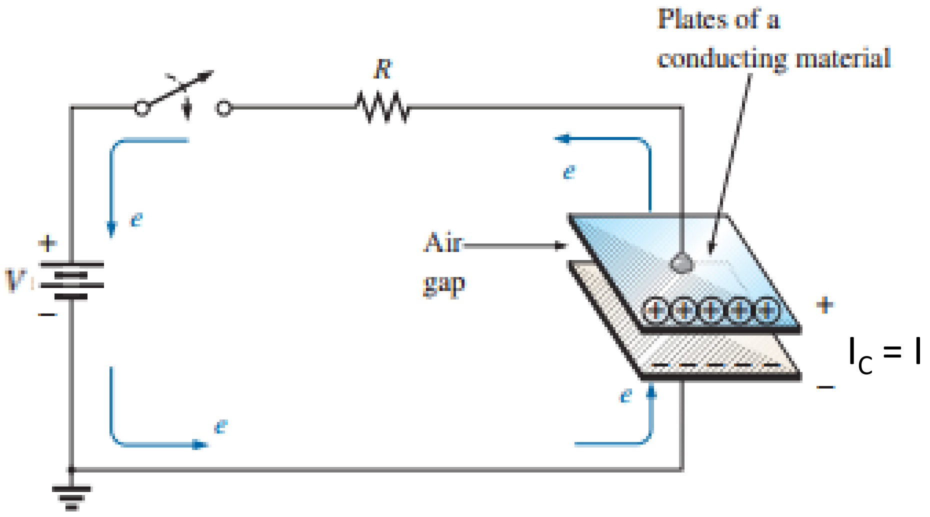
Dipped Capacitors

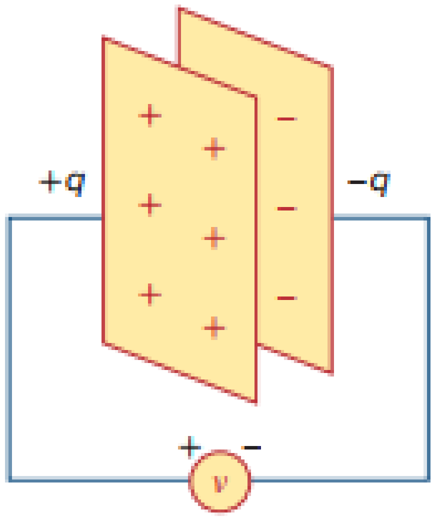


Variable Capacitors

Parallel Plate Capacitor

- Most widely used configuration is the two conducting surfaces (aluminium mainly) separated by a dielectric (air, ceramic, paper, or mica).
- The switch is open initially (no net charge).
- Closing the switch causes electrons to flow from and to the upper and lower plates respectively as shown by the arrows.
- Electron flow continues until the potential difference between the plates equals the applied potential.
- The final result is a net positive charge on the top plate and a negative charge on the bottom plate.





Capacitance

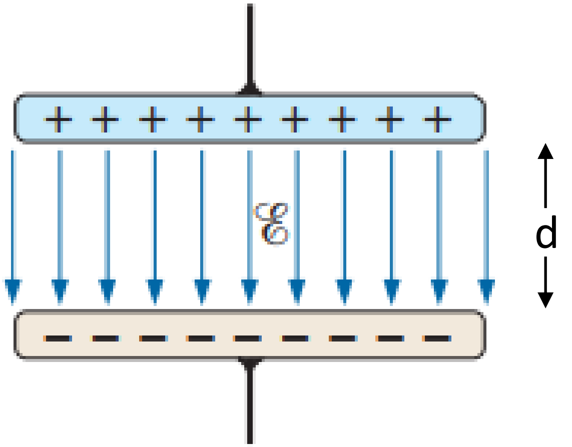
- *Capacitance* is a measure of a capacitor's ability to store charge.
- Increasing V increases E as $E \propto \frac{V}{d}$ as long as d is constant. An increase in E field causes increased charge separation i.e. increases q.
- So, $q \propto V$

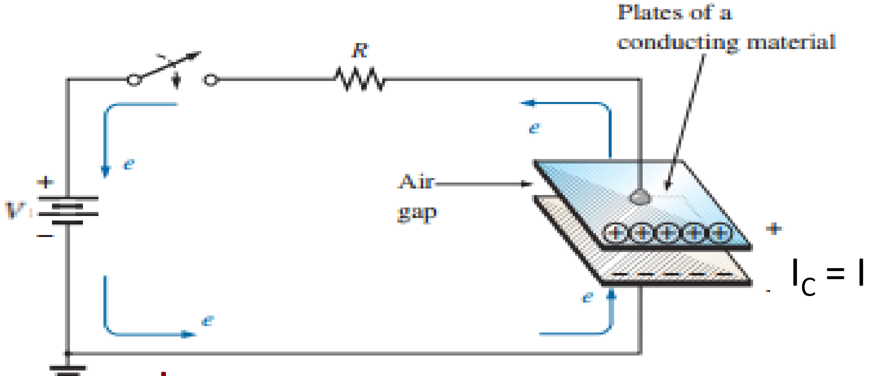
$\Rightarrow$ $q = CV$ [C is a proportionality constant $\equiv$ Capacitance]

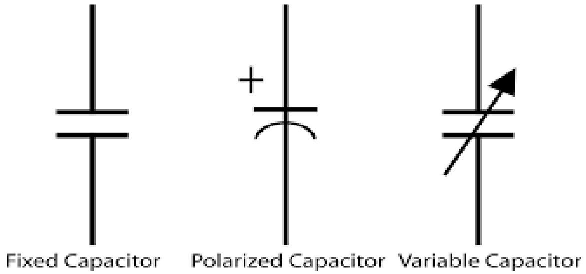
$\Rightarrow$ $C = \frac{q}{V}$ $[F\ (Farad),\ mF,\ \mu F]$

$\Rightarrow$ For a particular capacitor $\uparrow V, \uparrow q$ but $\frac{q}{V} = $ const. So, C does not depend on q or v. It depends on the physical dimension of the capacitor.

$\Rightarrow$ For the parallel plate capacitor, $C = \frac{\varepsilon A}{d}$







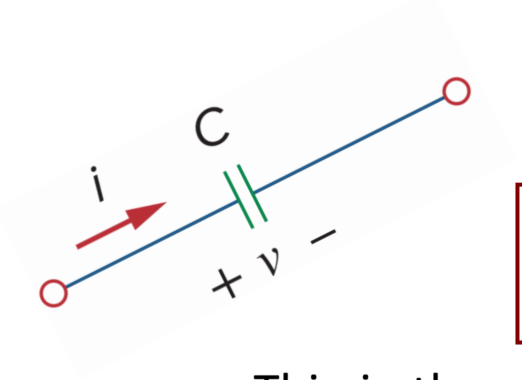
I-V relation of a Capacitor

- From the definition of the capacitance,

$$C = \frac{q}{v}$$

$$\Rightarrow \quad q = Cv$$

- Differentiating with respect to time,



$$\frac{dq}{dt} = C\frac{dv}{dt}$$

$$\boxed{i = C\frac{dv}{dt}}$$

- This is the characteristic equation of a capacitor.

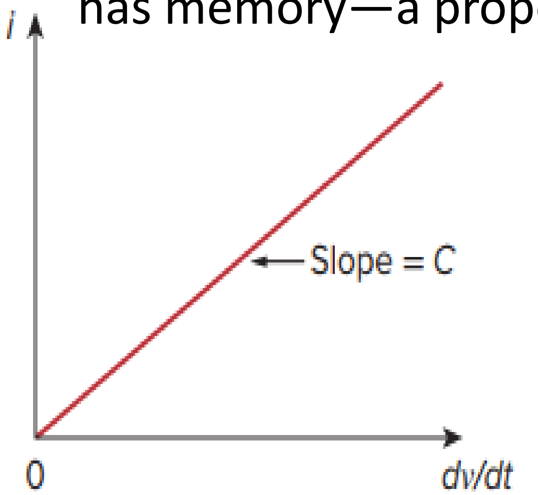
- Integrating with respect to time,

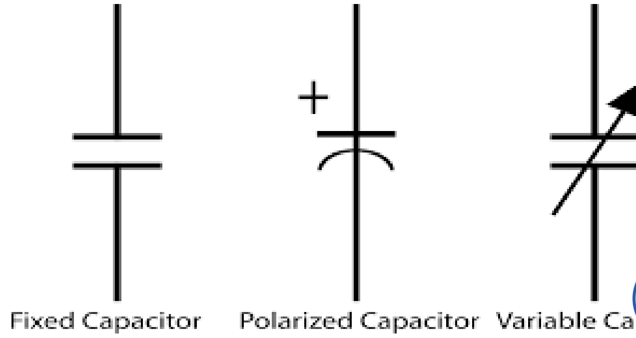
$$v(t) = \frac{1}{C}\int i(t)\,dt$$

- If the voltage of the capacitor at any time t_0 is $v(t_0) = q(t_0)/C$, then,

$$v(t) = \frac{1}{C}\int_{t_0}^{t} i(t)\,dt + v(i_0)$$

- It shows that capacitor voltage depends on the past history of the capacitor current. Hence, the capacitor has memory—a property that is often exploited.





Energy & Power of a Capacitor

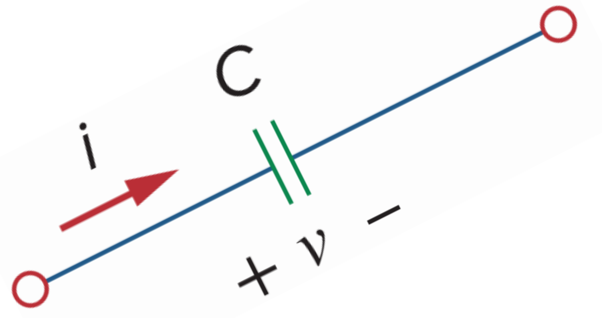
- The instantaneous power delivered to a capacitor according to the passive sign convention is,

$$p = v(t)i(t) = Cv(t)\frac{dv(t)}{dt}$$

- The energy stored in the capacitor is therefore

$$w(t) = \int_{-\infty}^{t} p(t)\, dt = \int_{-\infty}^{t} Cv(t)\frac{dv(t)}{dt} dt = \int_{v(-\infty)}^{v(t)} Cv(t)\; dv$$

$$\Rightarrow \quad w(t) = \frac{1}{2}Cv^2\bigg|_{v(-\infty)=V_0}^{v(t)=V}$$



- If the voltage across the capacitor was initially (at $t = -\infty$) V_0, then,

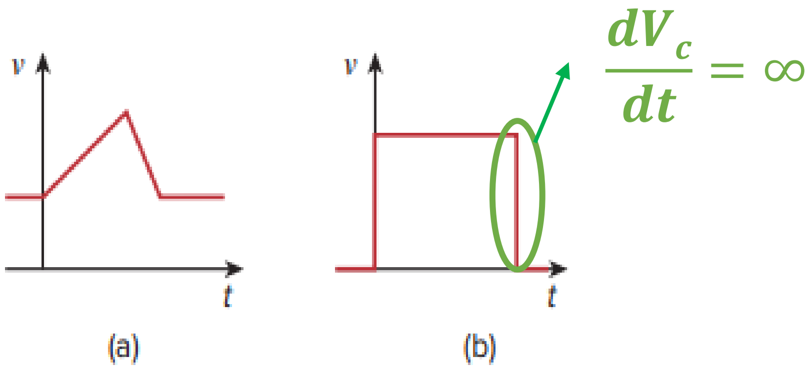
$$\Rightarrow \quad w(t) = \frac{1}{2}CV^2 - \frac{1}{2}CV_0^2$$

- In general, at any time t, if the voltage across a capacitor is V, then the stored energy can be found as,

$$w(t) = \frac{1}{2}Cv(t)^2 = \frac{1}{2}CV^2$$

Capacitor: important properties

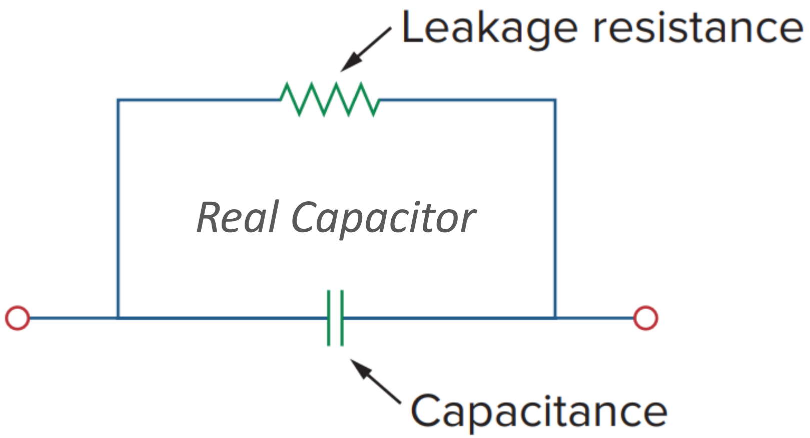
1. A capacitor is an <u>open circuit</u> to dc. At dc, $i_C = C\frac{dV_{c\,dc}}{dt} = 0$ [Open circuit]
2. The <u>voltage</u> on a capacitor cannot change abruptly.



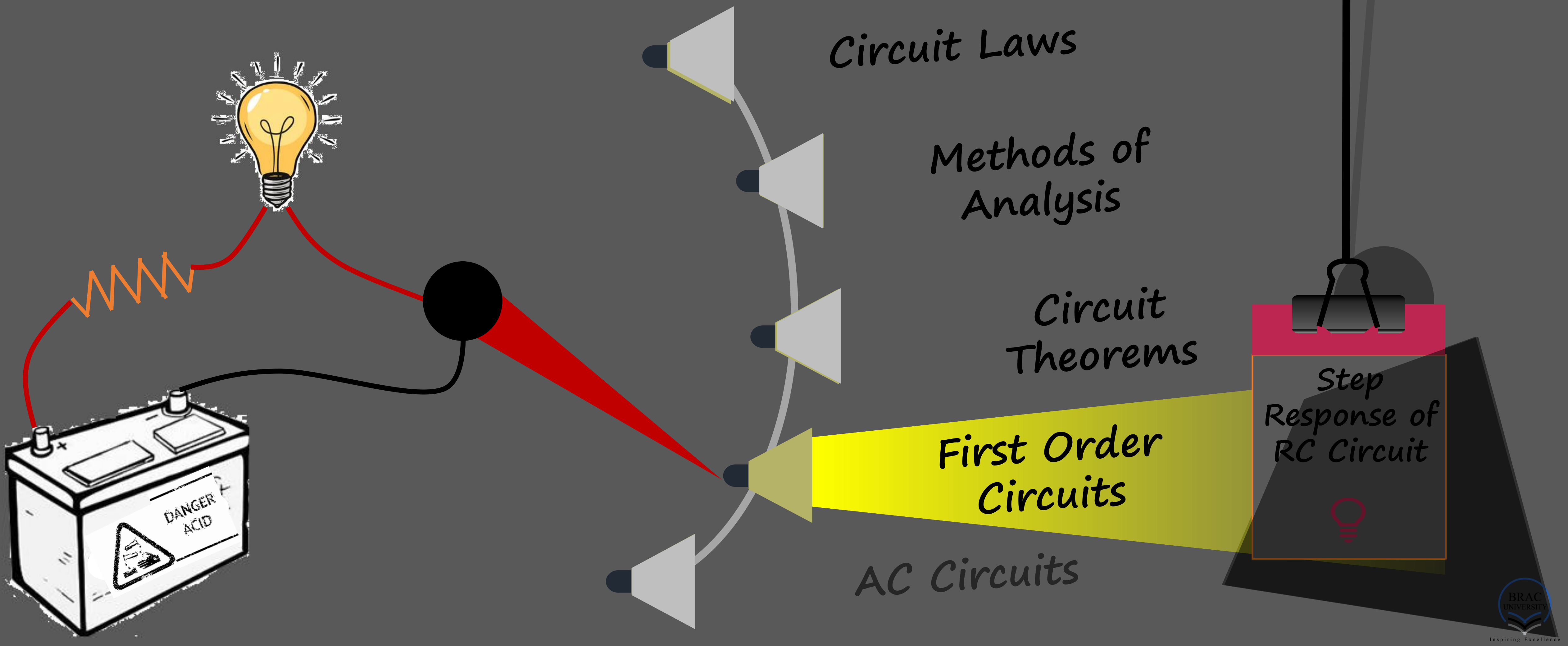
Voltage change across a capacitor (a) allowed and (b) not allowed

3. An ideal capacitor does not dissipate energy.

4. A real, nonideal capacitor has a parallel-model leakage resistance.



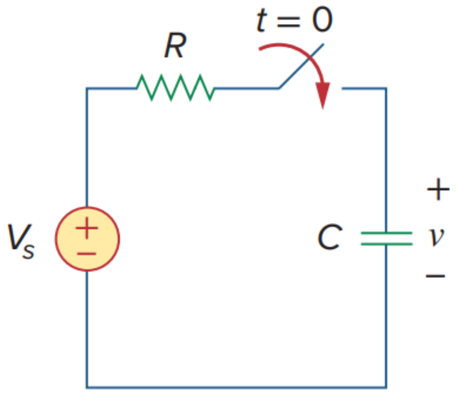
Course Outline: broad themes



Step Response of a RC circuit

- The *step response* of a circuit is its behaviour under the sudden application of dc voltage or current source. We assume the circuit response to be the capacitor voltage.

$\Rightarrow$ Since the voltage of a capacitor cannot change instantaneously,



$$\Rightarrow v(0^-) = v(0^+) = V_0$$

$\Rightarrow$ Using KCL (for $t > 0$),

$$\Rightarrow C\frac{dv}{dt} + \frac{v - V_s}{R} = 0$$

$$\Rightarrow \frac{dv}{dt} = -\frac{v - V_s}{RC}$$

$$\Rightarrow \frac{dv}{v - V_s} = -\frac{1}{RC}dt$$

Integrating both sides,

$$\Rightarrow [\ln(v - V_s)]_{V_0}^{v(t)} = -\left[\frac{t}{RC}\right]_0^t$$

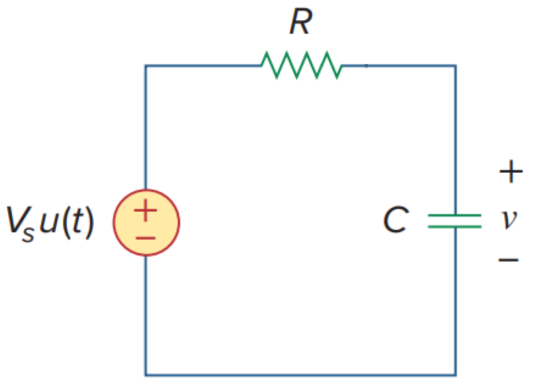
$$\Rightarrow \ln(v(t) - V_s) - \ln(V_0 - V_s) = -\frac{t}{RC} + 0$$

$$\Rightarrow ln\frac{v - V_s}{V_0 - V_s} = -\frac{t}{RC}$$

$$\Rightarrow \frac{v - V_s}{V_0 - V_s} = e^{-t/RC}$$

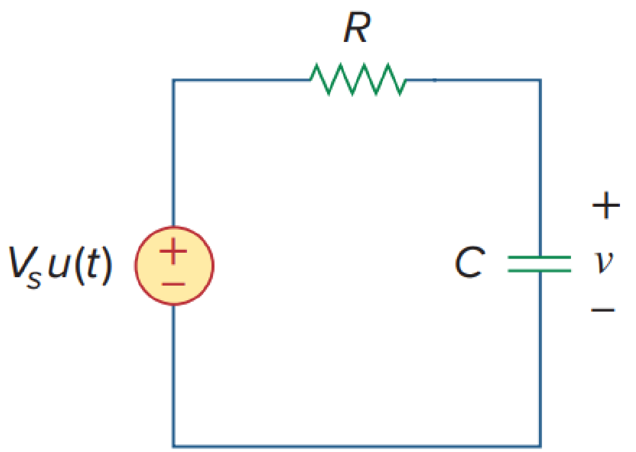
$$\Rightarrow v - V_s = (V_0 - V_s)e^{-t/RC}$$

$$\Rightarrow v(t) = V_s + (V_0 - V_s)e^{-t/RC}$$



Time Constant (charging) for RC circuit

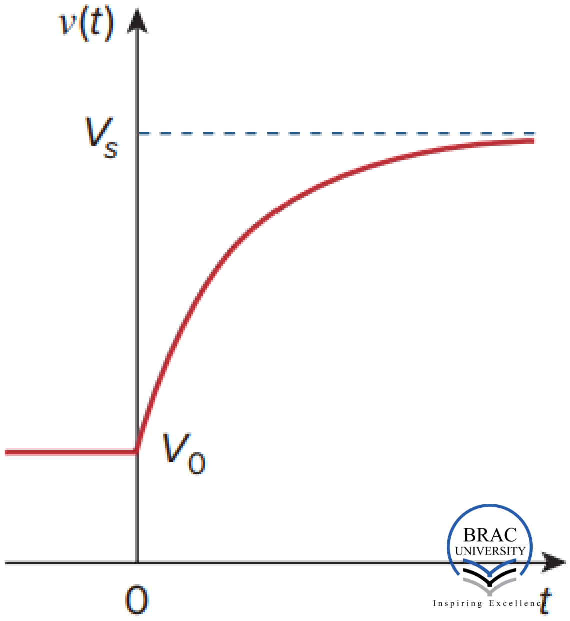
$$v(t) = \begin{cases} V_0, & t < 0 \\ V_s + (V_0 - V_s)e^{-\frac{t}{RC}}, & t > 0 \end{cases}$$



- This is known as the complete response (or total response) of the RC circuit to a sudden application of a dc voltage source. It is assumed that the capacitor was initially charged to V_0.

$$\Rightarrow \quad v(t) = \begin{cases} V_0, & t < 0 \\ V_s + (V_0 - V_s)e^{-\frac{t}{\tau}}, & t > 0 \end{cases}$$

$\Rightarrow$ where $\tau = RC$ is the *time constant* (unit in sec).

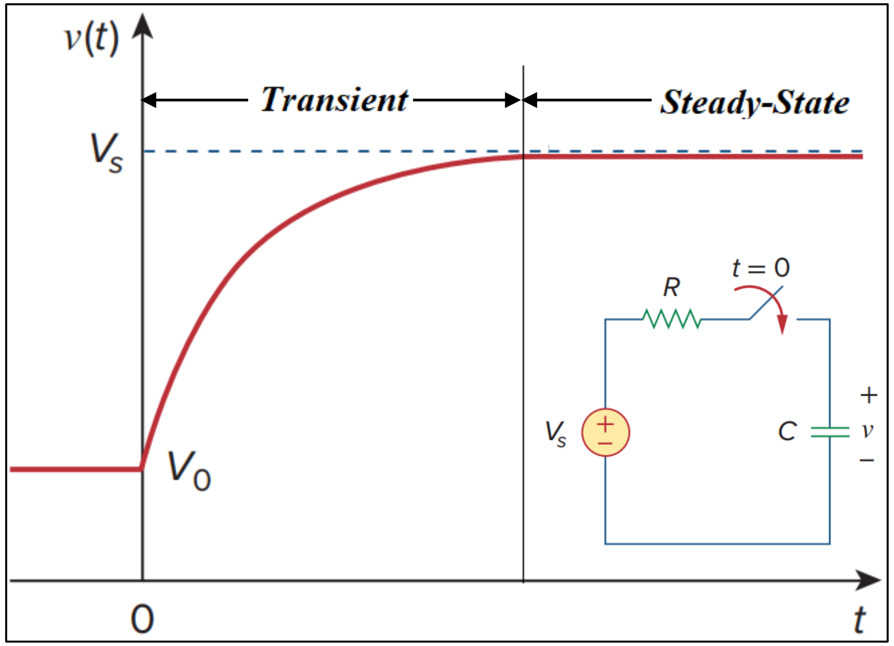


- Notice that, we write $\tau = RC$ for the circuit consisting of only a resistor R in series with the capacitor. As we know, all the linear two terminal circuits can be reduced to this form by Thevenin's Theorem, so the resistor R is actually the Thevenin Resistance R_{Th}. Therefore,

$$\tau = R_{Th}C$$

Transient and Steady-State Response

$$v(t) = \begin{cases} V_0, & t < 0 \\ V_s + (V_0 - V_s)e^{-\frac{t}{\tau}}, & t > 0 \end{cases}$$



- The *complete response* can be broken into two parts—one temporary and the other permanent, that is,

$$v(t) = v_{ss} + v_t, \qquad \text{where,}$$

$$v_{ss} = V_s \qquad \& \qquad v_t = (V_0 - V_s)e^{-\frac{t}{\tau}}$$

- The *transient response* (v_t) is the circuit's temporary response that will die out with time.

- The *steady-state response* (v_{ss}) is the behaviour of the circuit a long time after an external excitation is applied.

- The complete response can be written as,

$$v(t) = V_{final} + [V_{initial} - V_{final}]e^{-\frac{t}{\tau}}$$

$$or, \qquad v(t) = V(\infty) + [V(0) - V(\infty)]e^{-\frac{t}{\tau}}$$

Definition of τ (charging)

$$v(t) = V_{final} + [V_{initial} - V_{final}]e^{-\frac{t}{\tau}}$$

- At $t = \tau$,

$$v(t) = V_{final} + [V_{initial} - V_{final}]e^{-1}$$

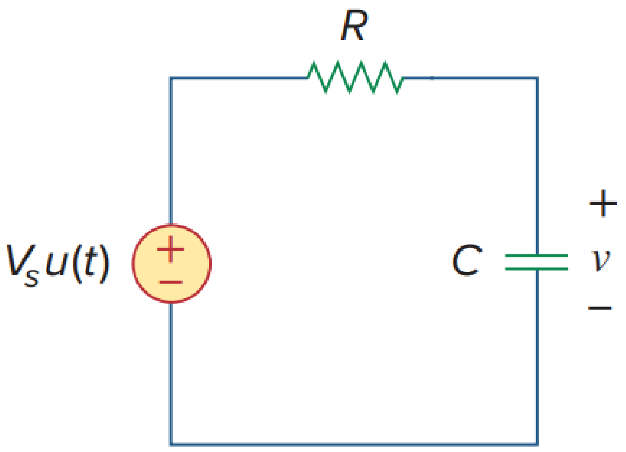
$$\Rightarrow \quad v(t) = V_{final}(1 - {}^{1}/_{e}) + V_{initial}({}^{1}/_{e})$$

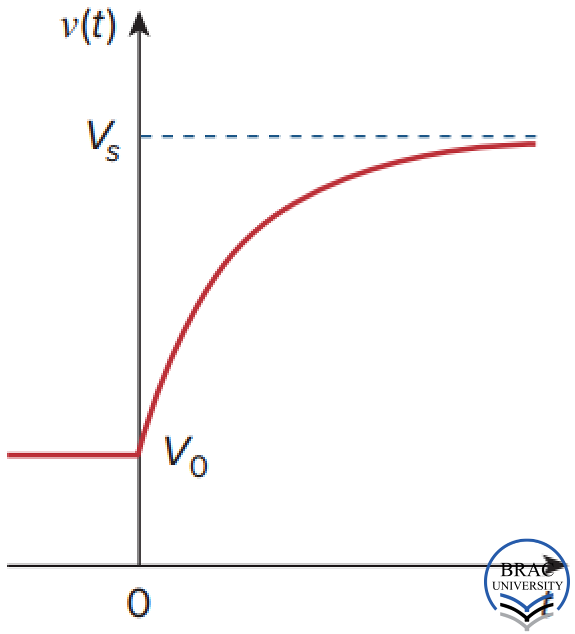
$$\Rightarrow \quad v(t) = V_{final}(1 - {}^{1}/_{e}) - V_{initial}(1 - {}^{1}/_{e}) + V_{initial}$$

$$\Rightarrow \quad v(t) = V_{initial} + [V_{final} - V_{initial}](1 - {}^{1}/_{e})$$

- We can define the time constant in this way,

- The *charging time constant* is the time required for the response to reach to a factor of $(1 - 1/e)$ or 63.2% towards V_{final} from an initial response $V_{initial}$.



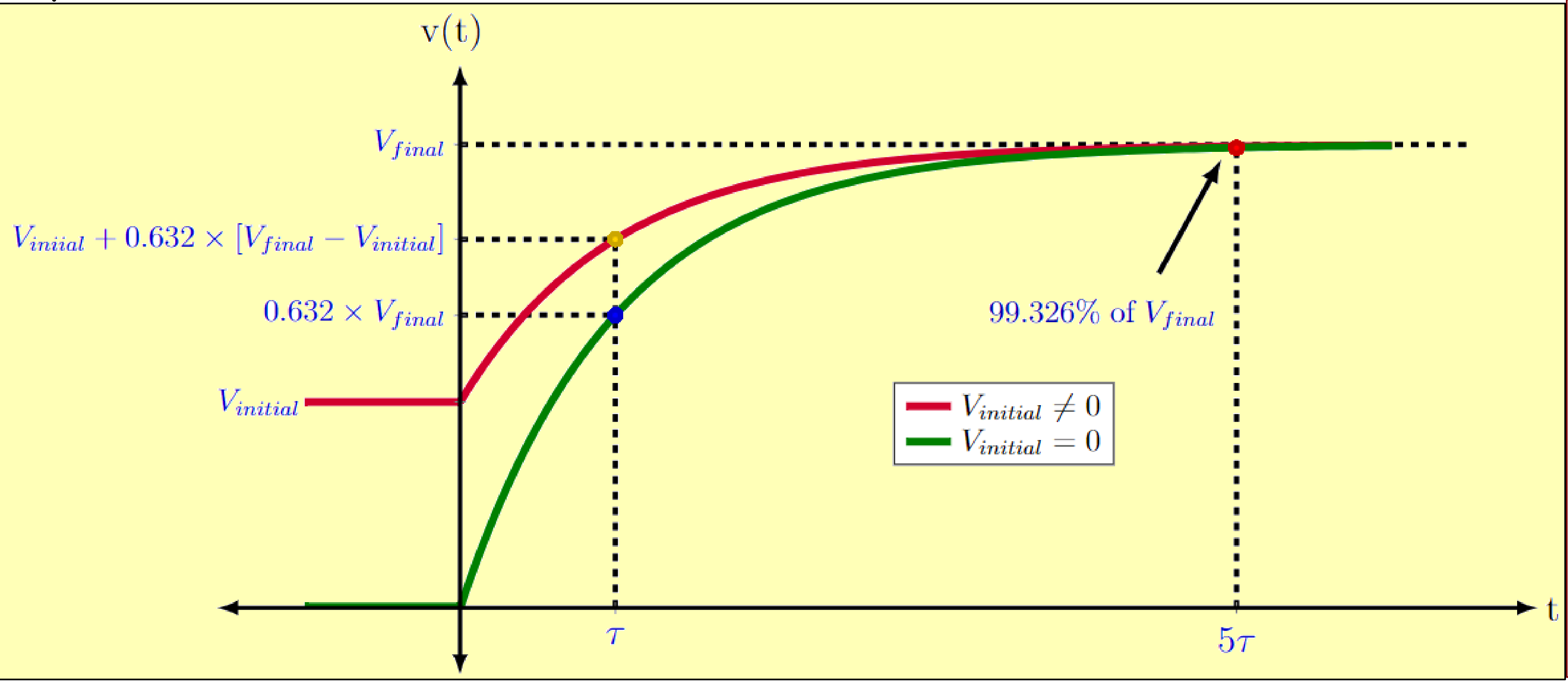


Time Constant (τ): graphically

At $t = \tau$, $v(t) = V_{initial} + [V_{final} - V_{initial}](1 - {}^{1}/_{e})$

$$\Rightarrow \quad v(t) = 63.2\% \times V_{final} \quad \text{when } V_{initial} = 0$$

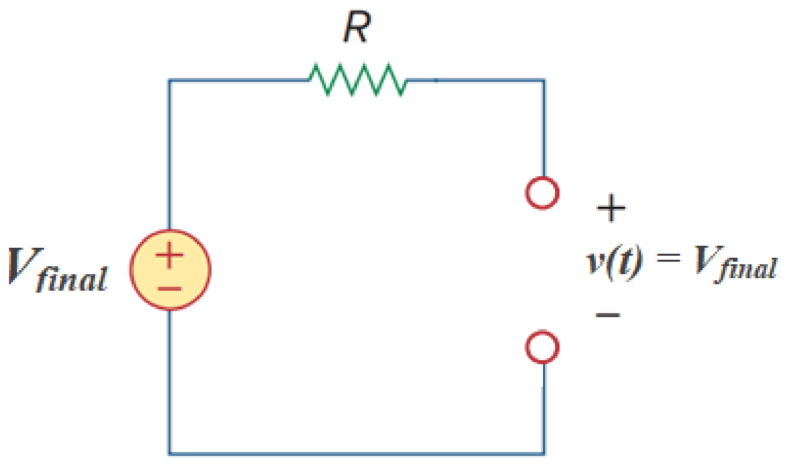
$$\Rightarrow \quad v(t) = V_{initial} + 63.2\% \times [V_{final} - V_{initial}] \quad \text{when } V_{initial} \neq 0$$



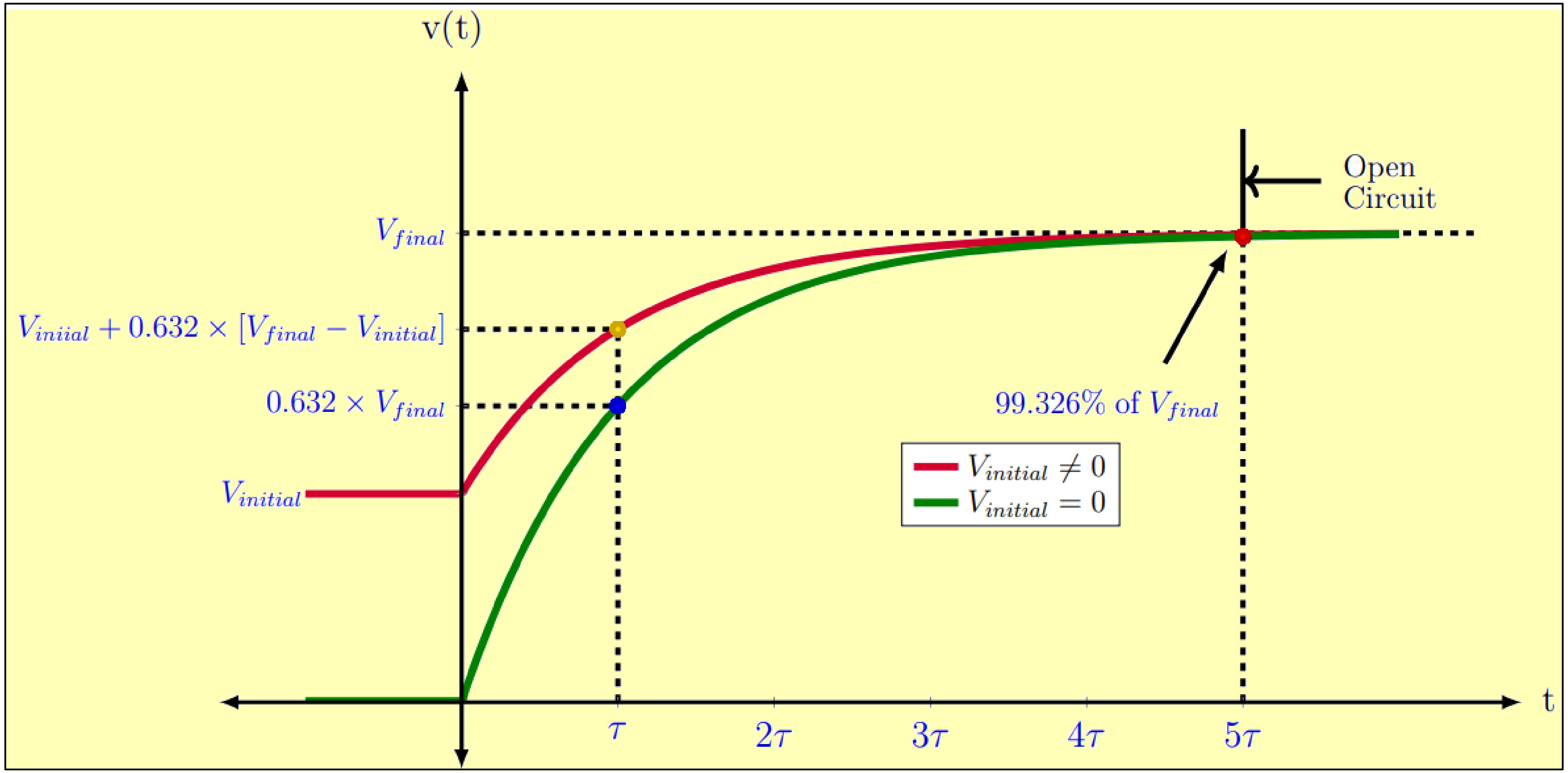
- As τ only depends on R_{Th} and C ($\tau = R_{Th}C$), for a given circuit, that is, for a fixed R_{Th} and C, the time needed for the capacitor voltage to rise to the final value (V_{final}) is the same whether or not the capacitor is initially charged ($V_{initial}$ zero or nonzero).

Significance of τ (charging): 5τ Time

- As can be seen from the following plot, the capacitor voltage reaches the final voltage approximately after 5 times the Time Constant (τ). The capacitor is fully charged and acts as open circuit from 5τ time onward. So, when designing circuits, the charging time of a capacitor under the application of a certain dc supply can be set by choosing R_{Th}.



at or after $t = 5\tau$



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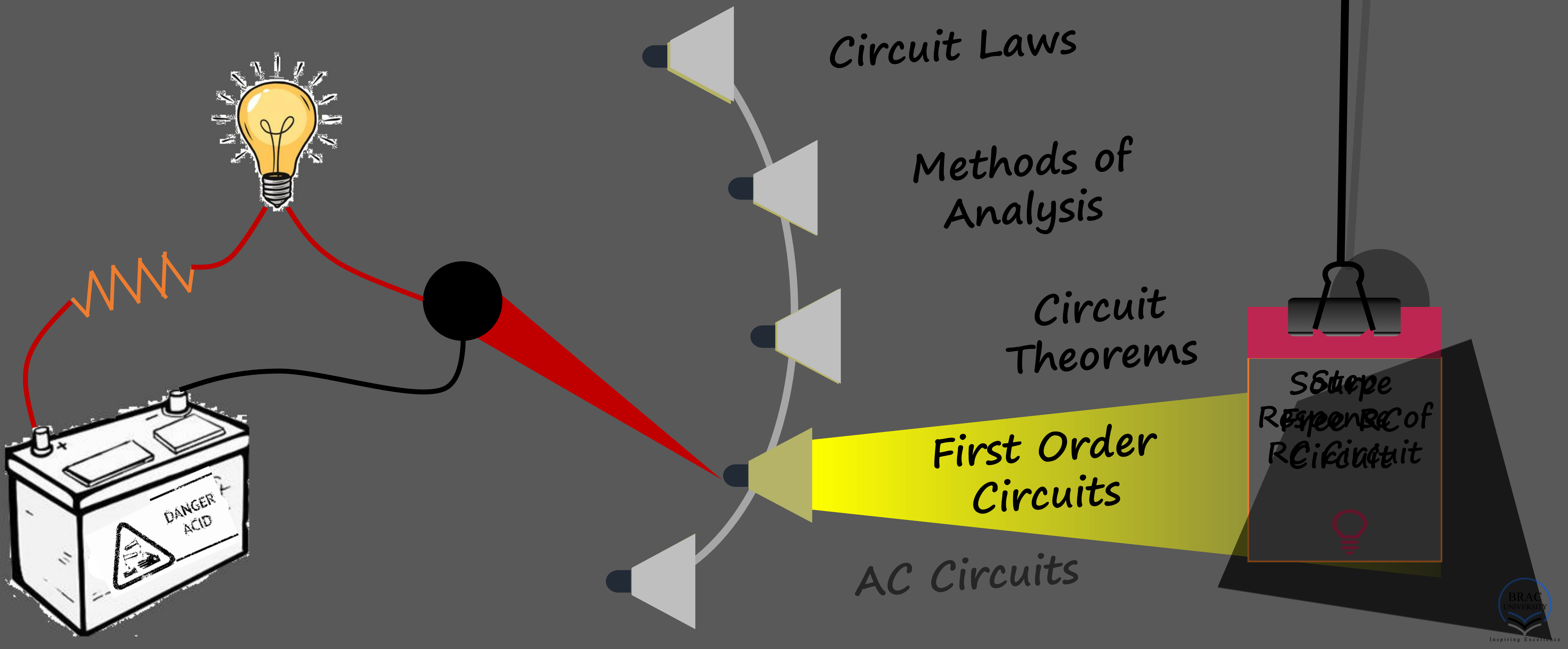


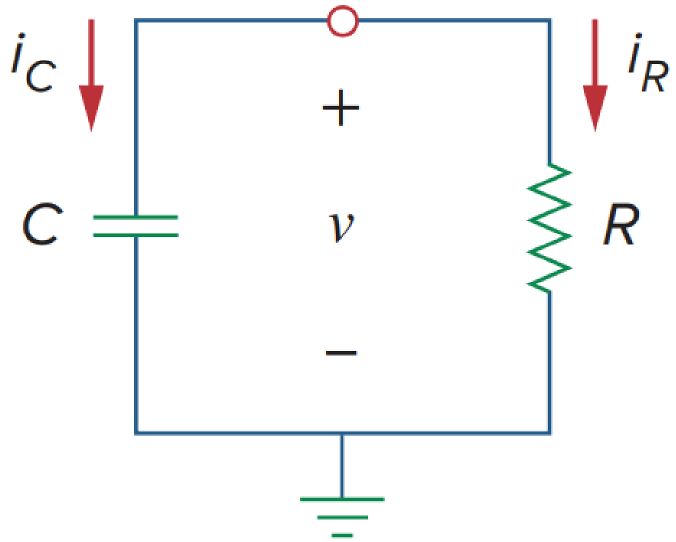
Source-Free RC circuit

- A *source-free RC circuit* occurs when its dc source is suddenly disconnected. The energy already stored in the capacitor is released to the resistors.

⇒ Assume that a capacitor is charged to V_0 and then it is connected to a resistor as shown. The capacitor starts to discharge the stored energy to the resistor.

⇒ Initially stored charge, $w(0) = \frac{1}{2}CV_0^2$

⇒ From the figure using KCL, $i_C + i_R = 0$



$$\Rightarrow C\frac{dv}{dt} + \frac{v}{R} = 0$$

$$\Rightarrow \frac{dv}{dt} + \frac{v}{RC} = 0$$

$$\Rightarrow \frac{dv}{v} = -\frac{1}{RC}dt$$

Integrating both sides,

$$\Rightarrow lnv = -\frac{t}{RC} + lnA$$

$$\Rightarrow ln\frac{v}{A} = -\frac{t}{RC}$$

$$\Rightarrow v = Ae^{-\frac{t}{RC}}$$

At $t = 0, v(0) = A = V_0$. So, $\boxed{v(t) = V_0 e^{-\frac{t}{RC}}}$

Time Constant (discharging) for RC circuit

$$v(t) = V_0 e^{-\frac{t}{RC}}$$

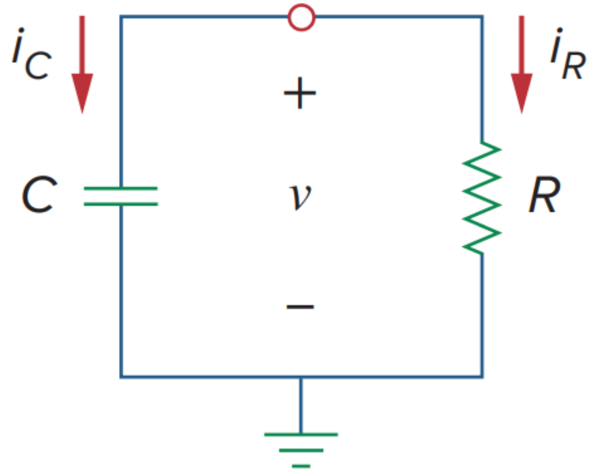
- This shows that the voltage response of the RC circuit is an exponential decay of the initial voltage. It is called the *natural response* of the circuit.

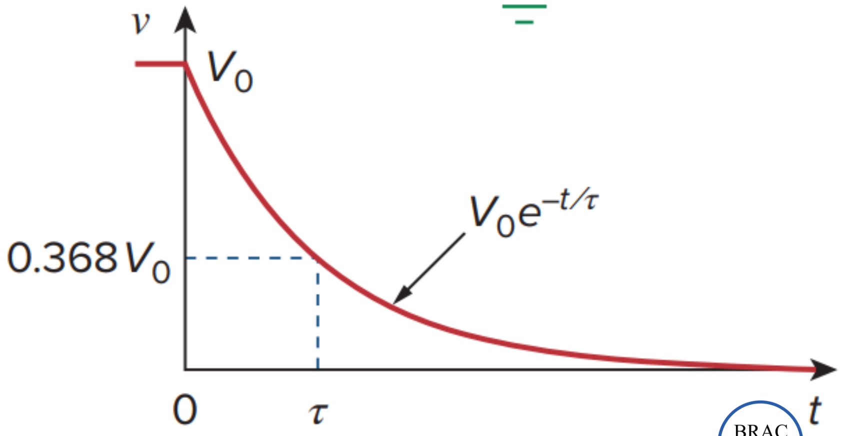
$$\Rightarrow \quad v(t) = V_0 e^{-\frac{t}{\tau}}$$

- where $\tau = RC$ is the time constant (unit in sec).

- Notice that, we write $\tau = RC$ for the circuit consisting of only a resistor R in series with the capacitor. As we know, all the linear two terminal circuits can be reduced to this form by Thevenin's Theorem, so the resistor R is actually the Thevenin Resistance R_{Th}. Therefore,

$$\boxed{\tau = R_{Th} C}$$





Definition of τ (discharging)

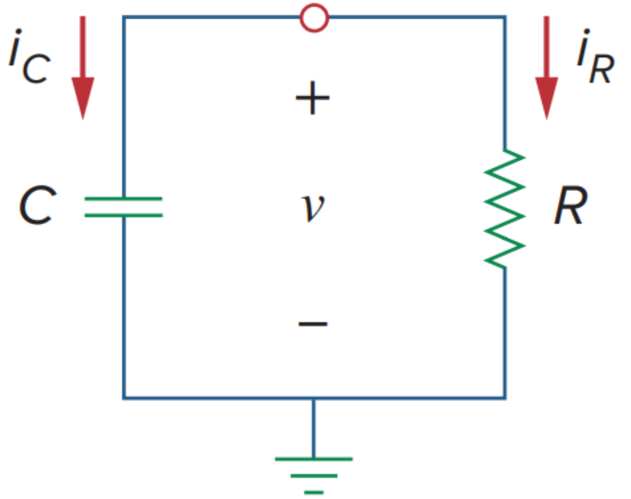
$$v(t) = V_0 e^{-\frac{t}{\tau}}$$

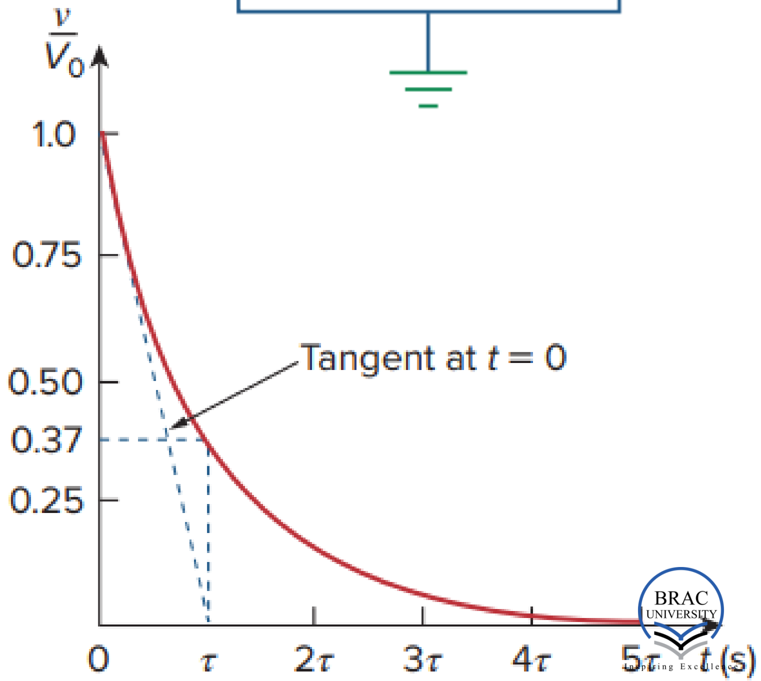
- At $t = \tau$,

$$v(t) = V_0 e^{-1}$$

$$\Rightarrow \quad v(t) = 0.368 \times V_0$$

- We can define the discharging time constant in this way,
- The *discharging time constant* is the time required for the response to fall to a factor of $^1/_e$ or 36.8% from an initial response $V_{initial}$ or V_0.
- Recall that the *charging time constant* is the time required for the response to reach to a factor of $(1 - 1/e)$ or 63.2% towards V_{final} from an initial response $V_{initial}$.

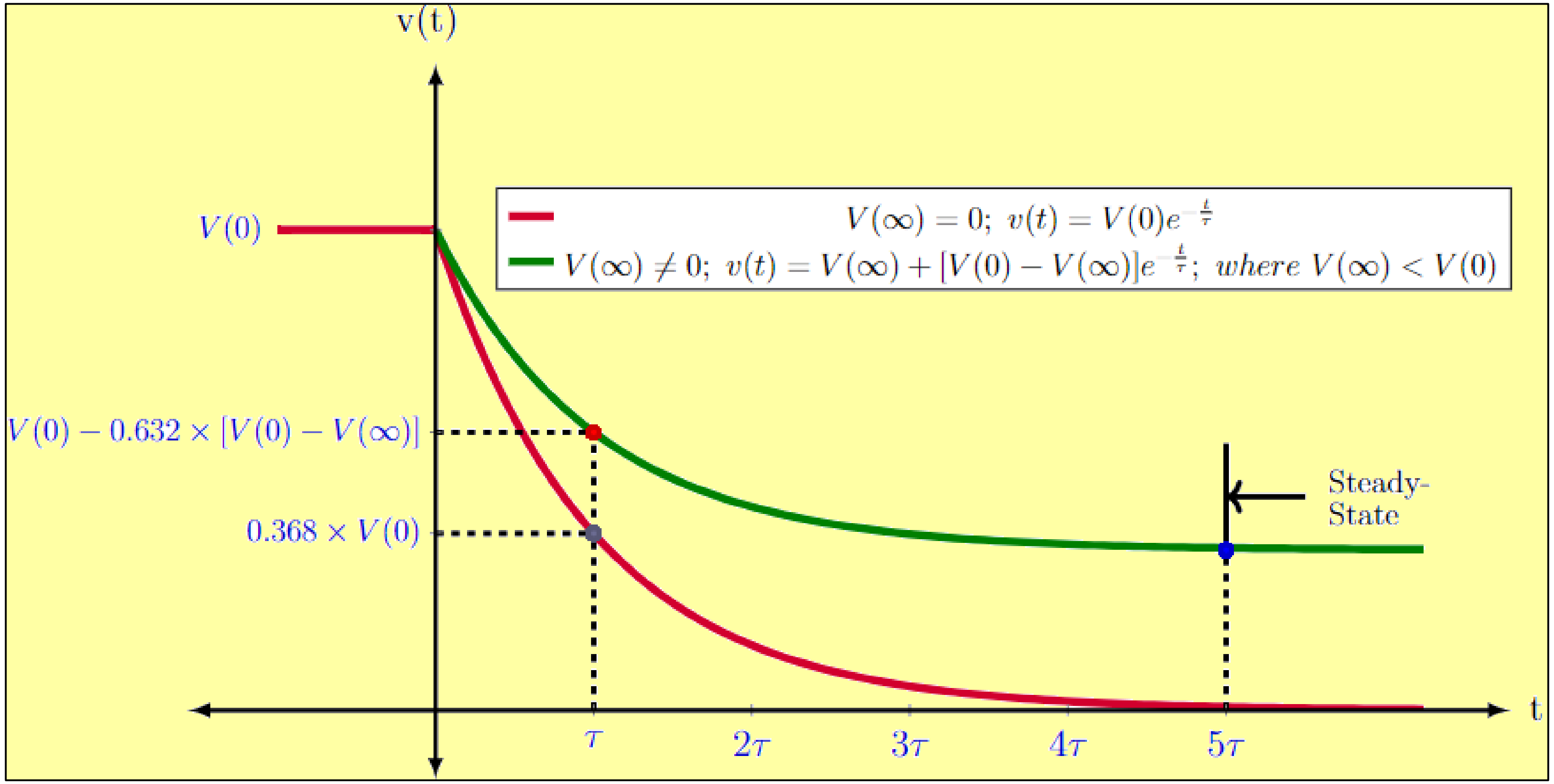




Significance of τ (discharging): 5τ Time

- As can be seen from the following plot, the capacitor voltage decreases to the final voltage approximately after 5 times the Time Constant (τ). In case where $V(\infty) = 0$, the capacitor is fully discharged from 5τ time onward. So, when designing circuits, the discharging time of a capacitor can be set by choosing R_{Th}.

- In the case that a capacitor is subjected to a final voltage lower than its initial voltage, the discharging τ is the time required for the response to decay to 63.2% from $V(0)$ towards $V(\infty)$. See Problem 6



Procedure

$$v(t) = V(\infty) + [V(0) - V(\infty)]e^{-t/\tau}$$

Determine the initial voltage of the capacitor $V_{initial}$ or $V(0)$

Consider only the active‡ portion of the circuit before switching. For example, if switching occurs at $t = 0$, consider the circuit for $t < 0$.

If the circuit includes any dc source (current or voltage), open the capacitor and determine the voltage at the open terminal. This is the $V(0)$. $V(0) = 0$ if there is no independent source in the circuit.

Determine the final voltage of the capacitor V_{final} or $V(\infty)$

Now consider the active‡ portion of the circuit after switching. For example, for $t > 0$.

Repeat the step. This time, the voltage across the capacitor is $V(\infty)$. Circuits with $V(\infty) = 0$ are called source free.

Determine the time constant (τ)

Again, only consider the active‡ portion after switching. For example, for $t > 0$.

Determine the Thevenin resistance (R_{Th}) as seen from the capacitor terminals

$\tau = R_{Th}C$

Determine $v(t)$

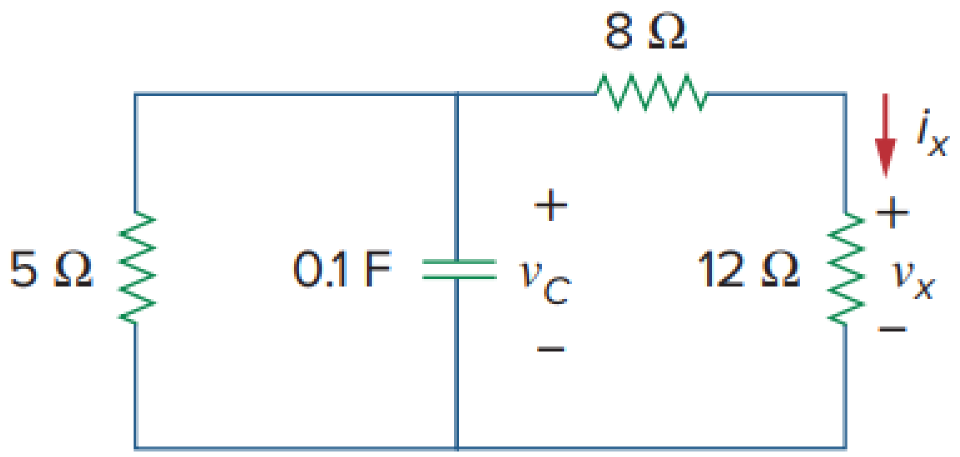
Plug in $V(0)$, $V(\infty)$, and τ into the equation for $v(t)$

Determine any other voltages or currents in the circuit using $v(t)$ and the circuit laws.

‡ active portion of the circuit excludes everything that has no influence on the capacitor

Example 1

- Let $V_C(0) = 15\ V$, Determine v_C, v_x, and i_x for $t > 0$.



<u>Solution</u>

The equivalent resistance as seen from the capacitor terminal is,

$$R_{eq} = (8 + 12)\,||\,5 = 4\ \Omega$$

Time constant, $\tau = R_{eq}C = 4 \times 0.1 = 0.4\ s$

Thus, for a source-free RC circuit, $V(\infty) = 0$. So,

$$v_C(t) = V(0)e^{-\frac{t}{\tau}} = 15e^{-2.5t}\ (V)$$

The voltage v_x can be found by simple voltage division.

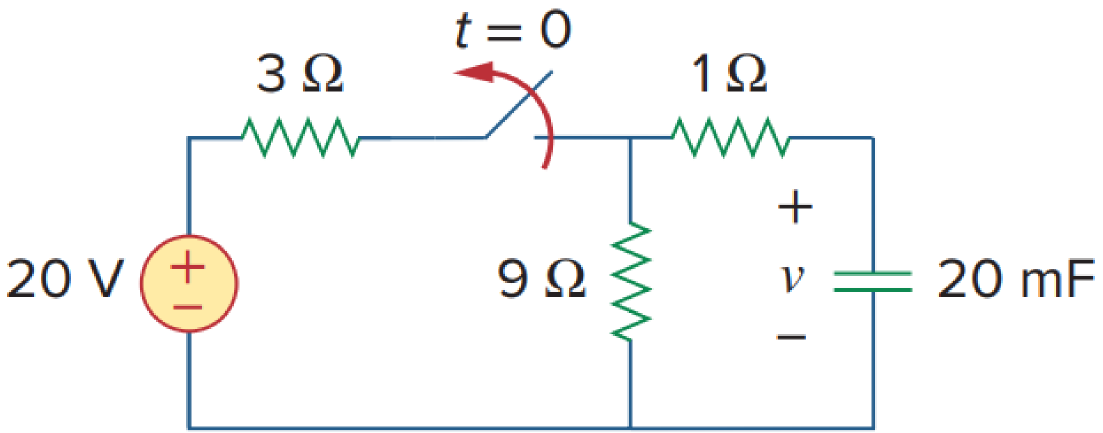
$$v_x(t) = \frac{12}{12+8} \times v_C(t) = 9e^{-2.5t}\ (V)$$

According to the Ohm's law,

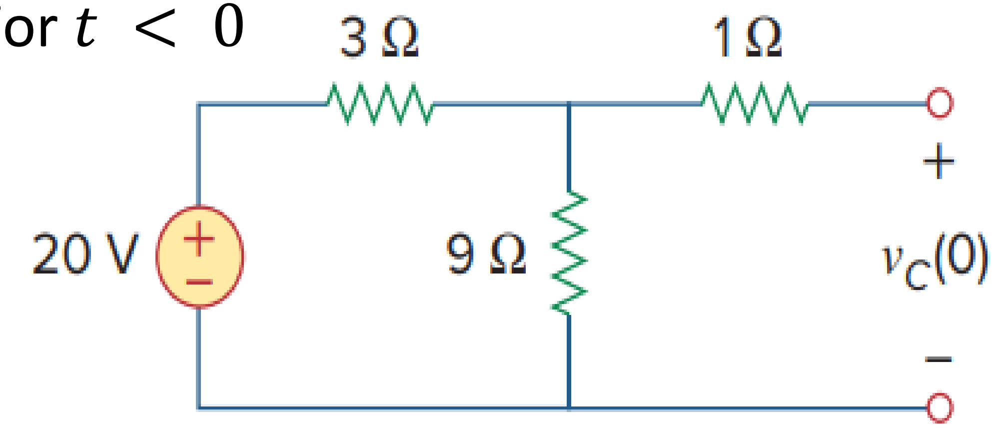
$$i_x = \frac{v_x}{12} = \frac{9e^{-2.5t}}{12} = 0.75e^{-2.5t}\ (\mathrm{A})$$

Example 2

- The switch in the circuit has been closed for a long time, and it is opened at $t = 0$. Find $v(t)$ for $t > 0$. Calculate the initial energy stored in the capacitor.



For $t < 0$



For $t < 0$, the switch is closed. With the capacitor open at dc, the circuit transforms into the one shown above.

No current flows through the $1\,\Omega$. So, the voltage across the $9\,\Omega$ is the $v_C(t)$ for $t < 0$,

$$v_C(t) = \frac{9}{9+3} \times 20 = 15\,V, \qquad t < 0$$

Since the voltage across the capacitor cannot change instantaneously,

$$v_C(0) = v_C(0^-) = 15\,V$$

Example 2: $t > 0$

For $t > 0$, the switch is open. The circuit transforms into the one shown above. As there is no independent source in the circuit, $V(\infty) = 0$.

The Thevenin resistance as seen from the capacitor terminal,

$$R_{Th} = 1 + 9 = 10\,\Omega$$

The time constant is,

$$\tau = R_{Th}C = 10 \times 20 \times 10^{-3} = 0.2\ s$$

So, the voltage across the capacitor for t > 0 is,

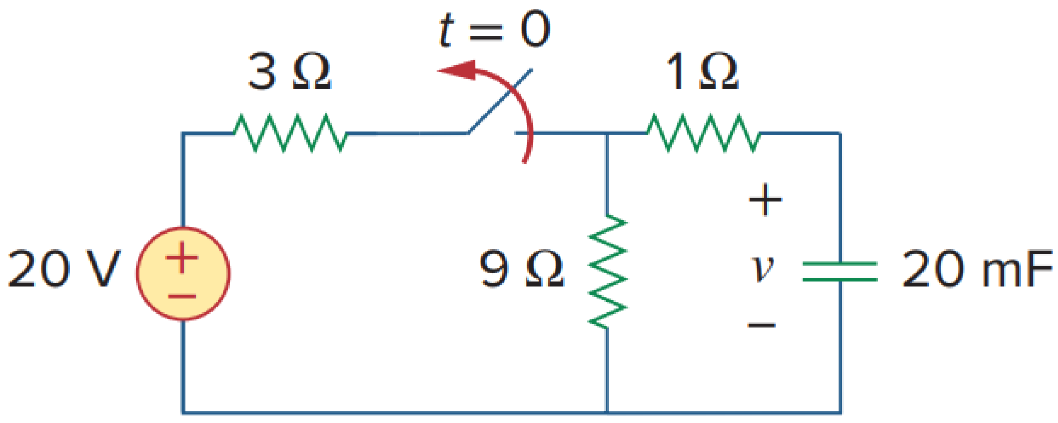
$$v_C(t) = V(0)e^{-\frac{t}{\tau}}$$

$$= 15e^{-5t}\ (V)$$

The initial energy stored in the capacitor is,

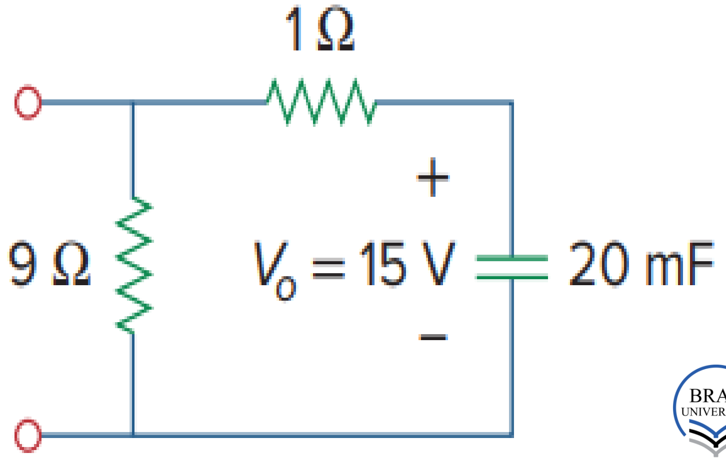
$$w_C(t) = \frac{1}{2}CV(0)^2$$

$$= \frac{1}{2} \times 20 \times 10^{-3} \times 15^2 = 2.25\ J$$



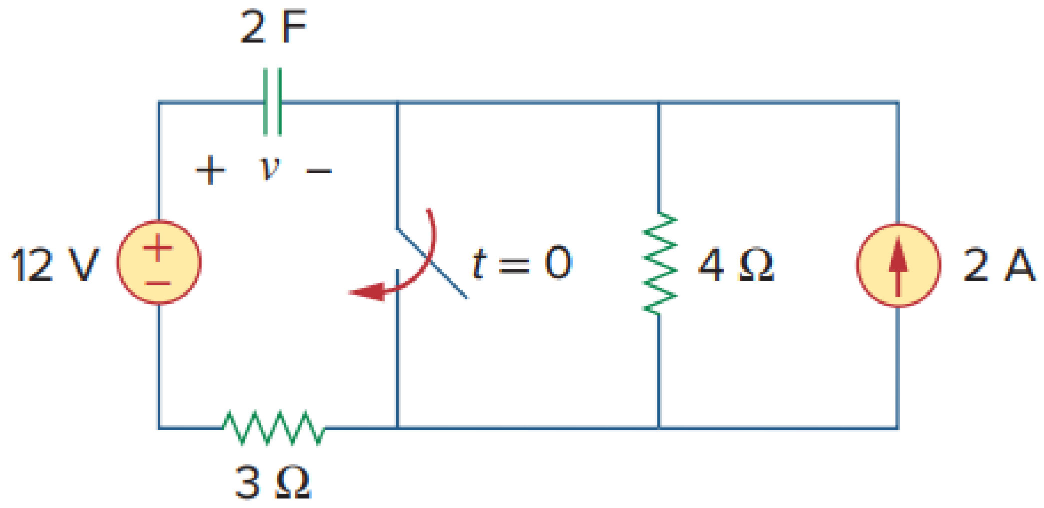
Original circuit

For $t > 0$

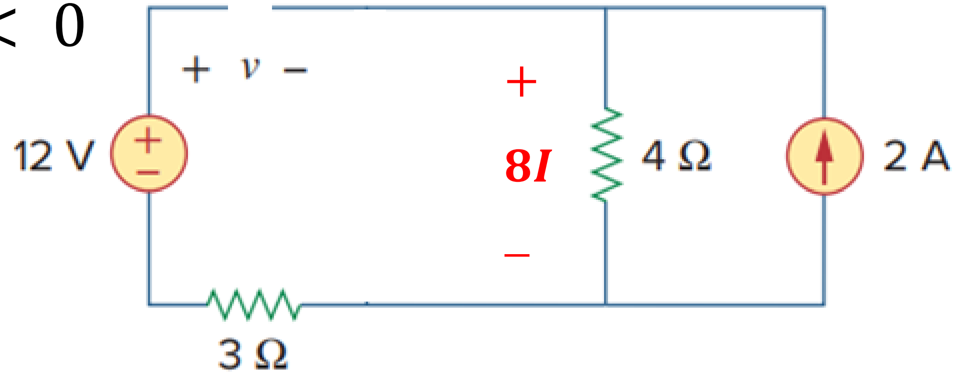


Example 3

- Calculate the capacitor voltage $v(t)$ for $t < 0$ and for $t > 0$.



For $t < 0$



For $t < 0$, the switch is open. With the capacitor open at dc, the circuit transforms into the one shown above.

The $2\,A$ current from the current source will flow only through the $4\,\Omega$ resistance. The voltage drop across the $4\,\Omega$ resistance is, $4 \times 2 = 8\,V$.

There is no voltage drop across the $3\,\Omega$ ($i = 0$ at open circuit). So,

$$v(t) = 12 - 8 = 4\,V, \qquad t < 0$$

Since the voltage across the capacitor cannot change instantaneously,

$$v(0) = v(0^-) = 4\,V$$

Example 3: $t > 0$

For $t > 0$, the switch is closed. With the capacitor again open at dc, the circuit transforms into the one shown above.

Again, there is no voltage drop across the $3\,\Omega$ ($i = 0$ at open circuit). So,

$$v(t) = 12\,V, \qquad \mathrm{t} > 0$$

This is the steady-state voltage across the capacitor for $t > 0$.

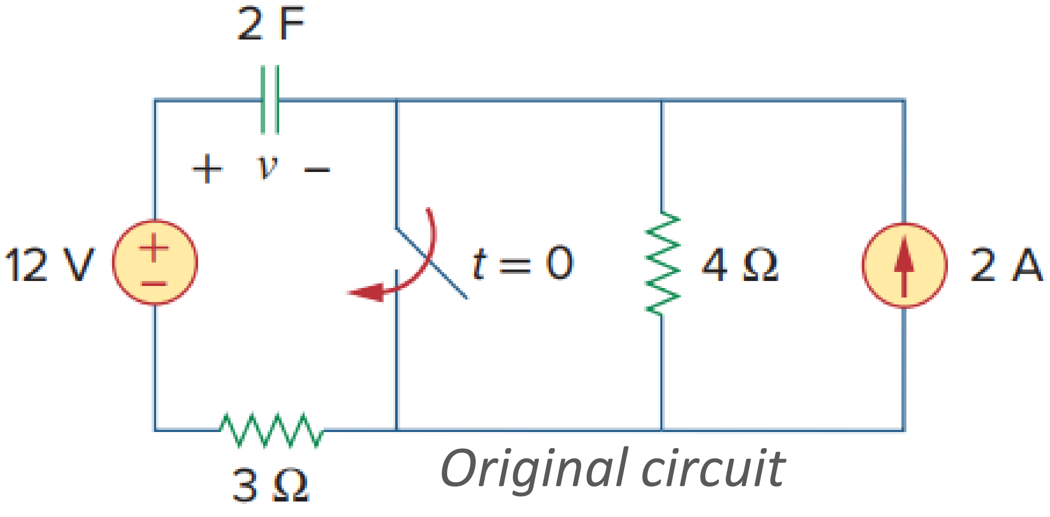
$$v(\infty) = 12\,V$$

The time constant is, $\tau = R_{Th}C = 3 \times 2 = 6\,s$

So,

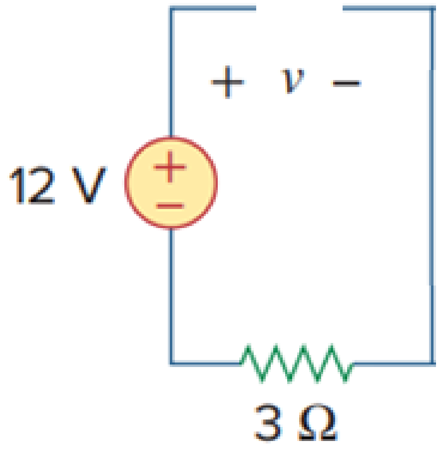
$$v(t) = V(\infty) + [V(0) - V(\infty)]e^{-t/\tau}$$

$$= 12 + [4 - 12]e^{-\frac{t}{6}} = 12 - 8e^{-\frac{t}{6}}$$

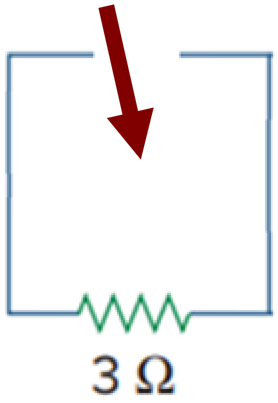


Original circuit

For $t > 0$

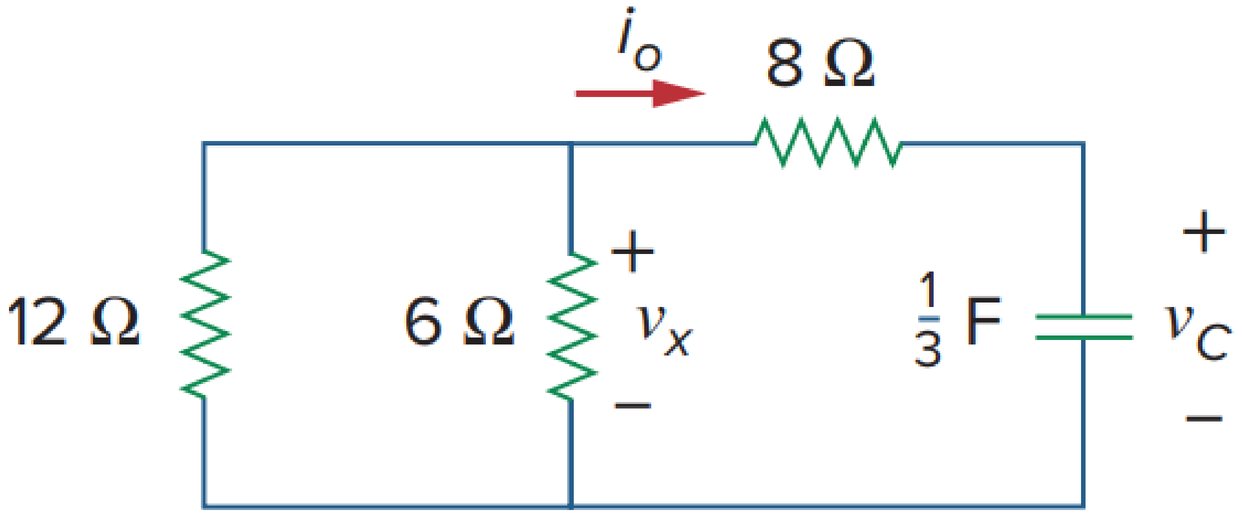


$R_{Th} = 3\,\Omega$



Problem 1

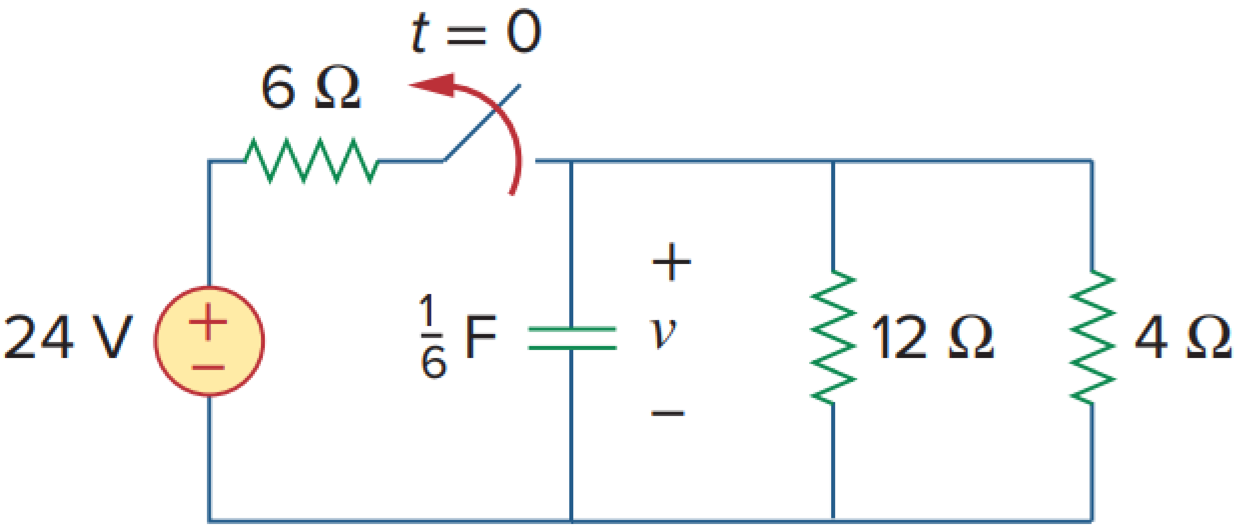
- Let $V_C\ (0) = 60\,V$, Find v_C, v_x, and i_x for $t > 0$.



Ans: $v_C = 60e^{-0.25t}\ V;\ v_x = 20e^{-0.25t}\ V;\ i_x = -5e^{-0.25t}\ A$

Problem 2

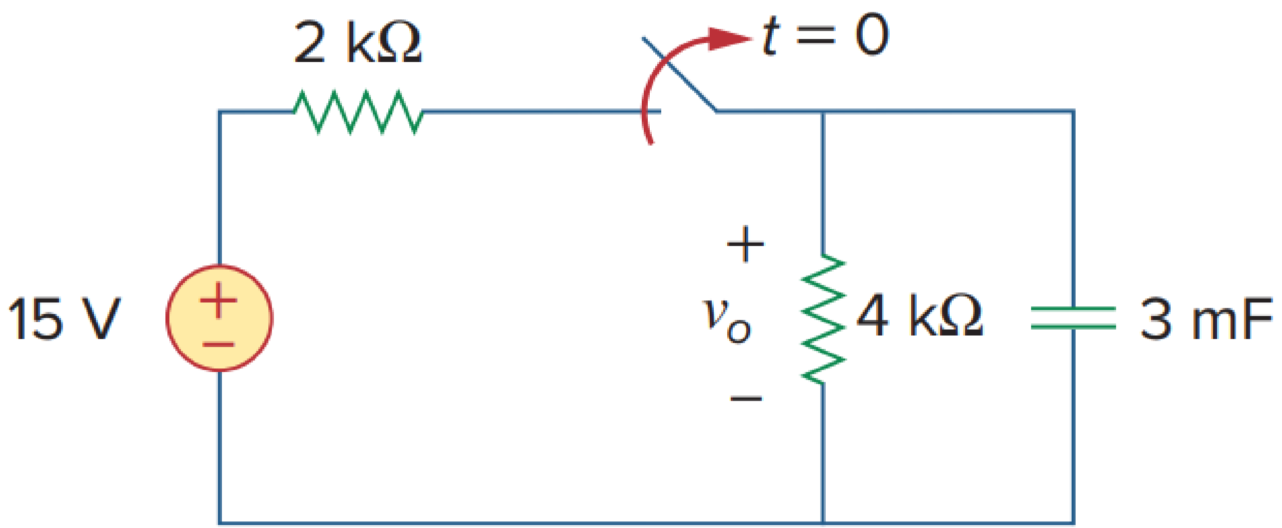
- The switch in the circuit has been closed for a long time, and it is opened at $t = 0$. Find $v(t)$ for $t > 0$. Calculate the initial energy stored in the capacitor.



Ans: $\boldsymbol{v(t) = 8e^{-2t}\ V;\ w_C(0) = 5.333\ J}$

Problem 3

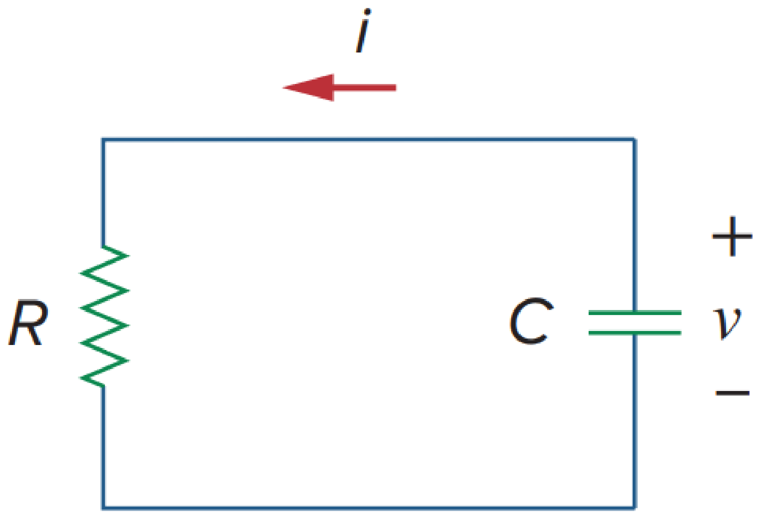
- The switch opens at $t = 0$. Find $v_0(t)$ for $t > 0$.



Ans: $\boldsymbol{v(t) = 10e^{-t/12}\ V}$

Problem 4

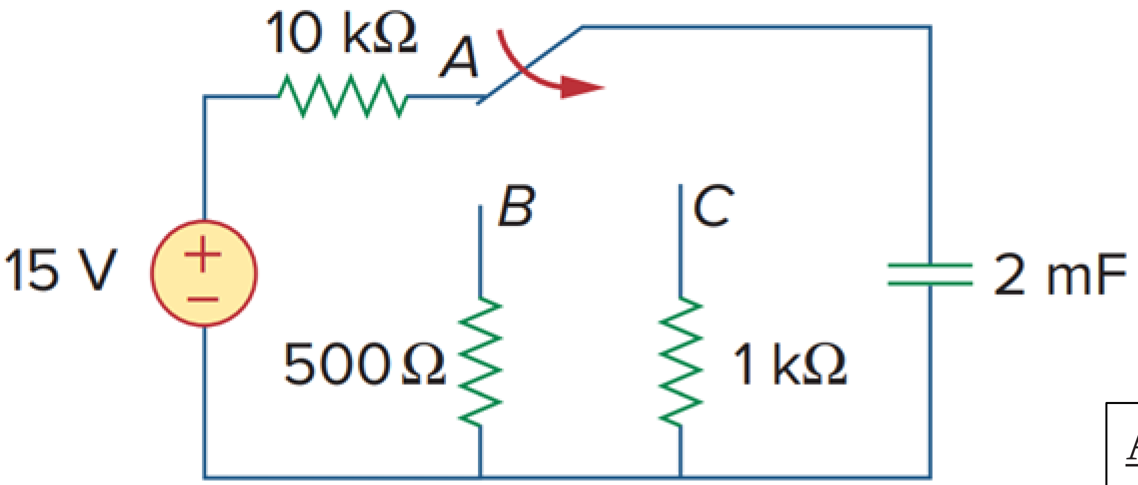
- For the circuit below, $v = 10e^{-4t}\ V$ and $i = 0.2e^{-4t} A$
  - (a) Find R and C.
  - (b) Determine the time constant.
  - (c) Calculate the initial energy in the capacitor.
  - (d) Obtain the time it takes to dissipate 50% of the initial energy.



Ans: $\boldsymbol{R = 50\ \Omega;\ C = 5\ mF;\ \tau = 0.25\ s;\ w_{C(0)} = 0.25\ J;\ t = 86\ ms}$

Problem 5

- Assume that the switch has been in position A for a long time and is moved to position B at $t = 0$. Then at $t = 1s$, the switch moves from B to C. Find $I_C(t)$ for $t > 0$.

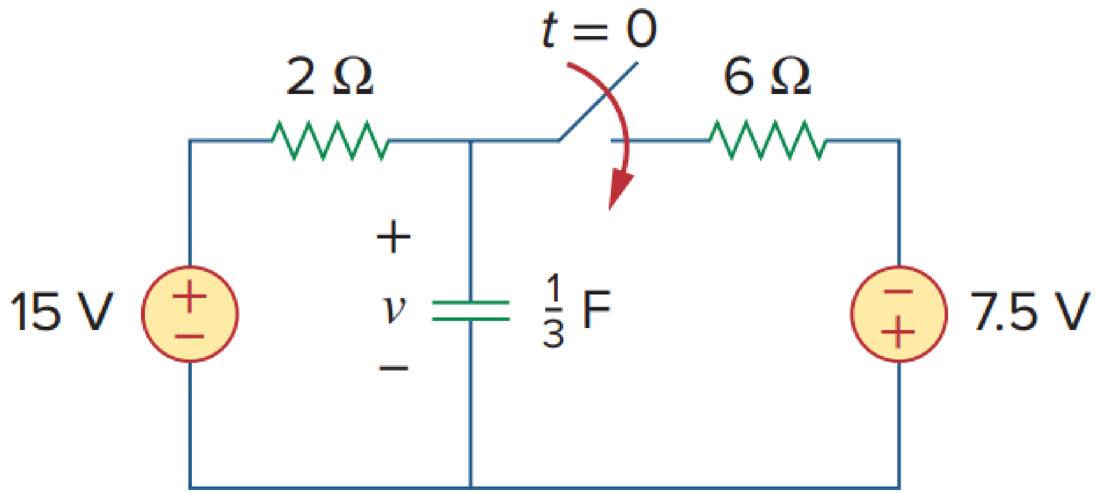


Ans: $\boldsymbol{v(t) = 15e^{-t}\, V\; for\; 0 < t < 1\, sec;}$

$\boldsymbol{v(t) = 5.518e^{-(t-1)/2}\, V\; for\; 1 < t < \infty\, sec;}$

Problem 6

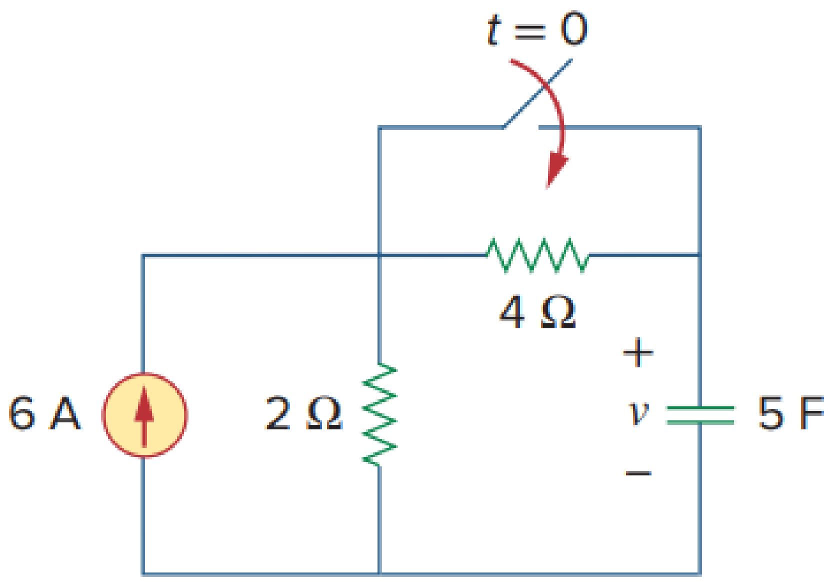
- Find $v(t)$ for $t > 0$ in the circuit shown below. Assume the switch has been open for a long time and is closed at $t = 0$. Calculate $v(t)$ at $t = 0.5s$.



Ans: $\boldsymbol{v_c(t) = 9.375 + 5.625e^{-2t}\ V\ for\ t > 0;\ v_c(0.5) = 11.444\ V}$

Problem 7

- Calculate the capacitor voltage for $t < 0$ and for $t > 0$.



Ans: $\boldsymbol{v(t) = 12\,V\ for\ t < 0;\ v(t) = 12\,V\ for\ t > 0}$

Problem 8

- The switch has been in position a for a long time. At t = 0 it moves to position b. Calculate $i(t)$ for all $t > 0$.

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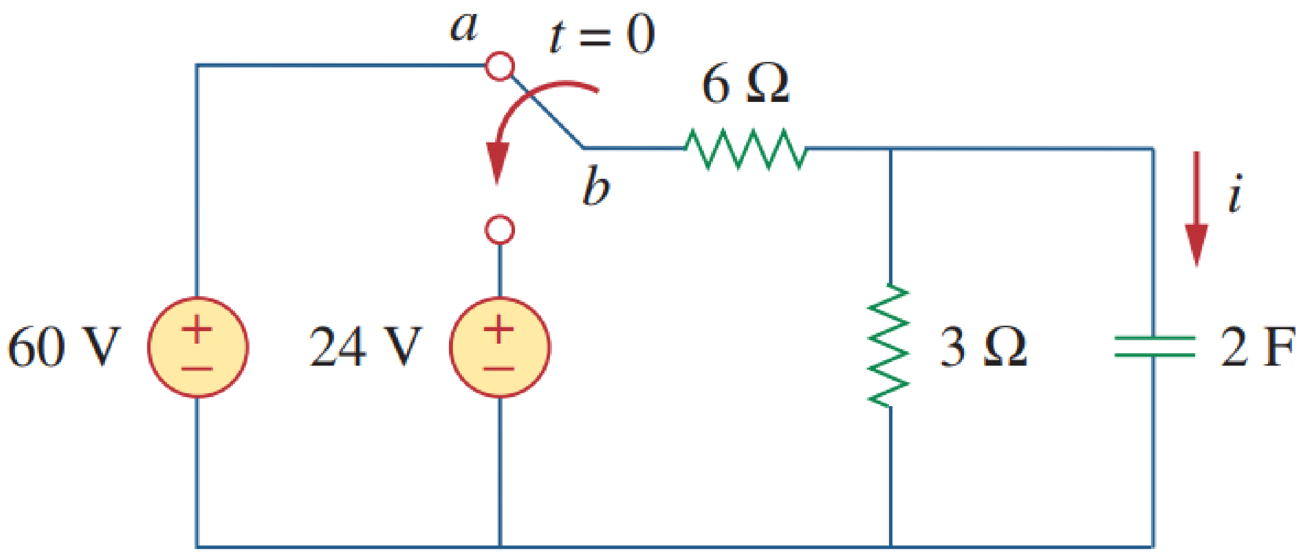
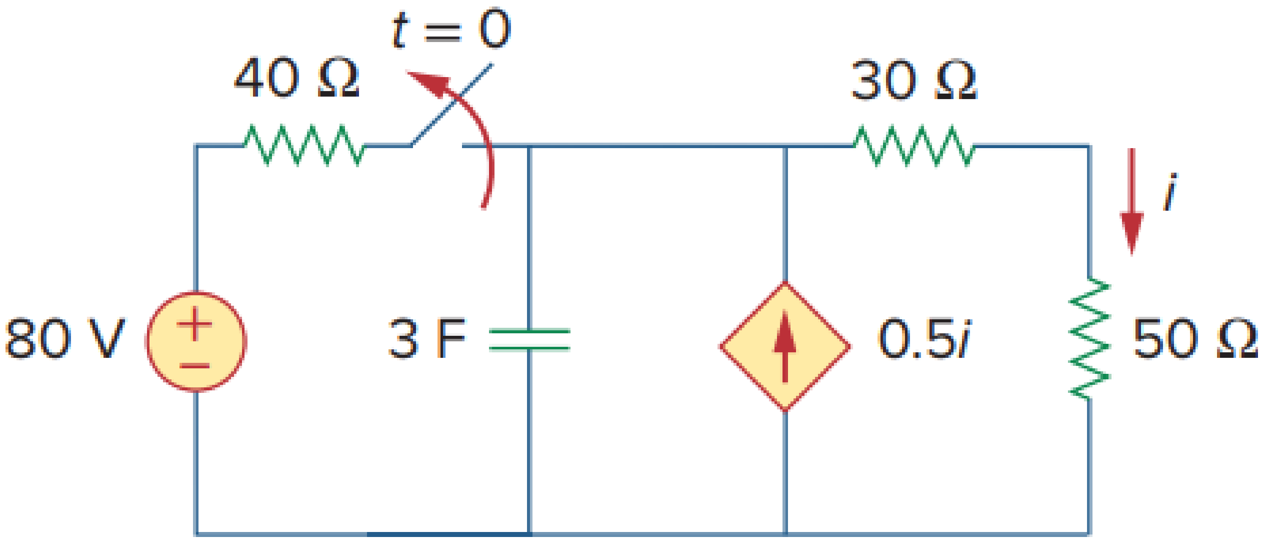


Ans: $\boldsymbol{i(t) = -6e^{-0.25t}\ A\ for\ t > 0}$

Problem 9

- Consider the circuit shown below. Find $i(t)$ for $t < 0$ and $t > 0$.



Ans: $\boldsymbol{i(t) = 0.8\,A\ for\ t < 0;\ i(t) = 0.8e^{-t/480}\,A\ for\ t > 0}$

Problem 11

- The figure below shows the voltage response of an RC circuit to a sudden DC voltage applied through an equivalent resistance of $4\ k\Omega$.

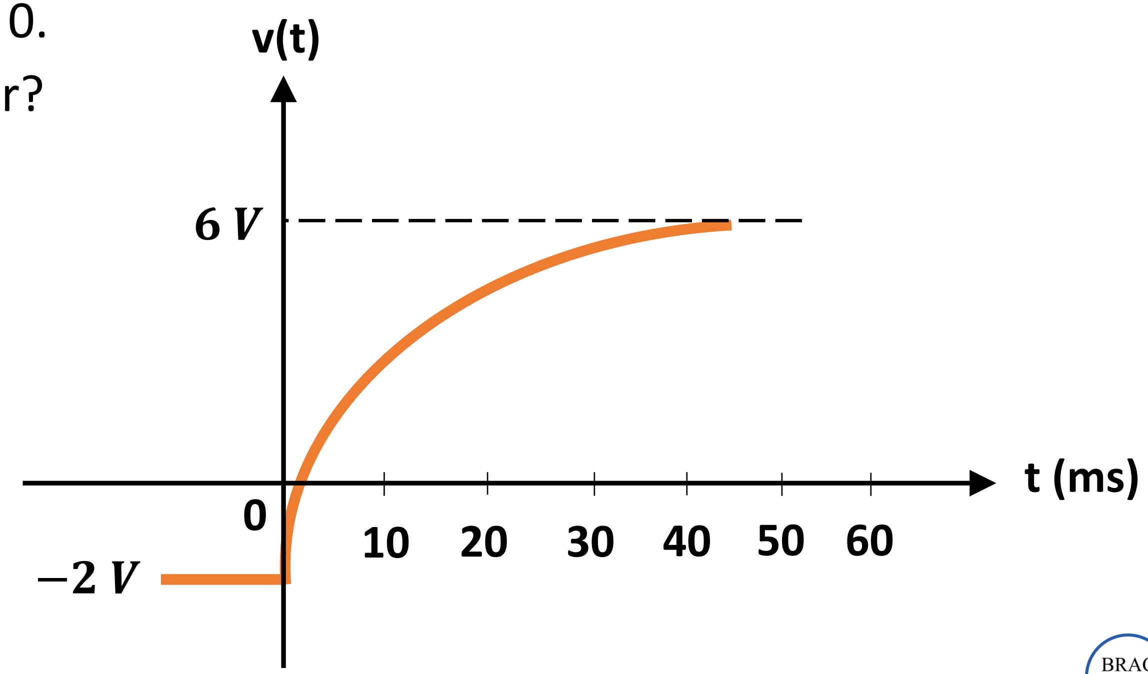
I. Define time constant.

II. Determine the approximate time constant from the figure.

III. Find the mathematical expression of v(t) for t > 0.

IV. What is the initial energy stored in the capacitor?

V. Draw the circuit diagram.

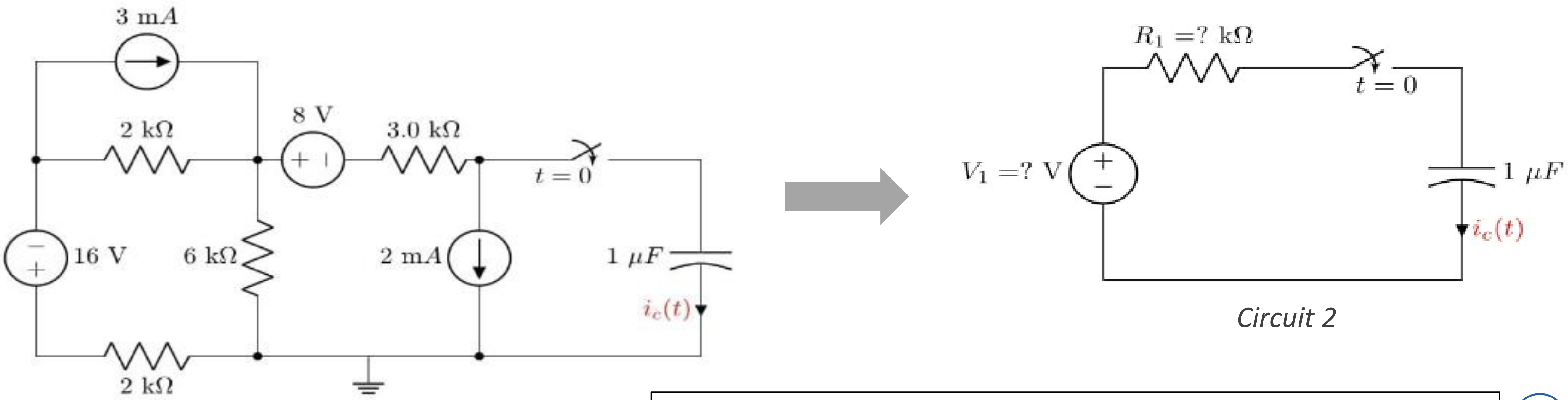


Ans: $(ii)\ \tau = \mathbf{9\ ms}$; $(iii)\ \boldsymbol{v(t) = 6 - 8e^{-1000t/9}\ I\ for\ t > 0}$; $(iv)\ \boldsymbol{w = 4.5 \times 10^{-6}\ J}$

Problem 12

I. Simplify the circuit 1 below so that it takes the form of the circuit 2. Determine the values of V_1 and R_1.

II. Perform transient analysis to determine $i_c(t)$ through the capacitor for $t > 0$.



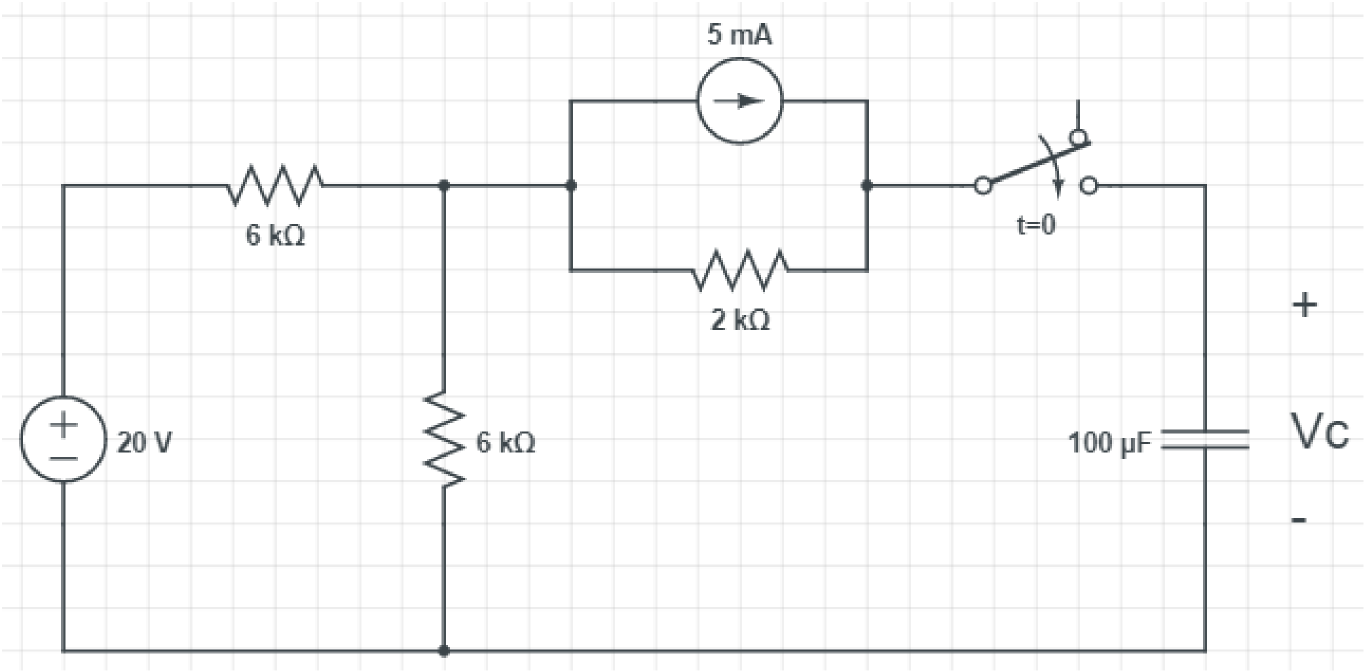
Circuit 1

Circuit 2

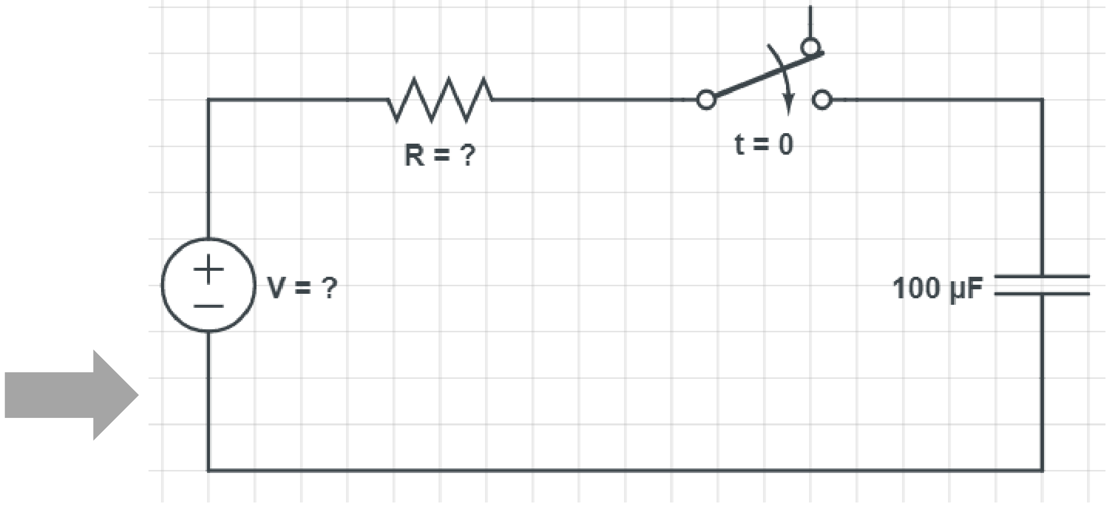
<u>*Ans*</u>: $\mathbf{V_1 = -24.8\ V}$; $\boldsymbol{R_1} = \mathbf{5.4\ k\Omega}$; $\boldsymbol{i_c(t) = -4.6 e^{-1000t/5.4} A}$

Problem 13

- Simplify the Circuit 1 below so that it takes the form of the Circuit 2. Determine the values of I and R.
- Perform transient analysis to determine $V_C(t)$ across the capacitor for $t > 0$.



Circuit 1

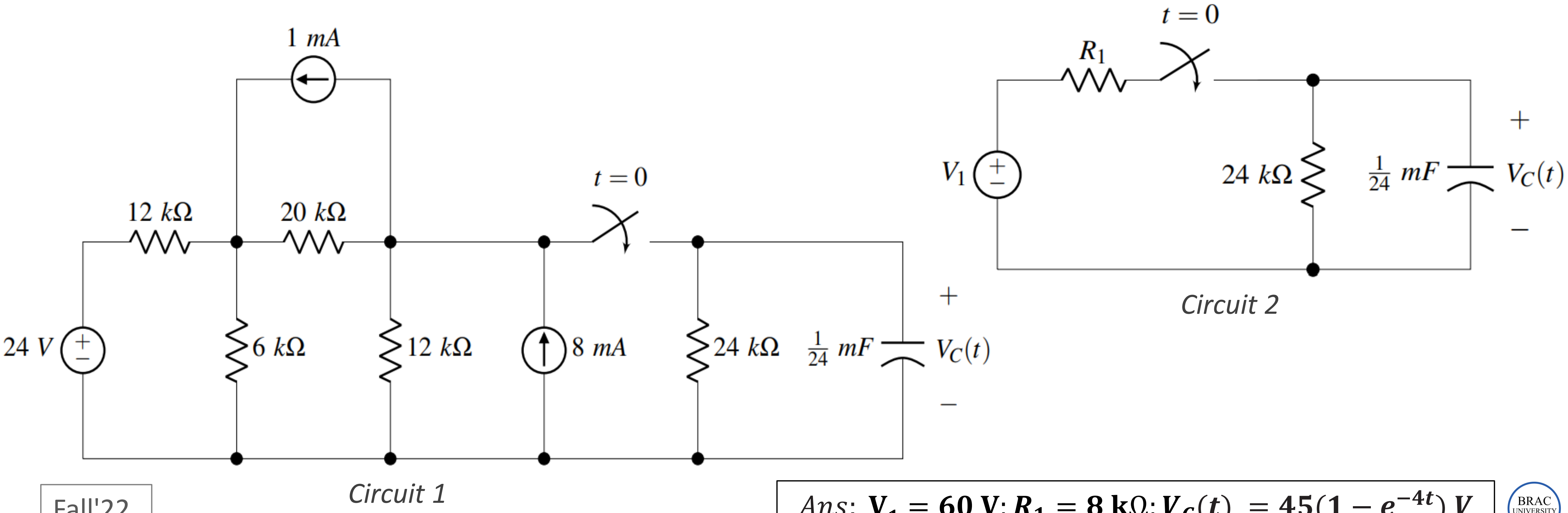


Circuit 2

Ans: $\mathbf{V = 20\ V; R = 5\ k\Omega;} \boldsymbol{V_C(t) = 20(1 - e^{-2t})\ V}$

Problem 14

- Simplify the Circuit 1 below so that it takes the form of the Circuit 2. Determine the values of V_1 and R_1. Perform transient analysis to determine $V_C(t)$ across the capacitor for $t > 0$.

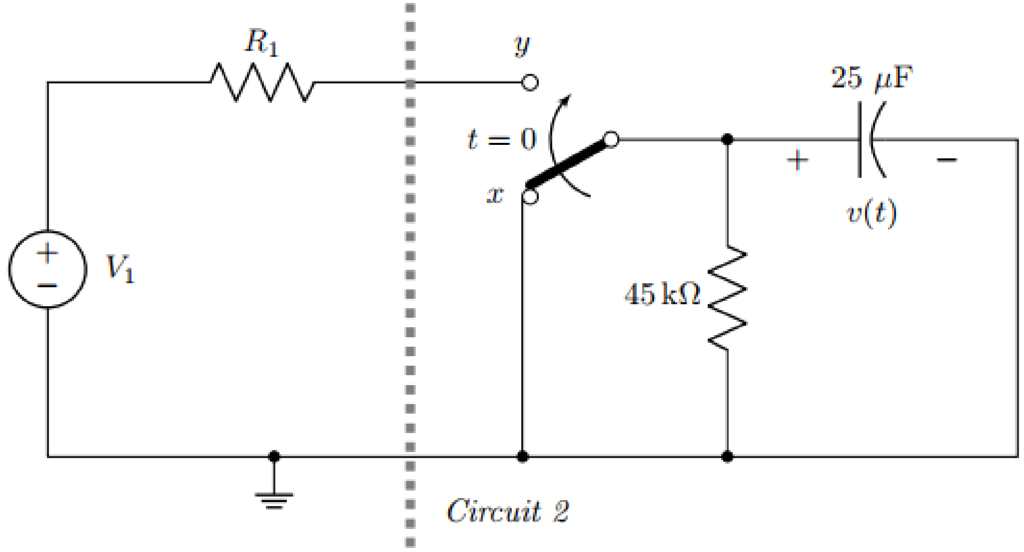


Fall'22

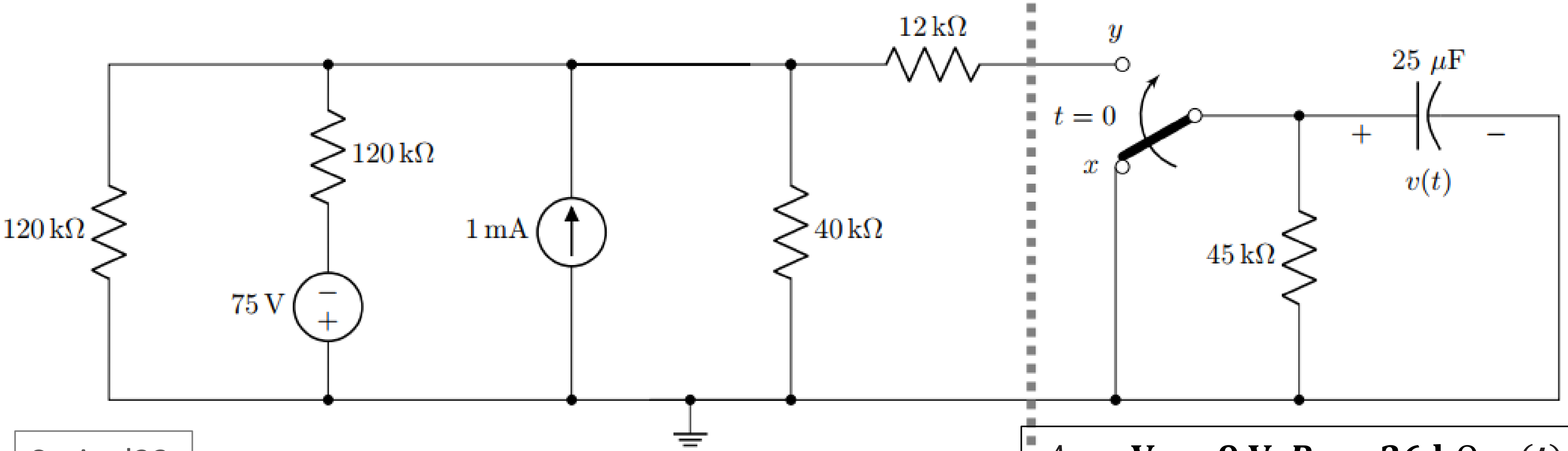
$\underline{Ans}$: $\mathbf{V_1 = 60\ V; R_1 = 8\ k\Omega; V_C(t) = 45(1 - e^{-4t})\ V}$

Problem 15

- Reduce the left portion with respect to the dashed grey line of Circuit 1 so that it takes the form of Circuit 2 as shown. Write down the values of V_1 and R_1.
- Now, analyse the Transient Behaviour of the circuit assuming that the switch moves from position x to position y at $t = 0$. Determine $v(t)$ for $t > 0$.



Circuit 2



Circuit 1

Spring'23

$\underline{Ans}$: $\mathbf{V_1 = 9\ V; R_1 = 36\ k\Omega; v(t) = 5(1 - e^{-2t})\ V}$