Chapter 10

1. (a) $\mathscr{E} = k\frac{Q_1}{r^2} = \frac{(9\times10^9)(4\,\mu\text{C})}{(1\,\text{m})^2} = \mathbf{36\times10^3\ N/C}$

   (b) $\mathscr{E} = k\frac{Q_1}{r^2} = \frac{(9\times10^9)(4\,\mu\text{C})}{(1\ \text{mm})^2} = \mathbf{36\times10^9\ N/C}$

   $\mathscr{E}$(1 mm): $\mathscr{E}$ (2 m) = 36×10^9: 36×10^3 = $\mathbf{1\times10^6}$

2. $\mathscr{E} = \frac{kQ}{r^2} \Rightarrow \sqrt{\frac{kQ}{\mathscr{E}}} = \sqrt{\frac{(9\times10^9)(2\mu\text{C})}{72\ \text{N/C}}} = \mathbf{15.81\ m}$

3. $C = \frac{Q}{V} = \frac{1200\,\mu\text{C}}{24\ \text{V}} = \mathbf{50\ \mu F}$

4. $Q = CV = (0.15\ \mu\text{F})(120\ \text{V}) = \mathbf{18\ \mu C}$

5. a. $1''\left[\frac{1\ \text{m}}{39.37''}\right] = 25.4\ \text{mm}$

   $\mathscr{E} = \frac{V}{d} = \frac{500\ \text{mV}}{25.4\ \text{mm}} = \mathbf{19.69\ V/m}$

   b. $\frac{25.4\ \text{mm}}{100} = 0.254\ \text{mm}$

   $\mathscr{E} = \frac{V}{d} = \frac{500\ \text{mV}}{0.254\ \text{mm}} = \mathbf{1.97\ kV/m}$

6. $V = \frac{Q}{C} = \frac{160\,\mu\text{C}}{6.8\,\mu\text{F}} = 23.53\ \text{V}$

   $\mathscr{E} = \frac{V}{d} = \frac{23.53\ \text{V}}{5\ \text{mm}} = \mathbf{4.71\ kV/m}$

7. $0.1''\left[\frac{1\ \text{m}}{39.37''}\right] = 2.54\ \text{mm}$

   $C = 8.85\times10^{-12}\varepsilon_r\frac{A}{d} = 8.85\times10^{-12}(1)\frac{(0.1\,\text{m}^2)}{2.54\ \text{mm}} = \mathbf{348.43\ pF}$

8. $C = 8.85\times10^{-12}\,\varepsilon_r\frac{A}{d} = 8.85\times10^{-12}(2.5)\frac{(0.1\,\text{m}^2)}{2.54\ \text{mm}} = \mathbf{871.06\ pF}$

9. $C = 8.85\times10^{-12}\varepsilon_r\frac{A}{d} \Rightarrow d = \frac{8.85\times10^{-12}(4)(0.15\,\text{m}^2)}{2\,\mu\text{F}} = \mathbf{2.66\ \mu m}$

10. $C = \varepsilon_r C_o \Rightarrow \varepsilon_r = \dfrac{C}{C_o} = \dfrac{6.8\text{ nF}}{1360\text{ pF}}$ = **5 (mica)**

11. a. $C = 8.85 \times 10^{-12}(7)\dfrac{(0.08\text{ m}^2)}{0.2\text{ mm}}$ = **24.78 nF**

b. $\mathscr{E} = \dfrac{V}{d} = \dfrac{80\text{ V}}{0.2\text{ mm}}$ = **400 kV/m**

c. $Q = CV$ = (24.78 nF)(200 V) = **4.96 μC**

12. a. $C = \dfrac{1}{2}(4.7\ \mu\text{F})$ = **2.35 μF**

b. $C = 2(4.7\ \mu\text{F})$ = **9.4 μF**

c. $C = 20(4.7\ \mu\text{F})$ = **94 μF**

d. $C = \dfrac{(4)\left(\dfrac{1}{3}\right)}{\left(\dfrac{1}{4}\right)}(4.7\ \mu\text{F})$ = **25.1 μF**

13. $d = \dfrac{8.85\times10^{-12}\varepsilon_r A}{C} = \dfrac{(8.85\times10^{-12})(5)(0.02\text{ m}^2)}{6800\text{ pF}} = 130.15\ \mu\text{m}$

$d = 130.15\ \mu\text{m}\left[\dfrac{10^{-6}\text{ m}}{1\ \mu\text{m}}\right]\left[\dfrac{39.37\text{ in.}}{1\text{ m}}\right]\left[\dfrac{1000\text{ mils}}{1\text{ in.}}\right] = 5.12\text{ mils}$

$5.12\text{ mils}\left[\dfrac{5000\text{ V}}{\text{mil}}\right]$ = **25.6 kV**

14. mica: $\dfrac{1200\text{ V}}{\dfrac{5000\text{ V}}{\text{mil}}} = 1200\text{ V}\left[\dfrac{\text{mil}}{5000\text{ V}}\right] = 0.24\text{ mils}$

$0.24\text{ mils}\left[\dfrac{1''}{1000\text{ mils}}\right]\left[\dfrac{1\text{ m}}{39.37\text{ in.}}\right]$ = **6.10 μm**

15. $\dfrac{200}{1\times10^6}(22\ \mu\text{F})/°\text{C} = 4400\text{ pF}/°\text{C}$

$\dfrac{4400\text{ pF}}{°\text{C}}[\Delta\text{T}] = \dfrac{4400\text{ pF}}{°\text{C}}[80°\text{C}]$ = **0.35 μF**

16. J = ±5%, Size $\Rightarrow$ 40 pF ± 2 pF, **38 pF $\rightarrow$ 42 pF**

17. F = ±1%, Size $\Rightarrow 47 \times 10^1\ \mu\text{F} = 470\ \mu\text{F} \pm 4.7\ \mu\text{F}$, **465.3 μF $\rightarrow$ 474.7 μF**

18. K = ±10%, Size $\Rightarrow 18 \times 10^2$ pF = **1800 pF ± 180 pF, 1620 pF $\rightarrow$ 1980 pF**

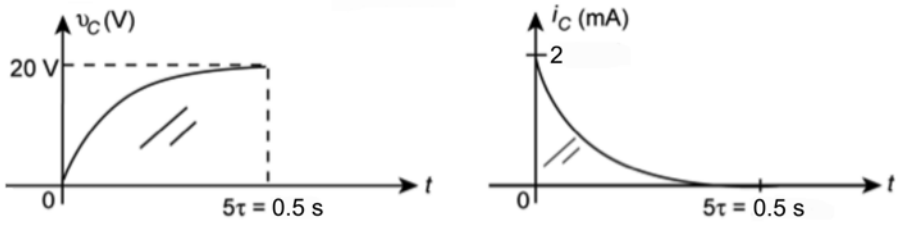
19. a. $\tau = RC = (10 \times 10^3\ \Omega)(10\ \mu\text{F})$ = **100 ms**

b. $v_C = E(1 - e^{-t/\tau})$ = **20 V(1 – $e^{-t/100\ \text{ms}}$)**

c. 1τ = 0.632(20 V) = **12.64 V**, 3τ = 0.95(20 V) = **19 V**
5τ = 0.993(20 V) = **19.87 V**

d. $i_C = \dfrac{20\ \text{V}}{10\ \text{k}\Omega} e^{-t/\tau}$ = **2 mA$e^{-t/100\ \text{ms}}$**
$v_R = Ee^{-t/\tau}$ = **20 V$e^{-t/100\ \text{ms}}$**

e.



20. a. τ = *RC* = (100 kΩ)(10 μF) = **1 s**

b. $v_C = E(1 - e^{-t/\tau})$ = **20 V(1 – $e^{-t/1\text{s}}$)**

c. 1τ = **12.64 V**, 3τ = **19 V**, 5τ = **19.87 V**

d. $i_C = \dfrac{20\ \text{V}}{100\ \text{k}\Omega} e^{-t/\tau}$ = **200 μA $e^{-t/1\text{s}}$**
$v_R = Ee^{-t/\tau}$ = **20V $e^{-t/1\text{s}}$**

e. Same as problem 21 with 5τ = 5 s and I_m = 200 μA

21. a. τ = *RC* = (2.2 kΩ + 3.3 kΩ)1 μF = (5.5 kΩ)(1 μF) = **5.5 ms**

b. $v_C = E(1 - e^{-t/\tau})$ = **100 V(1 – $e^{-t/5.5\ \text{ms}}$)**

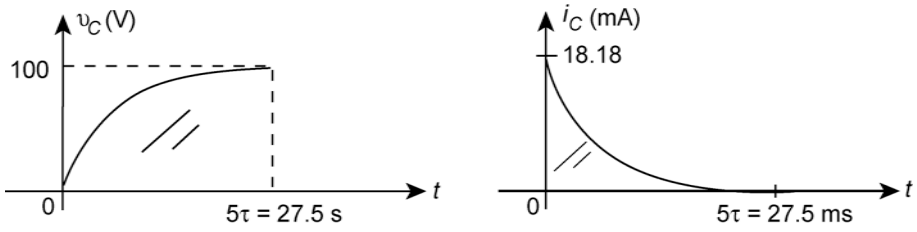
c. 1τ = **63.21 V**, 3τ = **95.02 V**, 5τ = **99.33 V**

d. $i_C = \dfrac{E}{R_T} e^{-t/\tau} = \dfrac{100\ \text{V}}{5.5\ \text{k}\Omega} e^{-t/\tau}$ = **18.18 mA$e^{-t/5.5\ \text{ms}}$**

$V_{R_2} = \dfrac{3.3\ \text{k}\Omega\ (100\ \text{V})}{3.3\ \text{k}\Omega + 2.2\ \text{k}\Omega} = 60\ \text{V}$

v_{R_2} = **60 V$e^{-t/5.5\ \text{ms}}$**

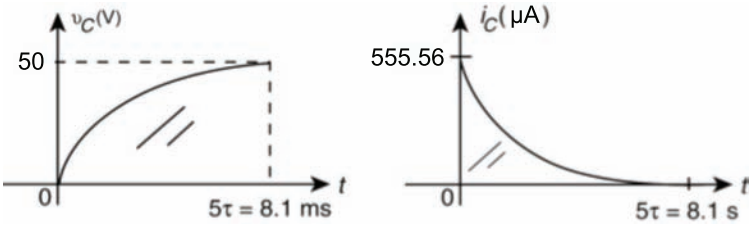
e.



22. a. $R = 68\ \text{k}\Omega + 22\ \text{k}\Omega = 90\ \text{k}\Omega$
$\tau = RC = (90\ \text{k}\Omega)(18\ \mu\text{F}) = \mathbf{1.62\ s}$

b. $v_C = E(1 - e^{-t/\tau}) = (80\ \text{V} - 30\ \text{V})(1 - e^{-t/\tau})$
$v_C = \mathbf{50\ V(1 - e^{-t/1.62s})}$

c. $i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{50\ \text{V}}{90\ \text{k}\Omega}e^{-t/\tau} = \mathbf{555.56\ \mu A e^{-t/1.62s}}$

d. 

23. a. $\mathbf{100\ \mu s}$

b. $v_C = 12\ \text{V}(1 - e^{-50\mu s/100\mu s}) = 12\ \text{V}(1 - e^{-0.5}) = 12\ \text{V}(1 - 0.607)$
$= 12\ \text{V}(.393) = \mathbf{4.72\ V}$

c. $v_C = 12\ \text{V}(1 - e^{-1\text{ms}/100\mu s}) = 12\ \text{V}(1 - e^{-10}) = 12\ \text{V}(1 - 45.4 \times 10^{-6})$
$\cong 12\ \text{V}(999.95 \times 10^{-3}) \cong \mathbf{12\ V}$

24. a. $\tau = 20\ \text{ms}, 5\tau = 5(20\ \text{ms}) = \mathbf{100\ ms}$

b. $\tau = RC, R = \dfrac{\tau}{C} = \dfrac{20\ \text{ms}}{10\ \mu\text{F}} = \mathbf{2\ k\Omega}$

c. $v_C\ (20\ \text{ms}) = 40\ \text{mV}(1 - e^{-20\text{ms}/20\text{ms}}) = 40\ \text{mV}(1 - e^{-1})$
$= 40\ \text{mV}(1 - .368) = 40\ \text{mV}(0.632) = \mathbf{25.28\ mV}$

d. $v_C = 40\ \text{mV}(1 - e^{-10}) = 40\ \text{mV}(1 - 45 \times 10^{-6}) \cong \mathbf{40\ mV}$

e. $Q = CV = (10\ \mu\text{F})(40\ \text{mV}) = \mathbf{0.4\ \mu C}$

f. $\tau = RC = (1000 \times 10^6\ \Omega)(10\ \mu\text{F}) = 10 \times 10^3\ \text{s}$
$5\tau = 50 \times 10^3\ \text{s}\left[\dfrac{1\ \text{min}}{60\ \text{s}}\right]\left[\dfrac{1\ \text{h}}{60\ \text{min}}\right] = \mathbf{13.89\ h}$

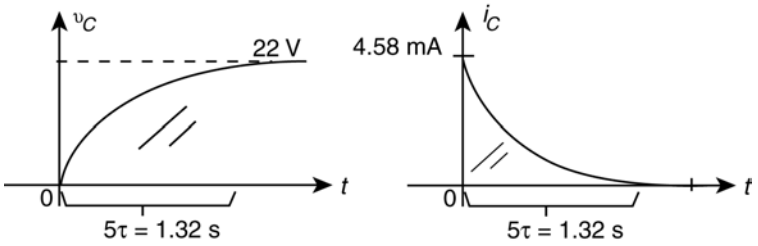
25. a. $\tau = RC = (4.7\ \text{k}\Omega)(56\ \mu\text{F}) = \mathbf{263.2\ ms}$

b. $v_C = E(1 - e^{-t/\tau}) = \mathbf{22\ V(1 - e^{-t/263.2ms})}$
$i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{22\ \text{V}}{4.7\ \text{k}\Omega}e^{-t/263.2\text{ms}} = \mathbf{4.68\ mA e^{-t/263.2ms}}$

c. $v_C(1\ \text{s}) = 22\ \text{V}(1 - e^{-1\text{s}/263.2\text{ms}}) = 22\ \text{V}(1 - e^{-3.8})$
$= 22\ \text{V}(1 - 22.37 \times 10^{-3}) = \mathbf{21.51\ V}$
$i_C\ (1\ \text{s}) = 4.68\ \text{mA}e^{-1\text{s}/263.2\text{ms}} = 4.68\ \text{mA}(22.37 \times 10^{-3}) = \mathbf{0.105\ mA}$

d. $v_C = \mathbf{21.51\ V}e^{-t/263.2\text{ms}}$
$i_C = \dfrac{21.51\ \text{V}}{4.7\ \text{k}\Omega}e^{-t/263.2\text{ms}} = \mathbf{4.58\ mA e^{-t/263.2ms}}$

e.



26. a. $\tau = RC = (3\ \text{k}\Omega + 2\ \text{k}\Omega)(2\ \mu\text{F}) = 10\ \text{ms}$

$\upsilon_C = \mathbf{30\ V(1 - e^{-t/10ms})}$

$i_C = \dfrac{30\ \text{V}}{5\ \text{k}\Omega} e^{-t/10\text{ms}} = \mathbf{6\ mA^{-t/10ms}}$

$\upsilon_{R_1} = i_C R_1 = (6\ \text{mA})(3\ \text{k}\Omega)e^{-t/10\text{ms}} = \mathbf{18\ V}e^{\mathbf{-t/10ms}}$

b. 100ms: $e^{-10} = 45.4 \times 10^{-6}$

$\upsilon_C = 30\ \text{V}(1 - 45.4 \times 10^{-6}) = \mathbf{30\ V}$

$i_C = 6\ \text{mA}(45.4 \times 10^{-6}) = \mathbf{0.27\ \mu A}$

$\upsilon_{R_1} = 18\ \text{V}(45.4 \times 10^{-6}) = \mathbf{0.82\ mV}$

c. 200 ms: $\tau' = R_2C = (2\ \text{k}\Omega)(2\ \mu\text{F}) = 4\ \text{ms}$

$\upsilon_C = \mathbf{30\ V}e^{\mathbf{-t/4ms}}$

$i_C = -\dfrac{30\ \text{V}}{2\ \text{k}\Omega} e^{-t/4\text{ms}} = \mathbf{-15\ mA}e^{\mathbf{-t/4ms}}$

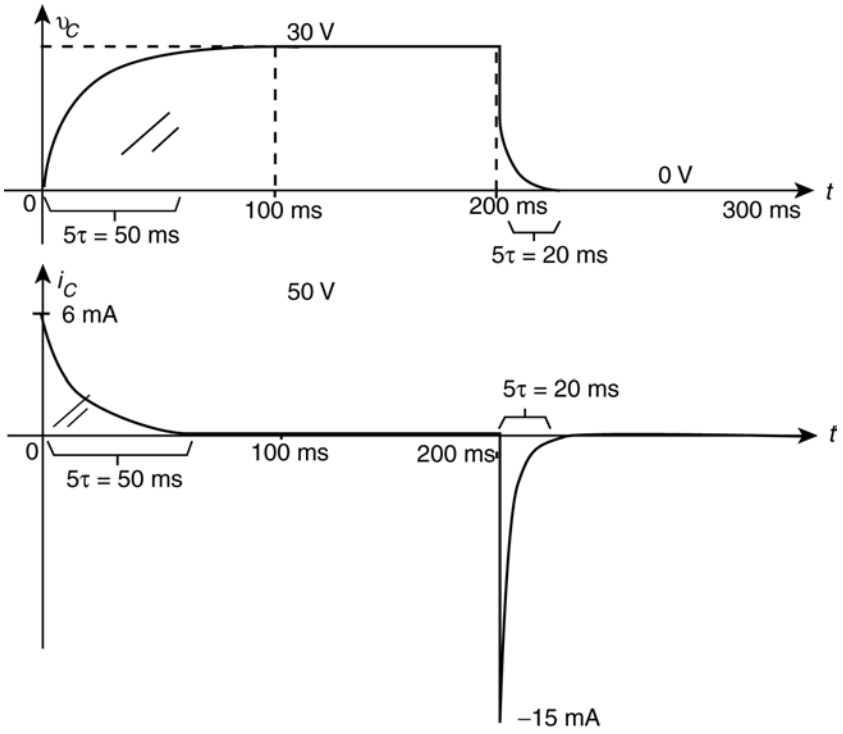
At $t = 0$: $\upsilon_{R_2} = i_C R_2 = (6\ \text{mA})(2\ \text{k}\Omega)e^{-t/10\ \text{ms}}$

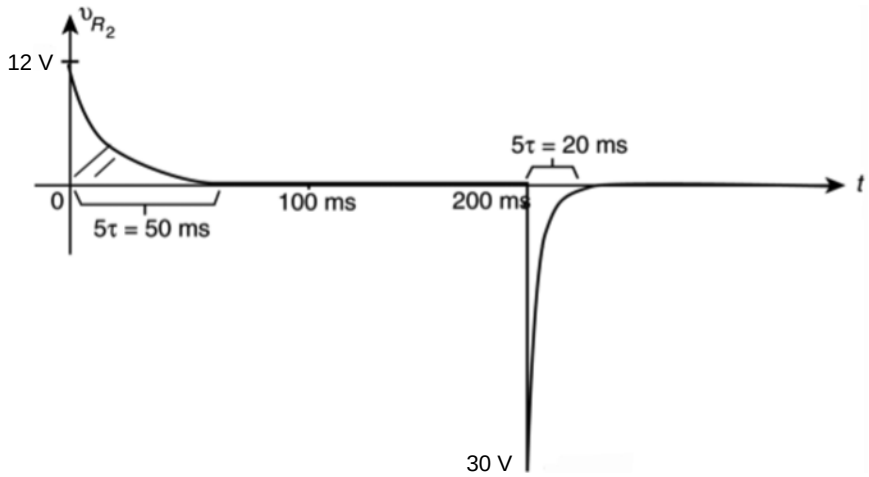
$= \mathbf{12\ V}e^{\mathbf{-t/10\ ms}}$

At $t = 200$ ms: $\upsilon_{R_2} = -(15\ \text{mA})(2\ \text{k}\Omega)e^{-t/4\ \text{ms}}$

$= \mathbf{-30\ V}e^{\mathbf{-t/4\ ms}}$

d.





27. a. $\tau = RC = (120\ \text{k}\Omega)(47\ \text{pF}) = 5.64\ \mu\text{s}$

$$\boldsymbol{v_C = 40\ \text{V}(1 - e^{-t/5.64\mu\text{s}})}$$

$$i_C = \frac{40\ \text{V}}{120\ \text{k}\Omega} e^{-t/5.64\mu\text{s}} = \boldsymbol{333.33\ \mu\text{A}e^{-t/5.64\mu\text{s}}}$$

b. $\tau' = RC = (270\ \text{k}\Omega)(47\ \text{pF}) = 12.69\ \mu\text{s}$

At 5τ

$v_C = 40\ \text{V}(1 - e^{-5\tau'/\tau})$

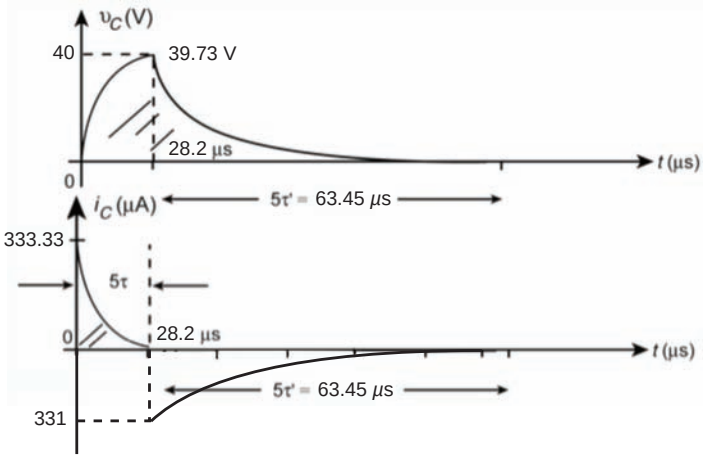
$= 40\ \text{V}(1 - e^{-5}) = 40\ \text{V}(1 - 6.74 \times 10^{-3})$

$= 39.73\ \text{V}$

$\therefore\ v_C = \boldsymbol{39.73\ \text{V}e^{-t/12.69\mu\text{s}}}$

$$i_C = -\frac{39.73\ \text{V}}{270\ \text{k}\Omega} e^{-t/12.69\mu\text{s}} = \boldsymbol{-331\ \mu\text{A}e^{-t/12.69\mu\text{s}}}$$

c.



28. a. $\tau = RC = (2\ \text{m}\Omega)(1000\ \mu\text{F}) = 2\ \mu\text{s}$

$5\tau = \mathbf{10\ \mu s}$

b. $I_m = \dfrac{V}{R} = \dfrac{12\ \text{V}}{2\ \text{m}\Omega} = \mathbf{6\ kA}$

c. yes

29. a. $v_C = V_f + (V_i - V_f)e^{-t/\tau}$

$\tau = RC = (4.7\ \text{k}\Omega)(4.7\ \mu\text{F}) = 22.1\ \text{ms},\ V_f = 40\ \text{V},\ V_i = 6\ \text{V}$

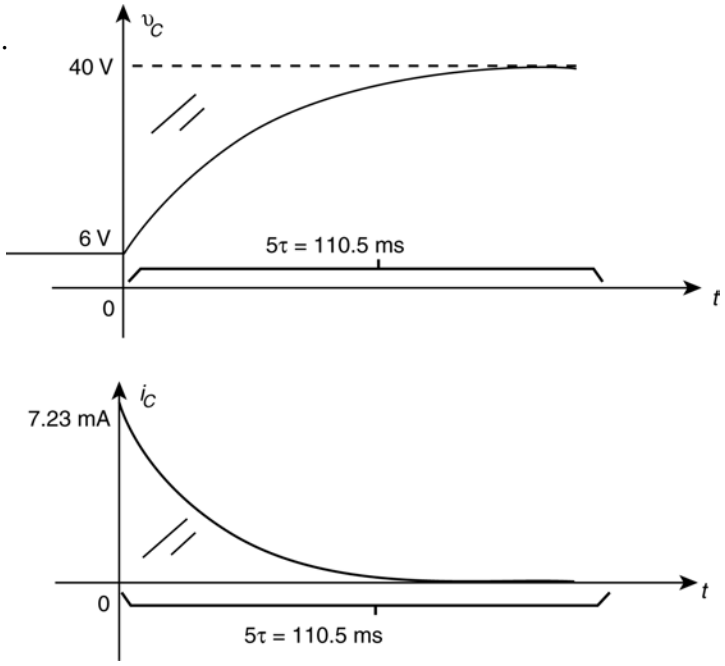
$v_C = 40\ \text{V} + (6\ \text{V} - 40\ \text{V})e^{-t/22.1\text{ms}}$

$v_C = \mathbf{40\ V - 34\ V}e^{\mathbf{-t/22.1ms}}$

b. Initially $V_R = E + v_C = 40\ \text{V} - 6\ \text{V} = 34\ \text{V}$

$i_C = \dfrac{V_R}{R}e^{-t/\tau} = \dfrac{34\ \text{V}}{4.7\ \text{k}\Omega}e^{-t/22.1\text{ms}} = \mathbf{7.23\ mA}\ e^{\mathbf{-t/22.1ms}}$

c.



30. a. $\tau = RC = (4.7\ \text{k}\Omega)(4.7\ \mu\text{F}) = 22.1\ \text{ms},\ V_f = 40\ \text{V},\ V_i = -40\ \text{V}$

$v_C = V_f + (V_i - V_f)e^{-t/\tau}$

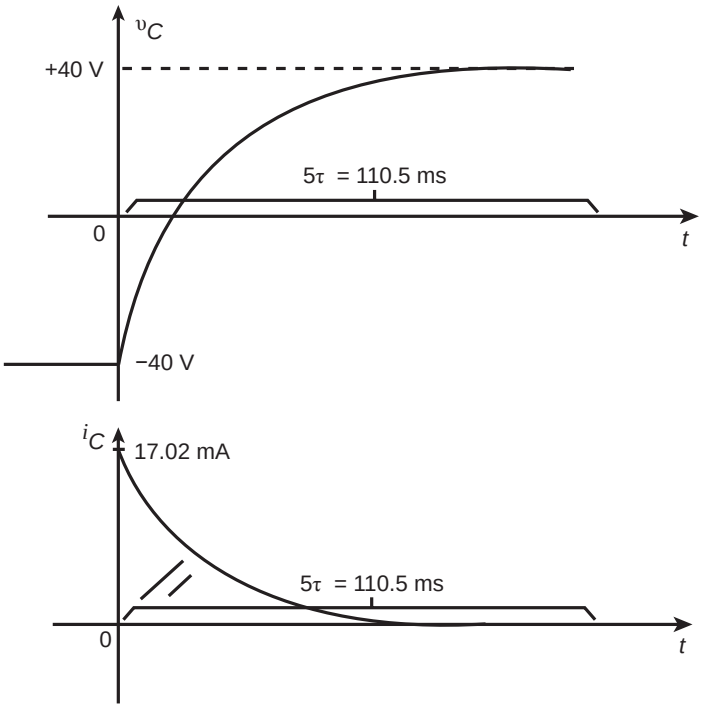
$= 40\ \text{V} + (-40\ \text{V} - 40\ \text{V})e^{-t/22.1\text{ms}}$

$v_C = \mathbf{40\ V - 80\ V}e^{\mathbf{-t/22.1ms}}$

b. Initially $V_R = E + v_C = 40\ \text{V} - (-40\ \text{V}) = 80\ \text{V}$

and $i_C = \dfrac{V_R}{R} = \dfrac{80\ \text{V}}{4.7\ \text{k}\Omega}e^{-t/22.1\text{ms}} = \mathbf{17.02\ mA}e^{\mathbf{-t/22.1ms}}$

c.



31. a. $\tau = RC = (4.7\ \text{k}\Omega)(4.7\ \mu\text{F}) = 22.1\ \text{ms}$, $V_f = 40\ \text{V}$, $V_i = 40\ \text{V}$

$\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$

$= 40\ \text{V} + (40\ \text{V} - 40\ \text{V})e^{-t/\tau}$

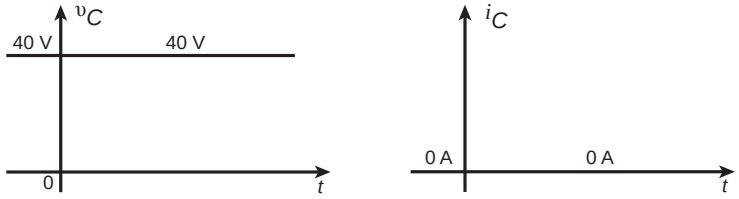
$= 40\ \text{V} + 0e^{-t/\tau}$

$\upsilon_C = \mathbf{40\ V}$

b. Initially $V_R = E - \upsilon_C = 40\ \text{V} - 40\ \text{V} = 0\ \text{V}$

and $i_C = \dfrac{V_R}{R}e^{-t/\tau} = \dfrac{0\ \text{V}}{R}e^{-t/\tau} = \mathbf{0\ A}$

c.



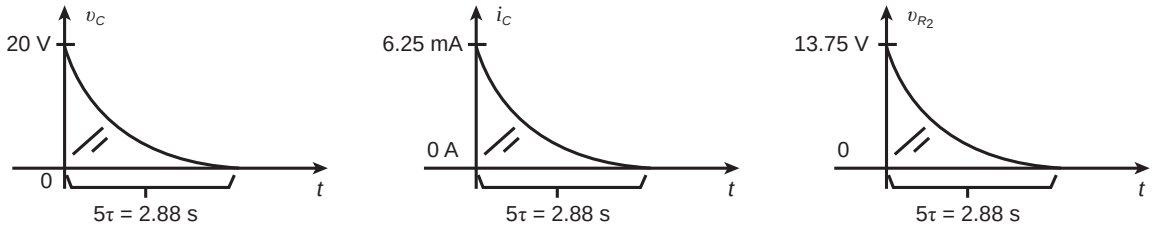
32. $\tau = RC = (R_1 + R_2)(C) = (1\ \text{k}\Omega + 2.2\ \text{k}\Omega)(180\ \mu\text{F}) = (3.2\ \text{k}\Omega)(180\ \mu\text{F}) = 576\ \text{ms}$

$\upsilon_C = \mathbf{20\ V}e^{\mathbf{-t/576ms}}$

$i_C = \dfrac{V_i}{R_1 + R_2}e^{-t/\tau} = \dfrac{20\ \text{V}}{3.2\ \text{k}\Omega}e^{-t/576\text{ms}} = \mathbf{6.25\ mA}e^{\mathbf{-t/576ms}}$

VDR: $V_{R_2} = \dfrac{2.2\ \text{k}\Omega\ (20\ \text{V})}{2.2\ \text{k}\Omega + 1\ \text{k}\Omega} = 13.75\ \text{V}$

$\upsilon_{R_2} = \mathbf{13.75\ V}e^{\mathbf{-t/576ms}}$



33. $v_C = V_f + (V_i - V_f)e^{-t/\tau}$

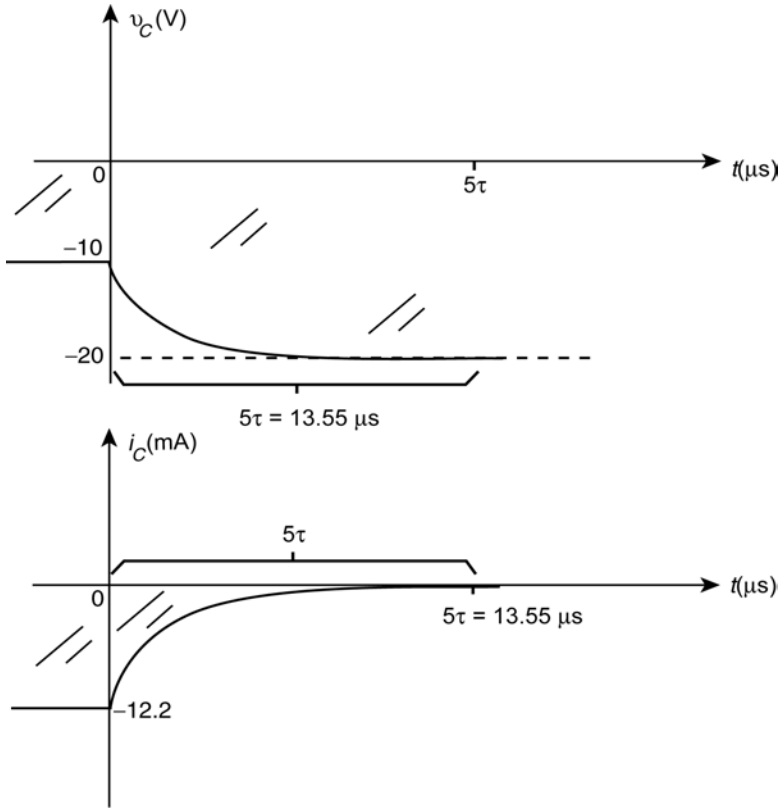
$\tau = RC = (820\ \Omega)(3300\ \text{pF}) = 2.71\ \mu\text{s},\ V_f = -20\ \text{V},\ V_i = -10\ \text{V}$

$v_C = -20\ \text{V} + (-10\ \text{V} - (-20\ \text{V}))e^{-t/2.71\mu\text{s}}$

$v_C = \mathbf{-20\ V + 10\ V}e^{\mathbf{-t/2.71\mu s}}$

$$I_m = \frac{-(20\ \text{V} - 10\ \text{V})}{820\ \Omega} = \frac{-10\ \text{V}}{820\ \Omega} = -12.2\ \text{mA}$$

$i_C = i_R = \mathbf{-12.2\ mA}e^{\mathbf{-t/2.71\mu s}}$



34. a. $R = 10\ \text{k}\Omega + 8.2\ \text{k}\Omega = 18.2\ \text{k}\Omega$

$\tau = RC = (18.2\ \text{k}\Omega)(6.8\ \mu\text{F}) = 123.76\ \text{ms}$

$v_C = V_f + (V_i - V_f)e^{-t/\tau}$

$V_f = 20\ \text{V} + 40\ \text{V} = 60\ \text{V}$

$V_i = -8\ \text{V}$

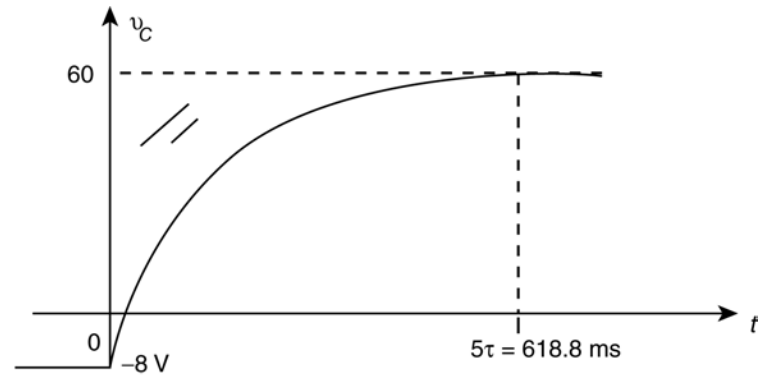
$v_C = 60\ \text{V} + (-8\ \text{V} - 60\ \text{V})e^{-t/123.76\ \text{ms}}$

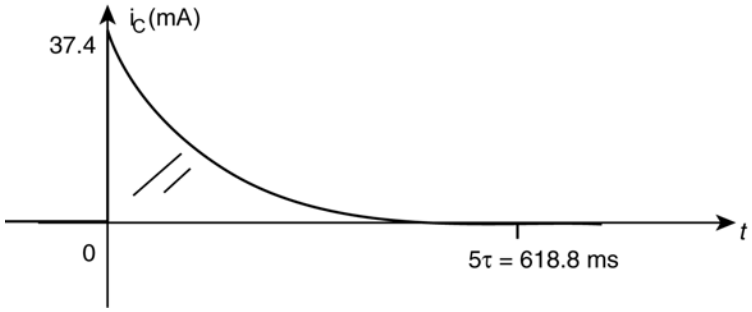
$v_C = \mathbf{60\ V - 68\ V}e^{\mathbf{-t/123.76\ ms}}$

$$I_m = \frac{8\ \text{V} + 20\ \text{V} + 40\ \text{V}}{18.2\ \text{k}\Omega} = 3.74\ \text{mA}$$

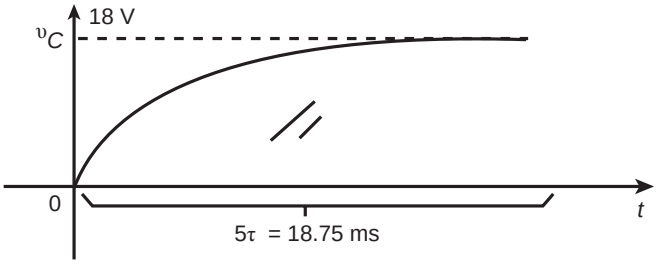
$i_C = \mathbf{3.74\ mA}e^{\mathbf{-t/123.76\ ms}}$

b.





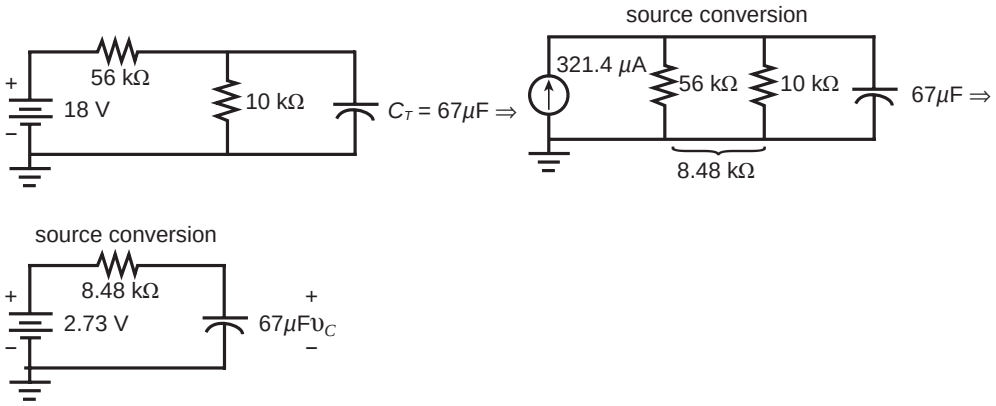
35. a. $C\tau = 20\ \mu\text{F} + 47\ \mu\text{F} = 67\ \mu\text{F}$
$\tau = RC = (56\ \text{k}\Omega)(67\ \mu\text{F}) = 3.75\ \text{s}$
$\upsilon_C = \mathbf{18\ V(1 - e^{-t/3.75\ s})}$



b. $\upsilon_C = 18\ \text{V}(1 - e^{-10\text{s}/5.75\ \text{s}})$
$= 18\ \text{V}(1 - e^{-2.67})$
$= 18\ \text{V}(1 - 69.25 \times 10^{-3})$
$= 18\ \text{V}(0.931)$
$= \mathbf{16.76\ V}$

c. $\upsilon_C = 18\ \text{V}(1 - e^{-5})$
$= 18\ \text{V}(1 - 6.74 \times 10^{-3})$
$= 18\ \text{V}(.993)$
$= 17.88\ \text{V}$
$Q_{20\mu\text{F}} = CV = (20\ \mu\text{F})(17.88\ \text{V}) = \mathbf{357.6\ \mu C}$
$Q_{47\mu\text{F}} = CV = (47\ \mu\text{F})(17.88\ \text{V}) = \mathbf{840.36\ \mu C}$

36. a. Network redrawn:



$\tau = RC = (8.48\ \text{k}\Omega)(67\ \mu\text{F}) = 568.2\ \text{ms}$

$\upsilon_C = \mathbf{2.73\ V(1 - e^{-t/568.2\ ms})}$

b. $\upsilon_C = 2.73\ \text{V}(1 - e^{-10\text{s}/568.2\ \text{ms}})$
$= 2.73\ \text{V}(1 - e^{-17.6})$
$= 2.73\ \text{V}(1 - 22.72 \times 10^{-9})$
$\cong \mathbf{2.73\ V}$

c. $\upsilon_C = 2.73\ \text{V}(1 - e^{-5}) = 2.73\ \text{V}\ (0.993) = 2.72\ \text{V}$
$Q_{20\mu\text{F}} = CV = (20\ \mu\text{F})(2.72\ \text{V}) = \mathbf{54.4\ \mu C}$
$Q_{47\mu\text{F}} = CV = (47\ \mu\text{F})(2.72\ \text{V}) = \mathbf{127.84\ \mu C}$

37. a. $\upsilon_C = 140\ \text{mV}(1 - e^{-1\text{ms}/2\ \text{ms}}) = 140\ \text{mV}(1 - e^{-0.5}) = 140\ \text{mV}(1 - 0.6065)$
$= 140\ \text{mV}(0.3935) = \mathbf{55.59\ mV}$

b. $\upsilon_C = 140\ \text{mV}(1 - e^{-10}) = 140\ \text{mV}(1 - 45.4 \times 10^{-6})$
$\cong \mathbf{139.99\ mV}$

c. $100\ \text{mV} = 140\ \text{mV}(1 - e^{-t/2\ \text{ms}})$
$0.714 = 1 - e^{-t/2\ \text{ms}}$
$0.286 = e^{-t/2\ \text{ms}}$
$\log_e 0.286 = \log_e e^{-t/2\ \text{ms}}$
$1.252 = -t/2\ \text{ms}$
$t = 1.252\ (2\ \text{ms}) = \mathbf{2.5\ ms}$

d. $\upsilon_C = 138\ \text{mV} = 140\ \text{mV}(1 - e^{t/2\ \text{ms}})$
$0.986 = 1 - e^{-t/2\ ms}$
$-14 \times 10^{-3} = -e^{-t/2\ \text{ms}}$
$\log_e 14 \times 10^{-3} = -t/2\ \text{ms}$
$-4.268 = -t/2\ \text{ms}$
$t = (4.268)(2\ \text{ms}) = \mathbf{8.54\ \mu s}$

38. $\tau = RC = (33\ \text{k}\Omega)(20\ \mu\text{F}) = 0.66\ \text{s}$

$$\upsilon_C = 12\ \text{V}(1 - e^{-t0.66\ \text{s}})$$
$$8\ \text{V} = 12\ \text{V}(1 - e^{-t0.66\ \text{s}})$$
$$8\ \text{V} = 12\ \text{V} - 12\ \text{V}(1 - e^{-t/0.66\ \text{s}})$$
$$-4\ \text{V} = -12\ \text{V}e^{-t0.66\ \text{s}}$$
$$0.333 = e^{-t0.66\ \text{s}}$$
$$\log_e 0.333 = -t/0.66\ \text{s}$$
$$-1.0996 = -t/0.66\ \text{s}$$
$$t = 1.0996(0.66\ \text{s}) = \mathbf{0.73\ s}$$

39. $$t = -\tau \log_e\left(1 - \frac{\upsilon_C}{E}\right)$$

$$10\ \text{s} = -\tau \log_e\left(1 - \frac{12\ \text{V}}{20\ \text{V}}\right)$$

$$.4$$

$$-916.29 \times 10^{-3}$$

$$\tau = \frac{10\ \text{s}}{0.916} = 10.92\ \text{s}$$

$$\tau = RC \Rightarrow R = \frac{\tau}{C} = \frac{10.92\ \text{s}}{200\ \mu\text{F}} = \mathbf{54.60\ k\Omega}$$

40. a. $\tau = RC = (12\ \text{k}\Omega + 8.2\ \text{k}\Omega)(6.8\ \mu\text{F}) = 137.36\ \text{ms}$

$$\upsilon_C = 60\ \text{V}(1 - e^{-t/\tau})$$
$$48\ \text{V} = 60\ \text{V}(1 - e^{-t/\tau})$$
$$0.8 = 1 - e^{-t/\tau}$$
$$0.2 = 1 - e^{-t/\tau}$$
$$\log_e 0.2 = \log_e e^{-t/\tau}$$
$$-1.61 = -t/\tau$$
$$t = (1.61)\tau = (1.61)(137.36\ \text{ms}) = \mathbf{221.15\ ms}$$

b. $$i_C = \frac{E}{R}e^{-t/\tau} = \frac{60\ \text{V}}{20.2\ \text{k}\Omega}e^{-t/\tau}$$

$$= 2.97\ \text{mA}e^{-t/137.36\ \text{ms}}$$
$$i_C(221.15\ \text{ms}) = 2.97\ \text{mA}e^{-221.15\ \text{ms}/137.36\ \text{ms}}$$
$$= 2.97\ \text{mA}e^{-1.61}$$
$$= 2.97\ \text{mA}\ (199.89 \times 10^{-3})$$
$$= \mathbf{0.594\ mA}$$

c. $t = 2\tau$

$$i_C = 2.97\ \text{mA}e^{-2\tau/\tau} = 2.97\ \text{mA}e^{-2}$$
$$= 0.4\ \text{mA} \qquad \underbrace{\qquad}_{0.135}$$

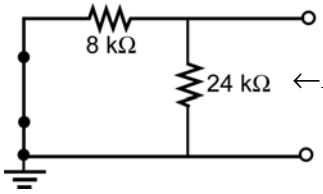
$$P = EI = (60\ \text{V})(0.4\ \text{mA}) = \mathbf{24\ mW}$$

41. a. $\upsilon_m = \upsilon_R = Ee^{-t/\tau} = 60\text{ V}e^{-1\tau/\tau} = 60\text{ V}e^{-1}$
$= 60\text{ V}(0.3679)$
$= \mathbf{22.07\text{ V}}$

b. $i_C = \dfrac{E}{R}e^{-t/\tau} = \dfrac{60\text{ V}}{10\text{ M}\Omega}e^{-2\tau/\tau} = 6\ \mu\text{A}e^{-2}$
$= 6\ \mu\text{A}(0.1353)$
$= \mathbf{0.81\ \mu A}$

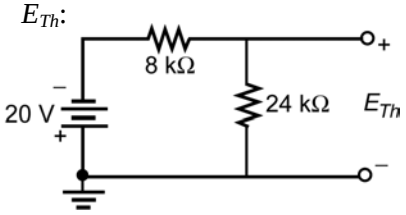
c. $\upsilon_C = E(1 - e^{-t/\tau})$ $\qquad \tau = RC = (10\text{ M}\Omega)(0.2\ \mu\text{F}) = 2\text{ s}$
$50\text{ V} = 60\text{ V}(1 - e^{-t/2\text{ s}})$
$0.8333 = 1 - e^{-t/2\text{ s}}$
$\log_e 0.1667 = -t/2\text{ s}$
$t = -(2\text{ s})(-1.792)$
$= \mathbf{3.58\text{ s}}$

42. a. Thevenin's theorem:
R_{Th}:

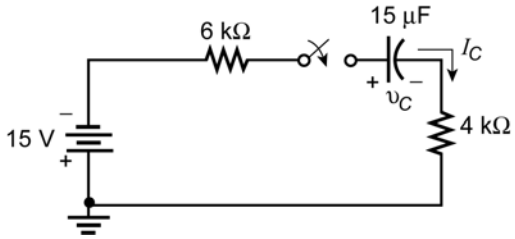


$\leftarrow R_{Th} = 8\text{ k}\Omega \parallel 24\text{ k}\Omega$
$= 6\text{ k}\Omega$

E_{Th}:



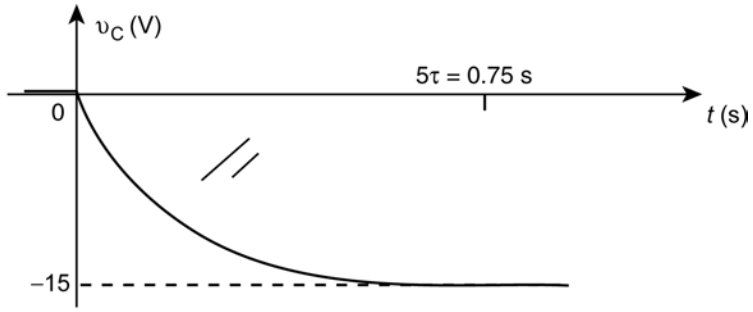
$E_{Th} = \dfrac{-24\text{ k}\Omega\ (20\text{ V})}{24\text{ k}\Omega + 8\text{ k}\Omega} = -15\text{ V}$

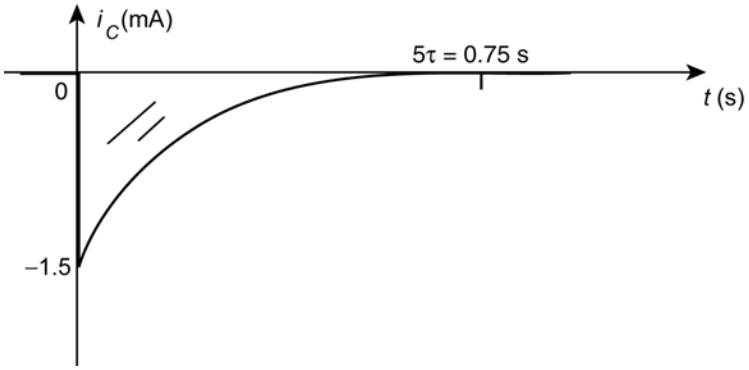


$\tau = RC = (10\text{ k}\Omega)(15\ \mu\text{F}) = 0.15\text{ s}$
$\upsilon_C = E(1 - e^{-t/\tau})$
$= \mathbf{-15\text{ V}(1 - e^{-t/0.15\text{ s}})}$

$i_C = \dfrac{E}{R}e^{-t/\tau} = -\dfrac{15\text{ V}}{10\text{ k}\Omega}e^{-t/0.15} = \mathbf{-1.5\text{ mA}e^{-t/0.15\text{ s}}}$

b.

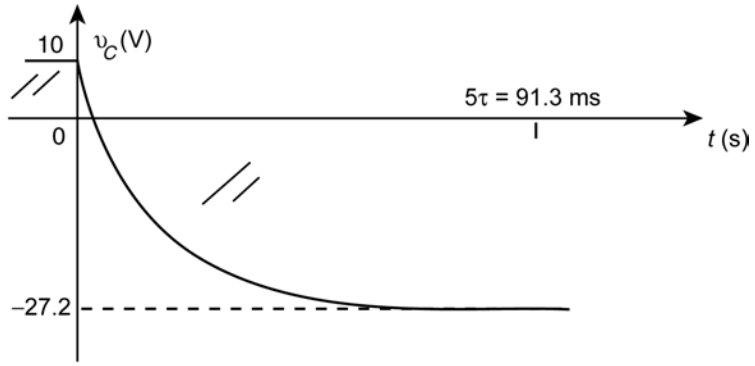


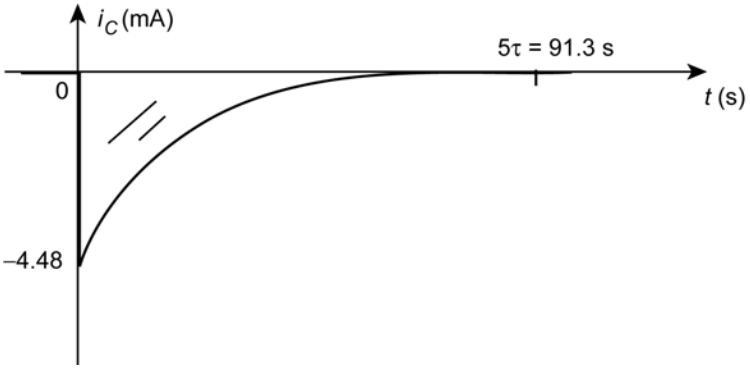


43. a. Source conversion and combining series resistors:

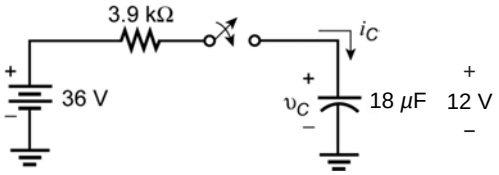
$E = -(4\text{ mA})(6.8\text{ k}\Omega) = -27.2\text{ V}$
$R_T = 6.8\text{ k}\Omega + 1.5\text{ k}\Omega = 8.3\text{ k}\Omega$
$V_f = -27.2\text{ V}$, $V_i = 10\text{ V}$
$\tau = RC = (8.3\text{ k}\Omega)(2.2\ \mu\text{F}) = 18.26\text{ ms}$
$\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$
$= -27.2\text{ V} + (10\text{ V} - (-27.2\text{ V}))e^{-t/18.26\text{ ms}}$
$\upsilon_C = \mathbf{-27.2\text{ V} + 37.2\text{ V}e^{-t/18.26\text{ ms}}}$
$\upsilon_R(0+) = -27.2\text{ V} - (-27.2\text{ V}))e^{-t/18.26\text{ ms}} = -37.2\text{ V}$
$i_C = -\dfrac{32.7\text{ V}}{8.3\text{ k}\Omega}e^{-t/18.26\text{ms}}$
$i_C = \mathbf{-4.48\text{ mA}e^{-t/18.26\text{ ms}}}$

b.





44. a. $R_{Th} = 3.9\ \text{k}\Omega + 0\ \Omega \parallel 1.8\ \text{k}\Omega = 3.9\ \text{k}\Omega$
$E_{Th} = 36\ \text{V}$



$\tau = RC = (3.9\ \text{k}\Omega)(18\ \mu\text{F}) = 70.2\ \text{ms}$

$\upsilon_C = V_f + (V_i - V_f)e^{-t/\tau}$

$= 36\ \text{V} + (+12\ \text{V} - 36\ \text{V})e^{-t/70.2\ \text{ms}}$

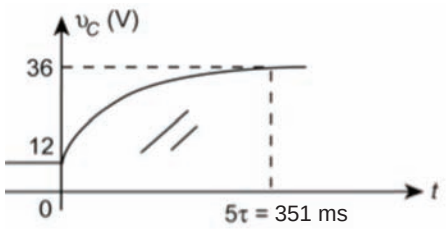
$\upsilon_C = \mathbf{36\ V - 24\ V}e^{\mathbf{-t/70.2\ ms}}$

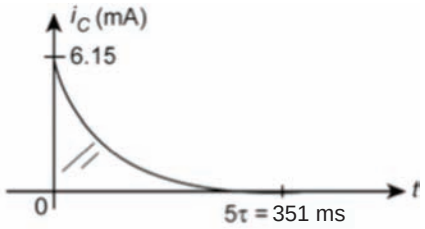
$\upsilon_R(0+) = 24\ \text{V} - 12\ \text{V} = 24\ \text{V}$

$$i_C = \frac{24\ \text{V}}{3.9\ \text{k}\Omega} e^{-t/70.2\text{ms}}$$

$i_C = \mathbf{6.15\ mA}e^{\mathbf{-t/70.2\ ms}}$

b.

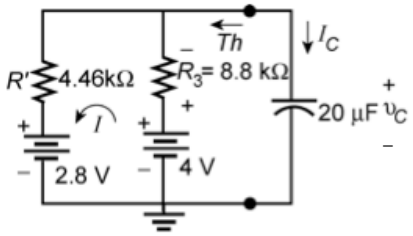




45. Source conversion:

$E = IR_1 = (5\text{ mA})(0.56\text{ k}\Omega) = 2.8\text{ V}$

$R' = R_1 + R_2 = 0.56\text{ k}\Omega + 3.9\text{ k}\Omega = 4.46\text{ k}\Omega$



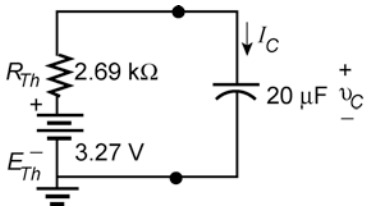
$R_{Th} = 4.46\text{ k}\Omega \parallel 6.8\text{ k}\Omega = 2.69\text{ k}\Omega$

$$I = \frac{4\text{ V} - 2.8\text{ V}}{6.8\text{ k}\Omega + 4.46\text{ k}\Omega} = \frac{1.2\text{ V}}{11.26\text{ k}\Omega} = 0.107\text{ mA}$$

$E_{Th} = 4\text{ V} - (0.107\text{ mA})(6.8\text{ k}\Omega)$

$= 4\text{ V} - 0.727\text{ V}$

$= 3.27\text{ V}$



$v_C = 3.27\text{ V}(1 - e^{-t/\tau})$

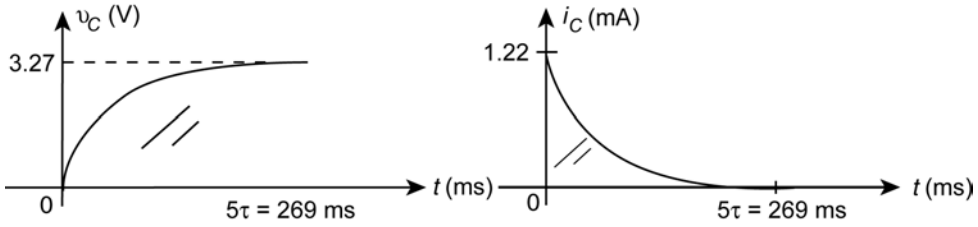
$\tau = RC = (2.69\text{ k}\Omega)(20\ \mu\text{F})$

$= 53.80\text{ ms}$

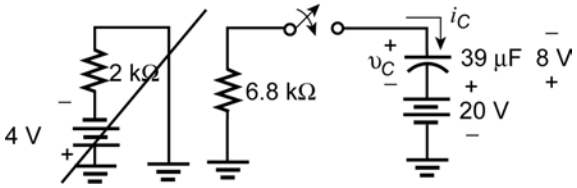
$v_C = \mathbf{3.27\text{ V}(1 - e^{-t/53.80\text{ ms}})}$

$$i_C = \frac{3.27\text{ V}}{2.69\text{ k}\Omega} e^{-t/\tau}$$

$= \mathbf{1.22\text{ mA}\ e^{-t/53.80\text{ ms}}}$



46. a.



$\tau = RC = (6.8\text{ k}\Omega)(39\ \mu\text{F}) = 265.2\text{ ms}$

$v_C = V_f + (V_i - V_f)e^{-t/\tau}$

$= -20\text{ V} + (-8\text{ V} - (-20\text{ V}))e^{-t/265.2\text{ ms}}$

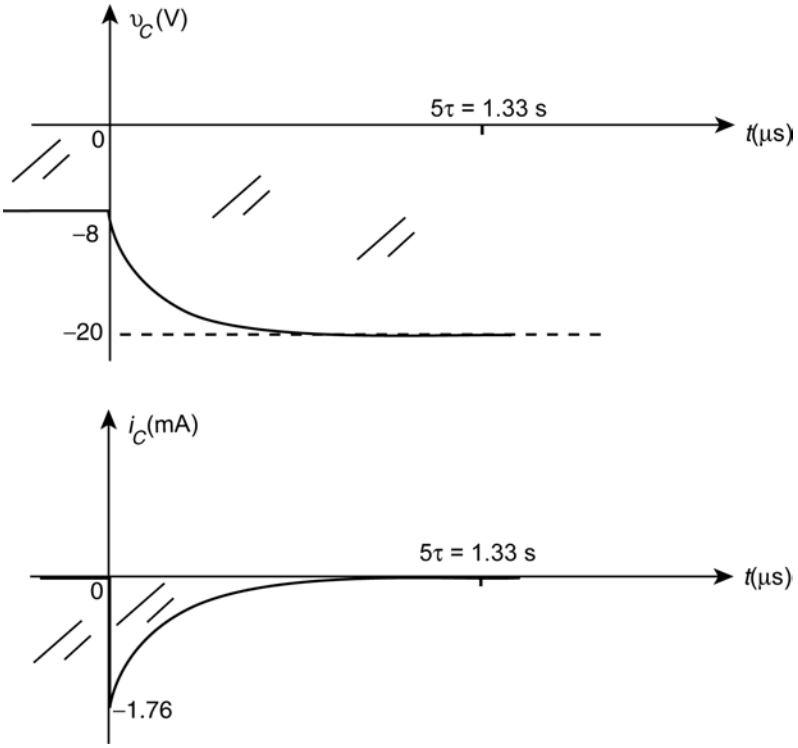
$v_C = \mathbf{-20\text{ V} + 12\text{ V}e^{-t/265.2\text{ ms}}}$

$v_R(0+) = +8\text{ V} - 20\text{ V} = -12\text{ V}$

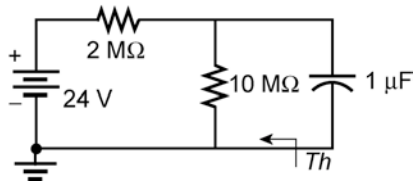
$$i_C = -\frac{12\text{ V}}{6.8\text{ k}\Omega} e^{-t/265.2\text{ms}}$$

$i_C = \mathbf{-1.76\text{ mA}e^{-t/265.2\text{ ms}}}$

b.



47. a.



R_{Th} = 2 MΩ || 10 MΩ = 1.67 MΩ

$$E_{Th} = \frac{10\ \text{M}\Omega(24\ \text{V})}{10\ \text{M}\Omega + 2\ \text{M}\Omega} = 20\ \text{V}$$

$v_C = E_{Th}(1 - e^{-t/\tau})$
$= 20\ \text{V}(1 - e^{-4\tau/\tau})$
$= 20\ \text{V}(1 - e^{-4})$
$= 20\ \text{V}(1 - 0.0183)$
$=$ **19.63 V**

$\tau = R_{Th}C = (1.67\ \text{M}\Omega)(1\ \mu\text{F}) = 1.67\ \text{s}$

$$i_C = \frac{E}{R}e^{-t/\tau}$$

$$3\ \mu\text{A} = \frac{20\ \text{V}}{1.67\ \text{M}\Omega}e^{-t/1.67\text{s}}$$

$$0.25 = e^{-t/1.67\text{s}}$$

$$\log_e 0.25 = -t/1.67\ \text{s}$$

$t = -(1.67\ \text{s})(-1.39)$
$=$ **2.32 s**

c. $v_{\text{meter}} = v_C$

$v_C = E_{Th}(1 - e^{-t/\tau})$

$10\ \text{V} = 20\ \text{V}(1 - e^{-t/1.67\text{s}})$

$0.5 = 1 - e^{-t/1.67\text{s}}$

$-0.5 = -e^{-t/1.67\text{s}}$

$\log_e 0.5 = -t/1.67\ \text{s}$

$t = -(1.67\ \text{s})(-0.69)$
$=$ **1.15 s**

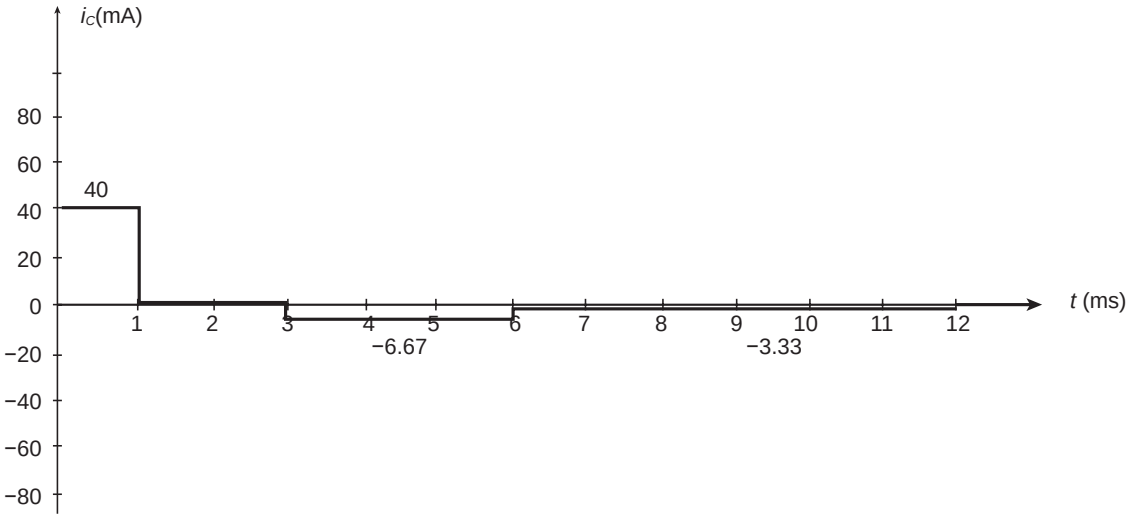
48. $i_{C_{ao}} = C\dfrac{\Delta v_C}{\Delta t}$

$0 \rightarrow 1$ ms: $i_C = 2 \times 10^{-6}\dfrac{(20\text{ V})}{1\text{ ms}} = \mathbf{40\text{ mA}}$

$1 \rightarrow 3$ ms: $i_C = 2 \times 10^{-6}\dfrac{(0\text{ V})}{1\text{ ms}} = \mathbf{0\text{ mA}}$

$3 \rightarrow 6$ ms: $i_C = -2 \times 10^{-6}\dfrac{(10\text{ V})}{3\text{ ms}} = \mathbf{-6.67\text{ mA}}$

$6 \rightarrow 12$ ms: $i_C = -2 \times 10^{-6}\dfrac{(10\text{ V})}{6\text{ ms}} = \mathbf{-3.33\text{ mA}}$



49. $i_{C_{ao}} = C\dfrac{\Delta v_C}{\Delta t}$

$0 \rightarrow 20\ \mu$s: $i_C = -4.7\ \mu\text{F}\dfrac{(5\text{ V})}{20\ \mu\text{s}} = \mathbf{-1.18\text{ A}}$

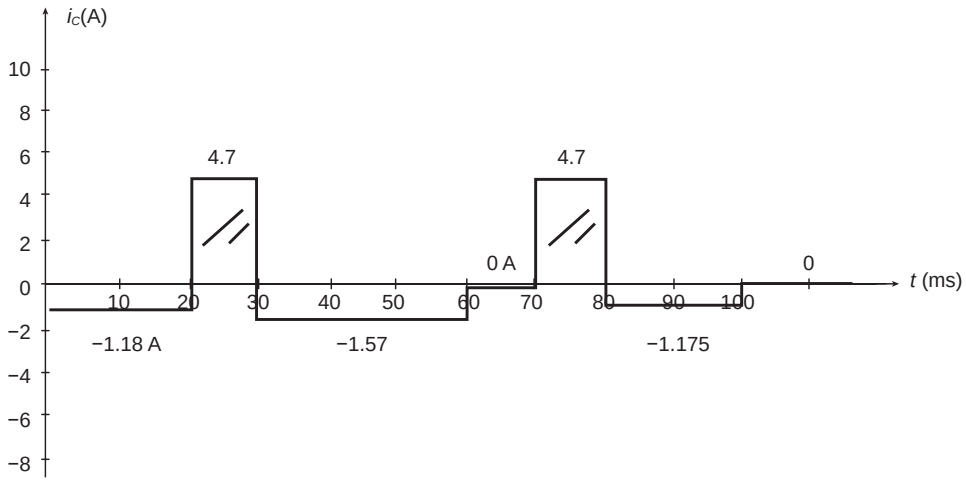
$20 \rightarrow 30\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(10\text{ V})}{10\ \mu\text{s}} = \mathbf{4.7\text{ A}}$

$30 \rightarrow 60\ \mu$s: $i_C = -4.7\ \mu\text{F}\dfrac{(10\text{ V})}{30\ \mu\text{s}} = \mathbf{-1.57\text{ A}}$

$60 \rightarrow 70\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(0\text{ V})}{10\ \mu\text{s}} = \mathbf{0\text{ A}}$

$70 \rightarrow 80\ \mu$s: $i_C = 4.7\ \mu\text{F}\dfrac{(10\text{ V})}{10\ \mu\text{s}} = \mathbf{4.7\text{ A}}$

$80\ \mu\text{s} \rightarrow 100\ \mu$s: $i_C = -4.7\ \mu\text{F}\dfrac{(5\text{ V})}{20\ \mu\text{s}} = \mathbf{-1.175\text{ A}}$



50. $i_C = C\dfrac{\Delta v_C}{\Delta t} \Rightarrow \Delta v_C = \dfrac{\Delta t}{C}(i_C)$

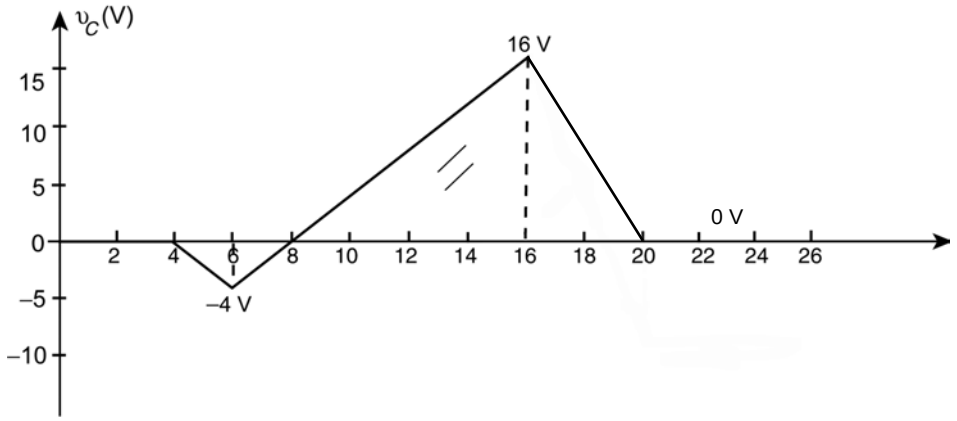
$0 \rightarrow 4$ ms: $i_C = 0$ mA $\quad \Delta v_C =$ **0 V**

$4 \rightarrow 6$ ms: $i_C = -40$ mA $\quad \Delta v_C = \dfrac{(2\text{ ms})}{20\ \mu\text{F}}(-40\text{ mA}) =$ **−4 V**

$6 \rightarrow 16$ ms: $i_C = +40$ mA $\quad \Delta v_C = \dfrac{(10\text{ ms})}{20\ \mu\text{F}}(40\text{ mA}) =$ **+20 V**

$16 \rightarrow 20$ ms: $i_C = -80$ mA $\quad \Delta v_C = \dfrac{(4\text{ ms})}{20\ \mu\text{s}}(-80\text{ mA}) =$ **−16 V**

$20 \rightarrow 25$ ms: $i_C = 0$ mA $\quad \Delta v_C =$ **0 V**



51. $6\ \mu\text{F} + 4\ \mu\text{F} = 10\ \mu\text{F}$, $8\ \mu\text{F} + 12\ \mu\text{F} = 20\ \mu\text{F}$
$10\ \mu\text{F} \parallel 20\ \mu\text{F} =$ **6.67 μF**

52. $C_T' = 6\ \mu\text{F} \parallel 12\ \mu\text{F} = 4\ \mu\text{F}$
$C_T'' = C_T' + 12\ \mu\text{F} = 4\ \mu\text{F} + 12\ \mu\text{F} = 16\ \mu\text{F}$
$6\ \mu\text{F} \parallel 6\ \mu\text{F} = 3\ \mu\text{F}$
$3\ \mu\text{F} \parallel 16\ \mu\text{F} = 2.53\ \mu\text{F}$
$C_T =$ **2.53 μF**

53. $10\ \mu\text{F} \parallel 100\ \mu\text{F} = 9.09\ \mu\text{F}$
$20\ \mu\text{F} + 9.09\ \mu\text{F} = 29.09\ \mu\text{F}$
$Q_T = C_T E = (29.09\ \mu\text{F})(20\text{ V}) = \mathbf{581.8\ \mu C}$
$Q_{20\mu\text{F}} = \text{CV} = (20\ \mu\text{F})(20\text{ V}) = \mathbf{400\ \mu C}$
$V_{20\mu\text{F}} = \mathbf{20\text{ V}}$
$Q_T' = C_T' E = (9.09\ \mu\text{F})(20\text{ V}) = 181.8\ \mu\text{C}$
$Q_T' = Q_{10\mu\text{F}} = Q_{100\mu\text{F}} = \mathbf{181.8\ \mu C}$
$V_{10\mu\text{F}} = \dfrac{Q}{C} = \dfrac{181.8\ \mu\text{C}}{10\ \mu\text{F}} = \mathbf{18.18\text{ V}}$
$V_{100\mu\text{F}} = \dfrac{Q}{C} = \dfrac{181.8\ \mu\text{C}}{100\ \mu\text{F}} = \mathbf{1.818\text{ V}}$

54. $360\ \mu\text{F} + 200\ \mu\text{F} = 560\ \mu\text{F}$
$470\ \mu\text{F} \parallel 560\ \mu\text{F} = 255.53\ \mu\text{F}$
$Q_T = Q_3 = C_T E = (255.53\mu\text{F})(56\text{ V}) = \mathbf{14.5\ mC}$
$V_3 = \dfrac{Q_3}{C_3} = \dfrac{14.5\text{ mC}}{470\ \mu\text{F}} = \mathbf{30.4\text{ V}}$
$\boldsymbol{V}_1 = V_2 = E - V_3 = 56\text{ V} - 30.4\text{ V} = \mathbf{25.6\text{ V}}$
$Q_1 = V_1 C_1 = (25.6\text{ V})(360\ \mu\text{F}) = \mathbf{9.2\ mC}$
$Q_2 = V_2 C_2 = (25.6\text{ V})(200\ \mu\text{F}) = \mathbf{5.1\ mC}$

55. steady state − ignore 10 kΩ resistor
$330\ \mu\text{F} + 120\ \mu\text{F} = 450\ \mu\text{F}$
$C_T = 220\ \mu\text{F} \parallel 450\ \mu\text{F} = 147.76\ \mu\text{F}$
$Q_T = Q_1 = C_T E = (147.76\ \mu\text{F})(20\text{ V}) = \mathbf{2.96\ mC}$
$V_1 = \dfrac{Q_1}{C_1} = \dfrac{2.96\text{ mC}}{220\ \mu\text{F}} = \mathbf{13.45\text{ V}}$
$V_3 = V_2 = E - V_1 = 20\text{ V} - 13.45\text{ V} = \mathbf{6.55\text{ V}}$
$Q_2 = C_2 V_2 = (330\ \mu\text{F})(6.55\text{ V}) = \mathbf{2.16\ mC}$
$Q_3 = C_3 V_3 = (120\ \mu\text{F})(6.55\text{ V}) = \mathbf{0.786\ mC}$

56. $V_{4\text{k}\Omega} = \dfrac{4\text{ k}\Omega(48\text{ V})}{4\text{ k}\Omega + 2\text{ k}\Omega} = \mathbf{32\text{ V}} = V_{0.08\mu\text{F}}$
$Q_{0.08\mu\text{F}} = (0.08\ \mu\text{F})(32\text{ V}) = \mathbf{2.56\ \mu C}$
$V_{0.04\mu\text{F}} = \mathbf{48\text{ V}}$
$Q_{0.04\mu\text{F}} = (0.04\ \mu\text{F})(48\text{ V}) = \mathbf{1.92\ \mu C}$

57. $W_C = \dfrac{1}{2}CV^2 = \dfrac{1}{2}(120\text{ pF})(12\text{ V})^2 = \mathbf{8{,}640\text{ pJ}}$

58. $W = \dfrac{Q^2}{2C} \Rightarrow Q = \sqrt{2CW} = \sqrt{2(6\ \mu\text{F})(1200\text{ J})} = \mathbf{0.12\text{ C}}$

59. a. $V_{200\mu\text{F}} = \dfrac{(220\text{ k}\Omega + 3.3\text{ k}\Omega)(12\text{ V})}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega + 1.2\text{ k}\Omega} = 9.85\text{ V}$
$V_{100\mu\text{F}} = \dfrac{(3.3\text{ k}\Omega)(12\text{ V})}{2.2\text{ k}\Omega + 3.3\text{ k}\Omega + 1.2\text{ k}\Omega} = 5.91\text{ V}$

$W_{200\mu F} = \frac{1}{2}(200\ \mu F)(9.85\ V)^2 =$ **970 mJ**

$W_{100\mu F} = \frac{1}{2}(100\ \mu F)(5.91\ V)^2 =$ **1.75 mJ**

60. a. $W_C = \frac{1}{2}CV^2 = \frac{1}{2}(1000\ \mu F)(100\ V)^2 =$ **5 pJ**

b. $Q = CV = (1000\ \mu F)(100\ V) =$ **0.1 C**

c. $I = Q/t = 0.1\ C/(1/2000) =$ **200 A**

d. $P = V_{av}I_{av} = W/t = 5\ J(1/2000\ s) =$ **10,000 W**

e. $t = Q/I = 0.1\ C/10\ mA =$ **10 s**