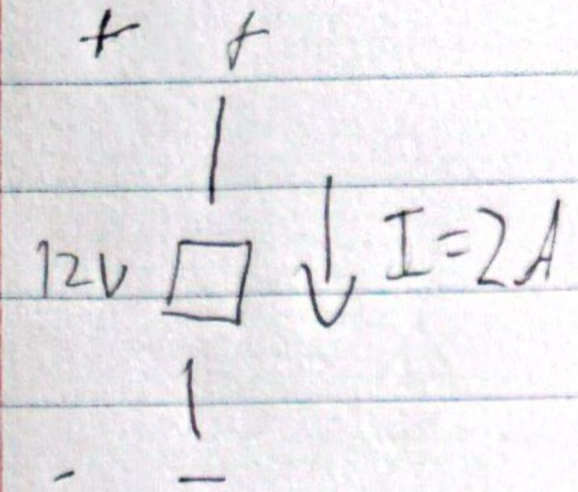
circuits day II

$I(t) = \frac{dq}{dt}$ $\quad V(t) = \frac{dW}{dq}$

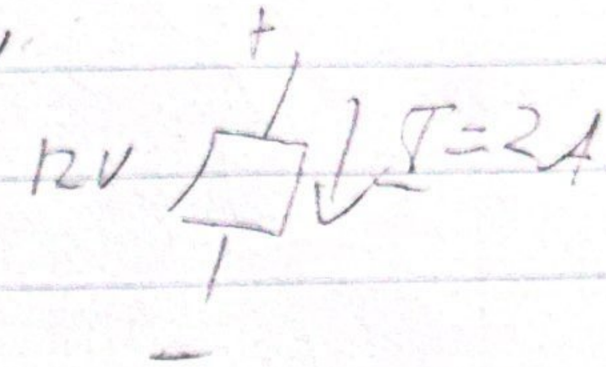
$\frac{dq}{dt}\frac{dW}{dq} = \frac{dW}{dt} = \boxed{P = IV}$ $\quad I \cdot V$

* current & voltage is the power

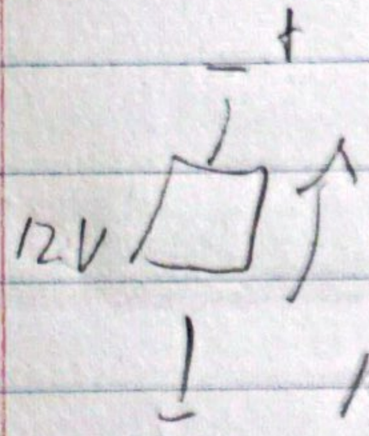



$P = IV = 2A(12)V = 24W$

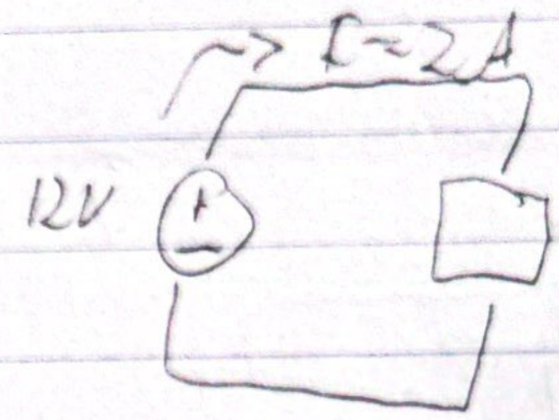
for $I = 2A$




$P = 12(-2) = 24W$




$P = -12(2) = -24W$




3600 W, 3 sec

$$W = \int_{t_0}^{t_0} p(t)\,dt = \int_0^3 3600\,dt = 10{,}800\ J$$

G Giga 1 billion $= 10^9$

M mega 1 million $= 10^6$

k kilo $1{,}000 = 10^3$

m milli $= 10^{-3}$

micro $= 10^{-6}$

nano $= 10^{-9}$

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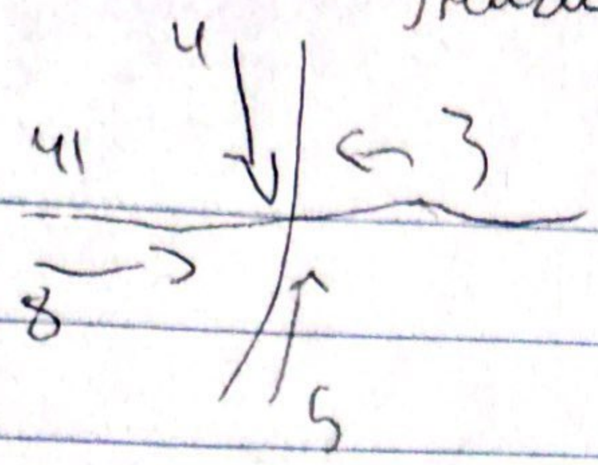
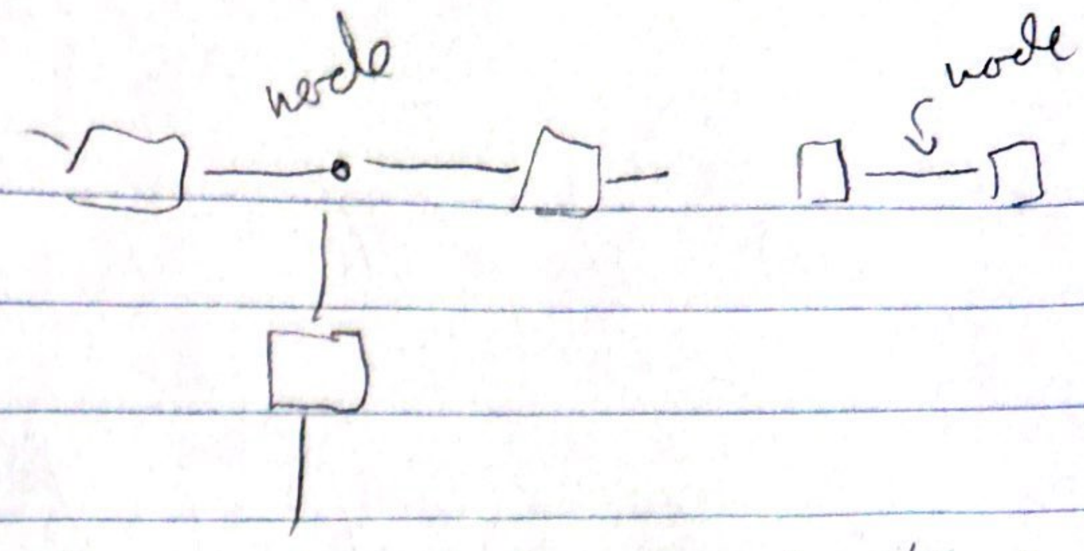
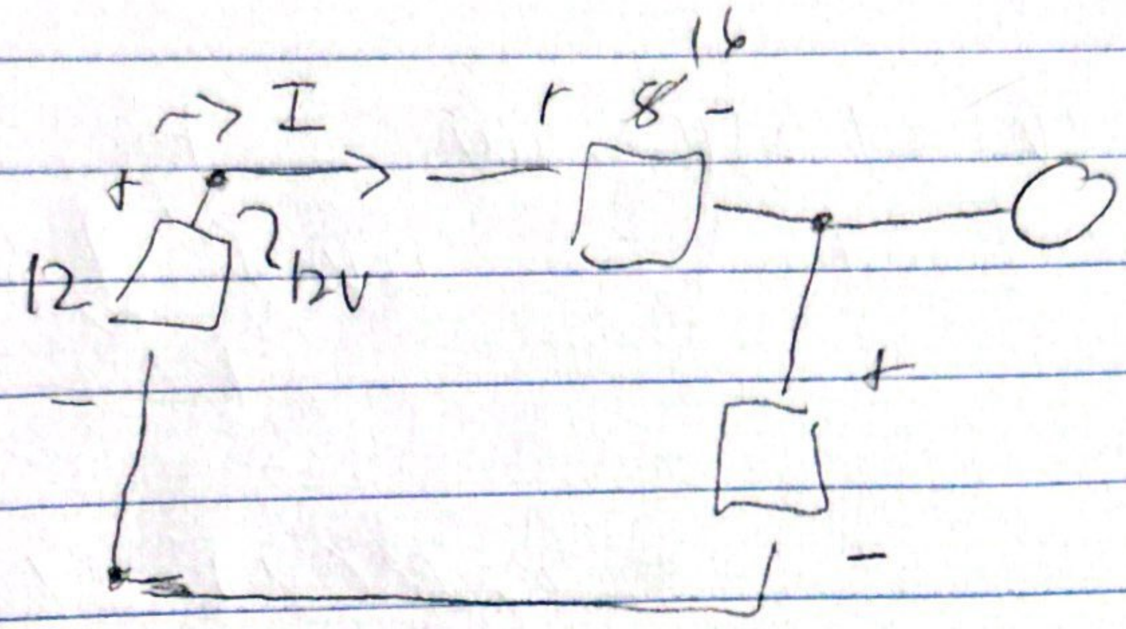
Hazlitt



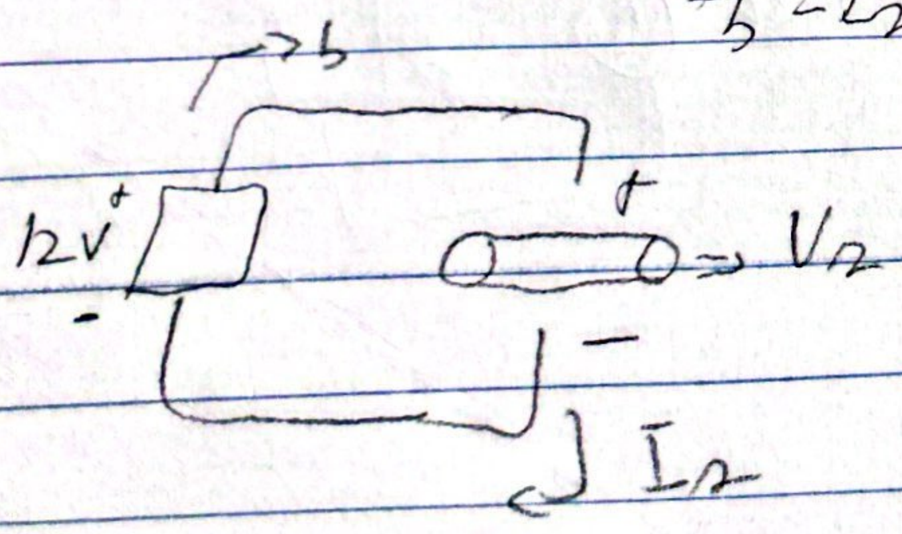

* Kirchoff's law (current)
$I_1 = I_2 = I_3$

* Kirchoff's law (voltage)



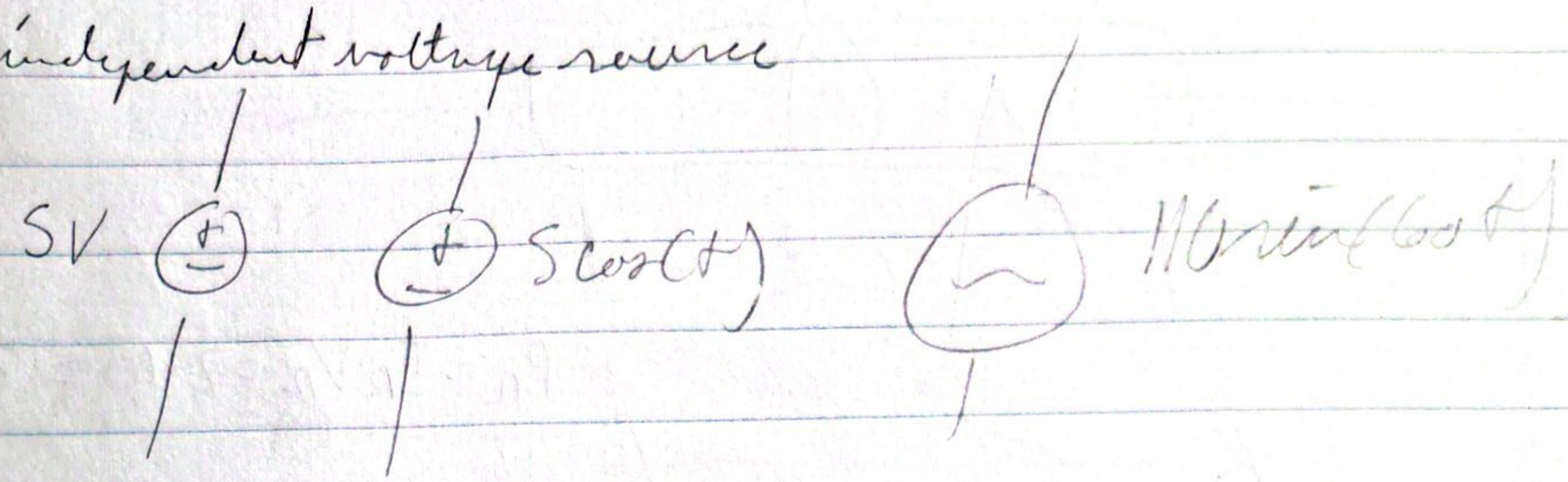

$I_3 = I_2$

$P_3 = 12 I_3$

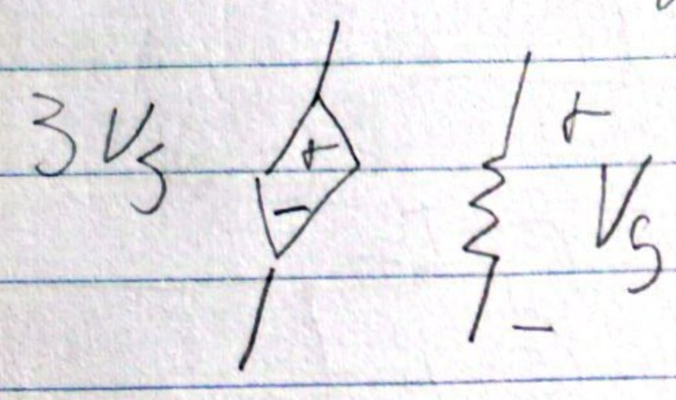



$P_2 = 12 I_2 = P_3$

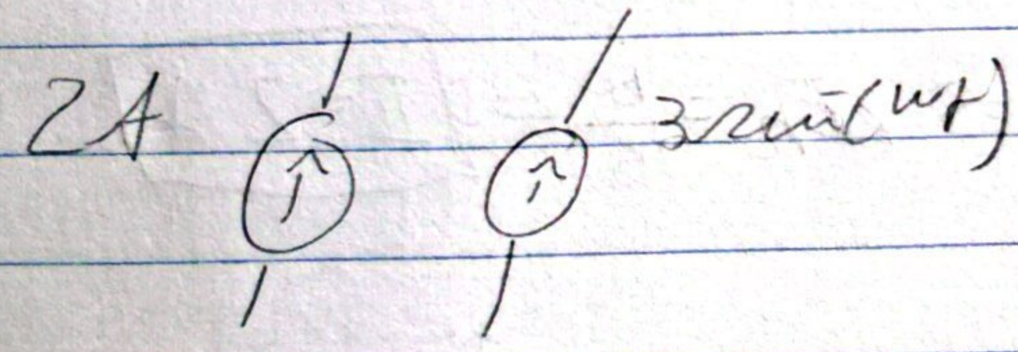
independent voltage source



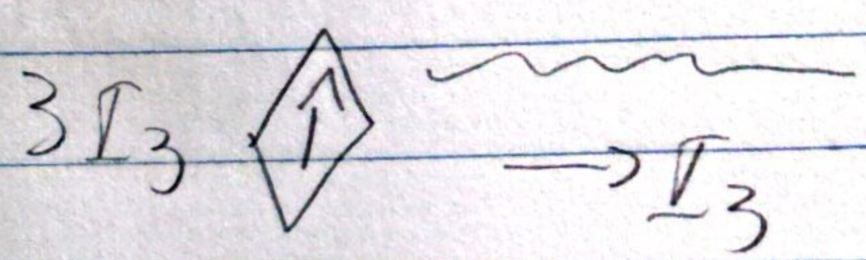

dependent Voltage source



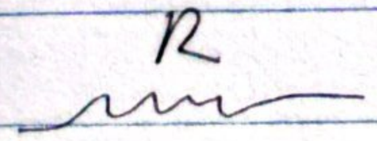

independent current source




dependent current source




ohm's law




$V = IR$

$R = \frac{V}{I}$

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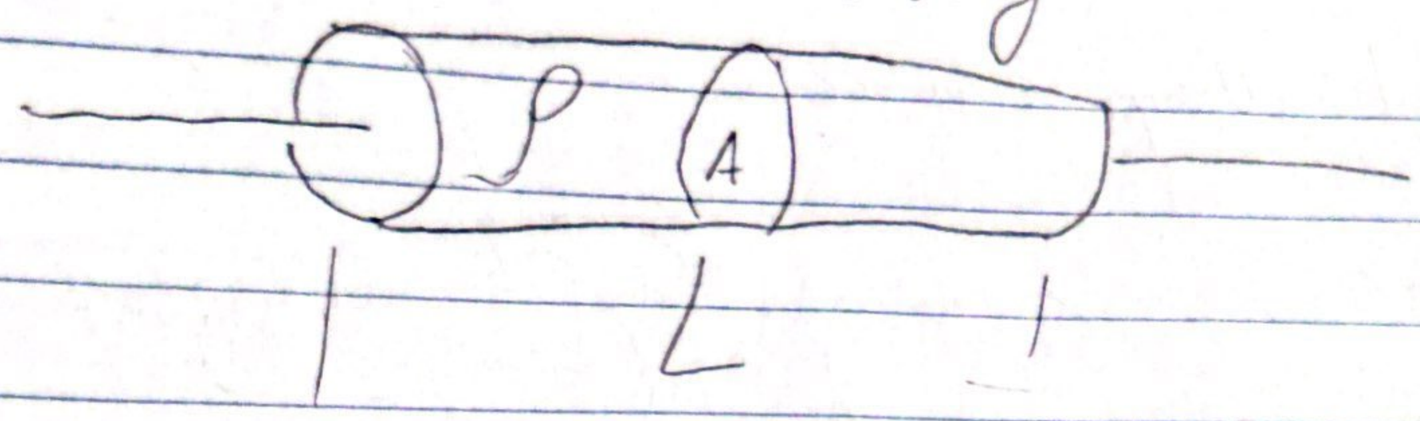
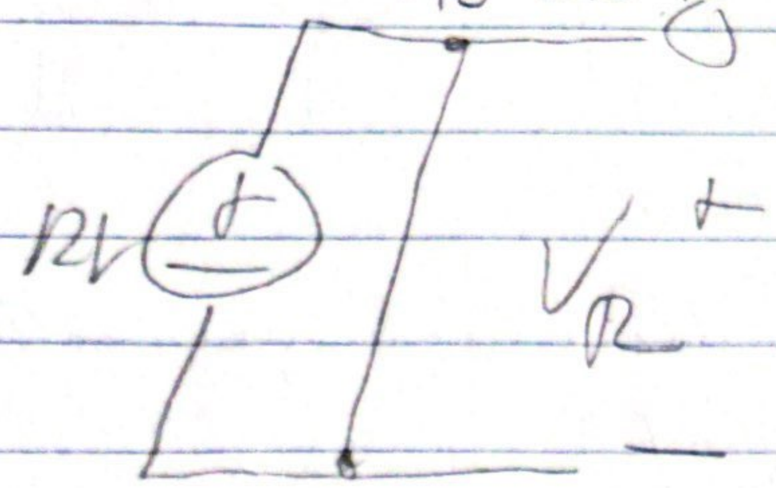
$\rho$ = resistivity



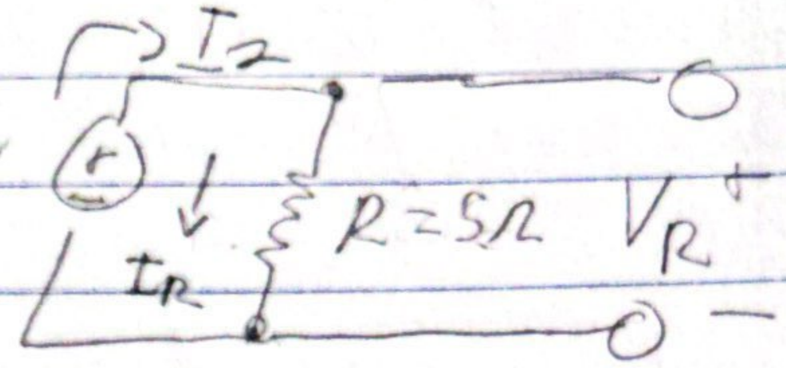

$P_R = I_R V_R = 2 \cdot 10 = 20W$

$$R = \frac{\rho L}{A}$$




$$\boxed{\begin{aligned} V &= IR \\ P &= IV = I^2R \\ P &= IV = \frac{V^2}{R} \end{aligned}}$$

$P = \sqrt{V \cdot R}$

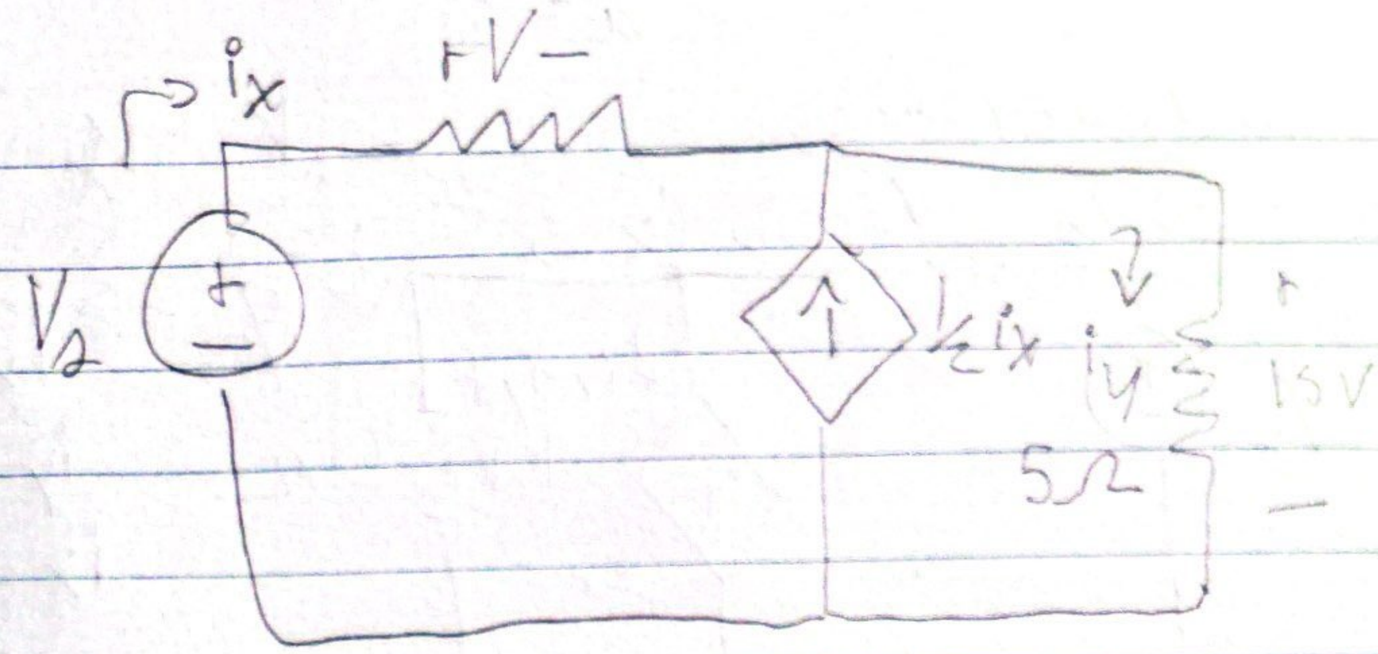



$V_2 = V_R = 10V$

$V_R = I_R R \Rightarrow 10 I_R = 5 \Rightarrow I_R = \frac{10}{5} \Rightarrow \boxed{I = 2A}$

Scanned with CamScanner

ex:




$i_y = i_x + \frac{1}{2} i_x = 1.5 i_x$

$V = IR$

$15 = i_y 5 = 3$

$i_y = 2 \Rightarrow i_x = 2$

$i_y = 2$

$V_x = V_2 - 15$

$20 = V_2 - 15$

$V_2 = 35$

$V = IR$

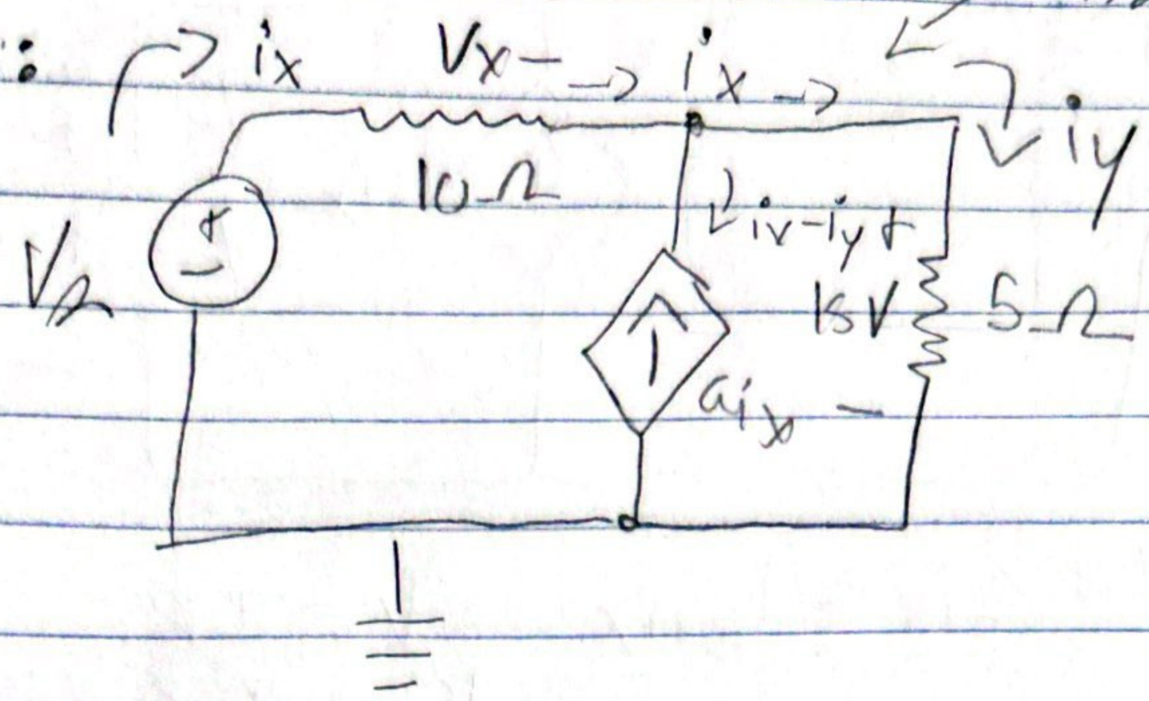
$V_x = 2 \cdot 10 = 20V$

Scanned with CamScanner

$a = 1/2$

Circuits 08/26/25

ex:




$V = IR$

$i_x - i_y = -ai_x$

$i_y - i_x = ai_x$

$i_x = ai_x + i_x = (a+1)i_x$

$i_x = ai_x + i_x = (1.5)i_x$

$i_y = 1.5 i_x$

$15V$

$V_2 - V_x = 15$

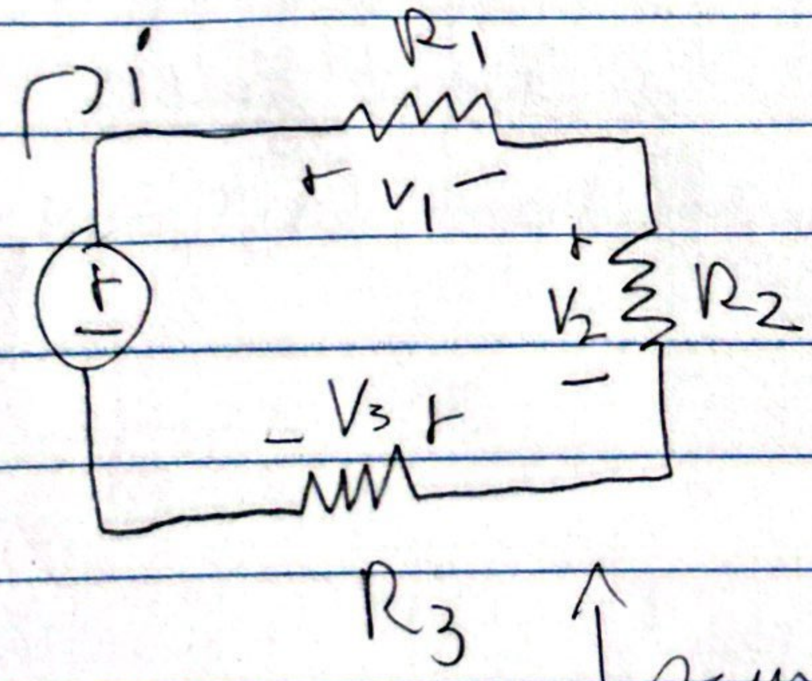
$V_2 = 15 + V_x$

$V_x = i_x(10) = \frac{15}{7.5}$

$V_x = i_x 10 = \frac{150}{7.5}$

$15V = 1.5 i_x 5 \Rightarrow \boxed{i_x = \frac{15}{(1.5)5}}$

$\boxed{i_x = 2}$




$V = V_1 + V_2 + V_3$

$V_1 = iR_1$

$V_2 = iR_2$

$V_3 = iR_3$

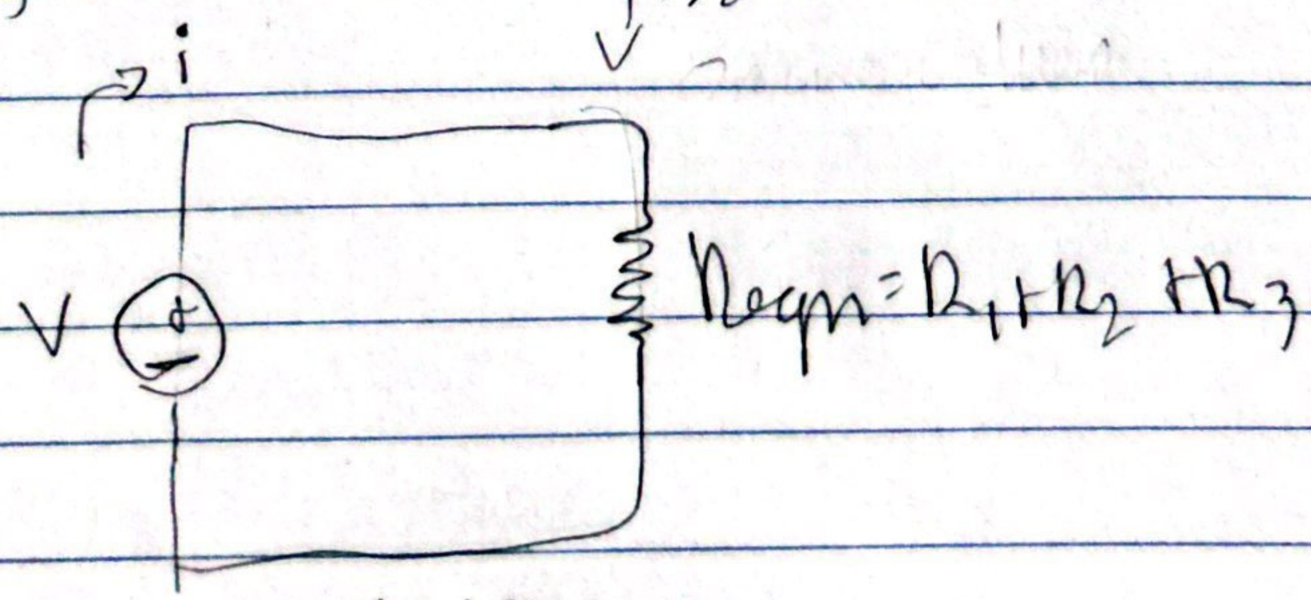
$V = V_1 + V_2 + V_3$

$V = iR_1 + iR_2 + iR_3$

$V = i(R_1 + R_2 + R_3)$

$R_{eqn}(R_1 + R_2 + R_3)$

same circuit because of same values




$V = iR_{eqn}$

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$i = i_1 + i_2 + i_3$

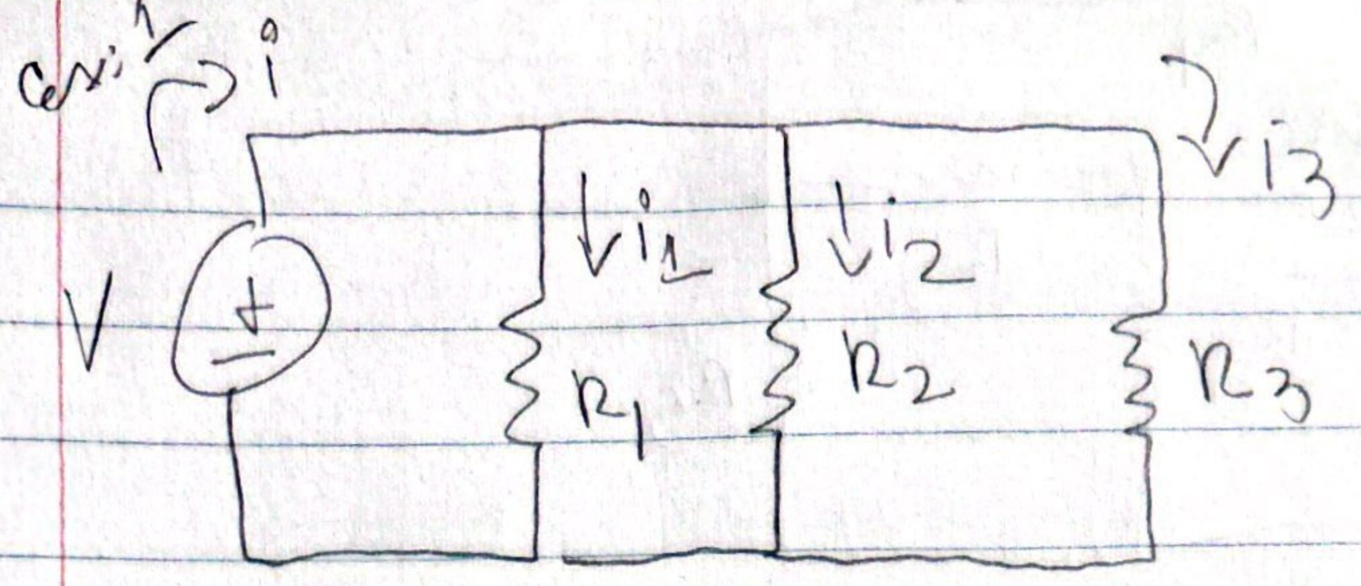
$G = \frac{1}{R}$ $\quad V = \sqrt{PR}$

$V = IR$

$I = \frac{V}{R}$

$P = \frac{V}{I}$

ex: 1




$i_1 = \frac{V}{R_1}$

$i_2 = \frac{V}{R_2}$

$i_3 = \frac{V}{R_3}$

$i = i_1 + i_2 + i_3$

$= \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$

$V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$

$\boxed{i = V R_{eq}}$

$R_{eq} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

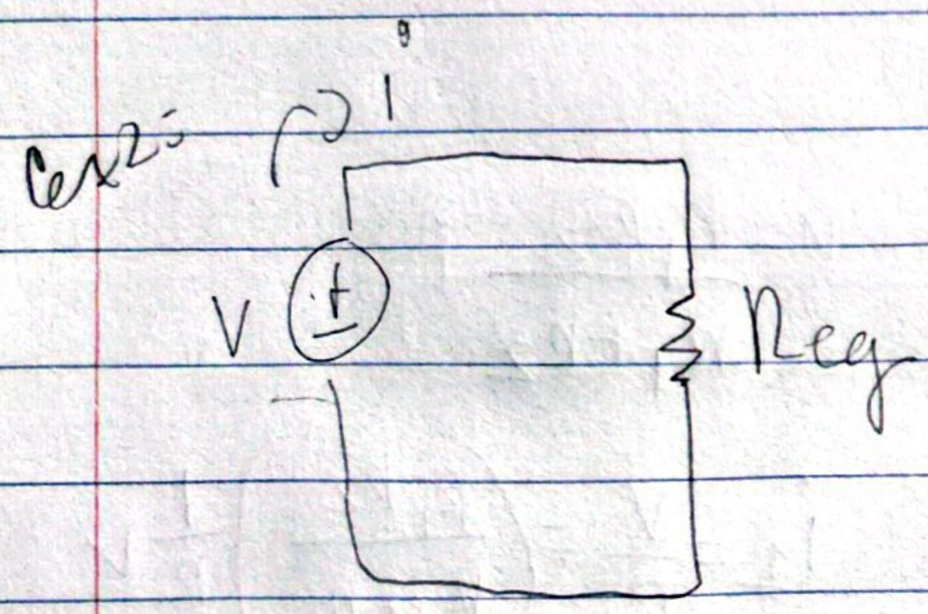
redefine

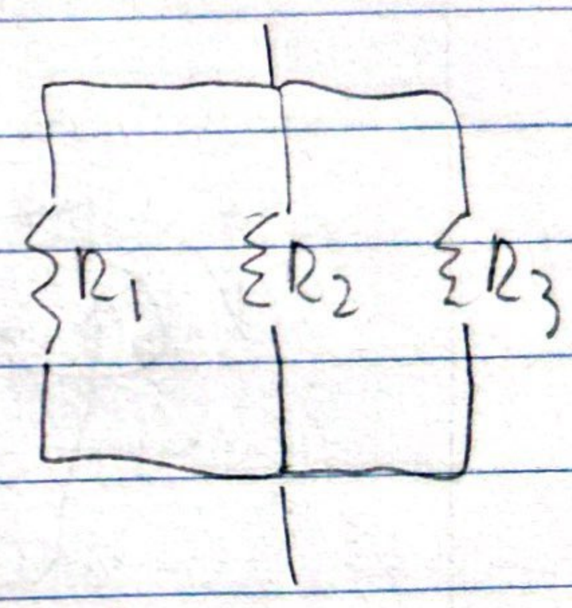
$R_{eq} = \frac{1}{1/R_1 + 1/R_2 + 1/R_3}$

$i = \frac{V}{R_{eq}}$

$i = V/R_{eq}$

ex: 2

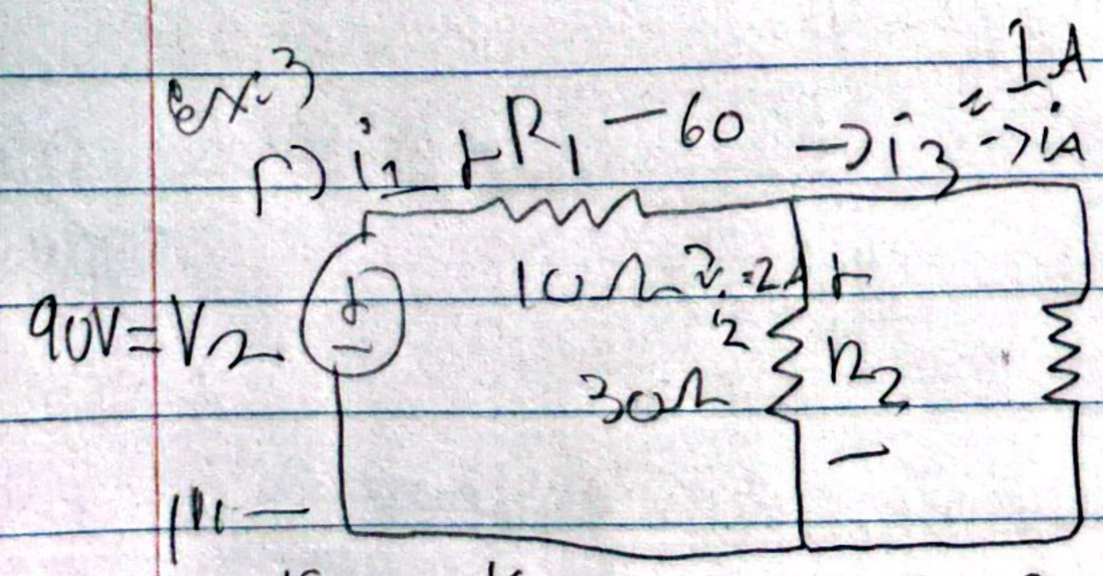



$\frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$

$\frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 R_2}{R_1 + R_2}$

ex: 3

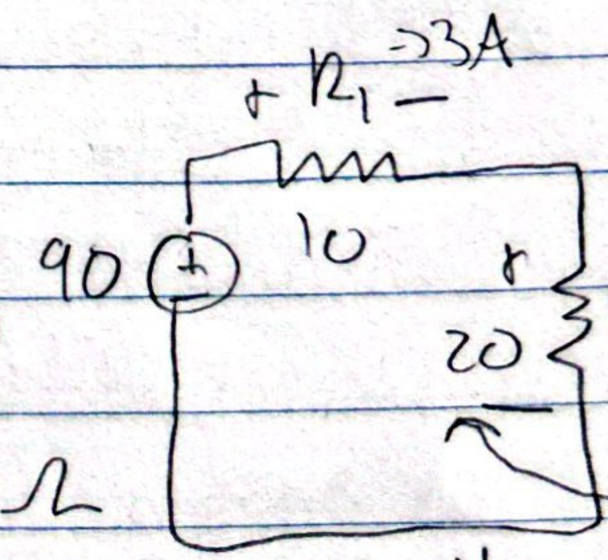



$i = \frac{V}{R}$ $\quad 3 = \frac{V}{R}$ $\quad V = 3R$ $\quad V = 3(10) = 30$

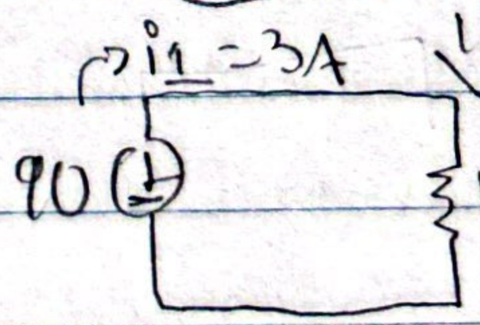
$i_2 = \frac{V}{R} = \frac{30}{60} = 2$ $\quad i = i_2 + i_3$

$i_3 = \frac{V}{R} = \frac{60}{60} = 1$ $\quad \boxed{3 = 2 + 1}$

$\Rightarrow$




$R_{eq} = \frac{R_2 R_3}{R_2 + R_3} = \frac{30 \cdot 60}{90} = 20$




$R_{eq} = R_1 + \frac{R_2 R_3}{R_2 + R_3} = 30$

$10 \quad 20$

$V = IR$ $\quad 90 = I(30) = \boxed{I = 3A}$

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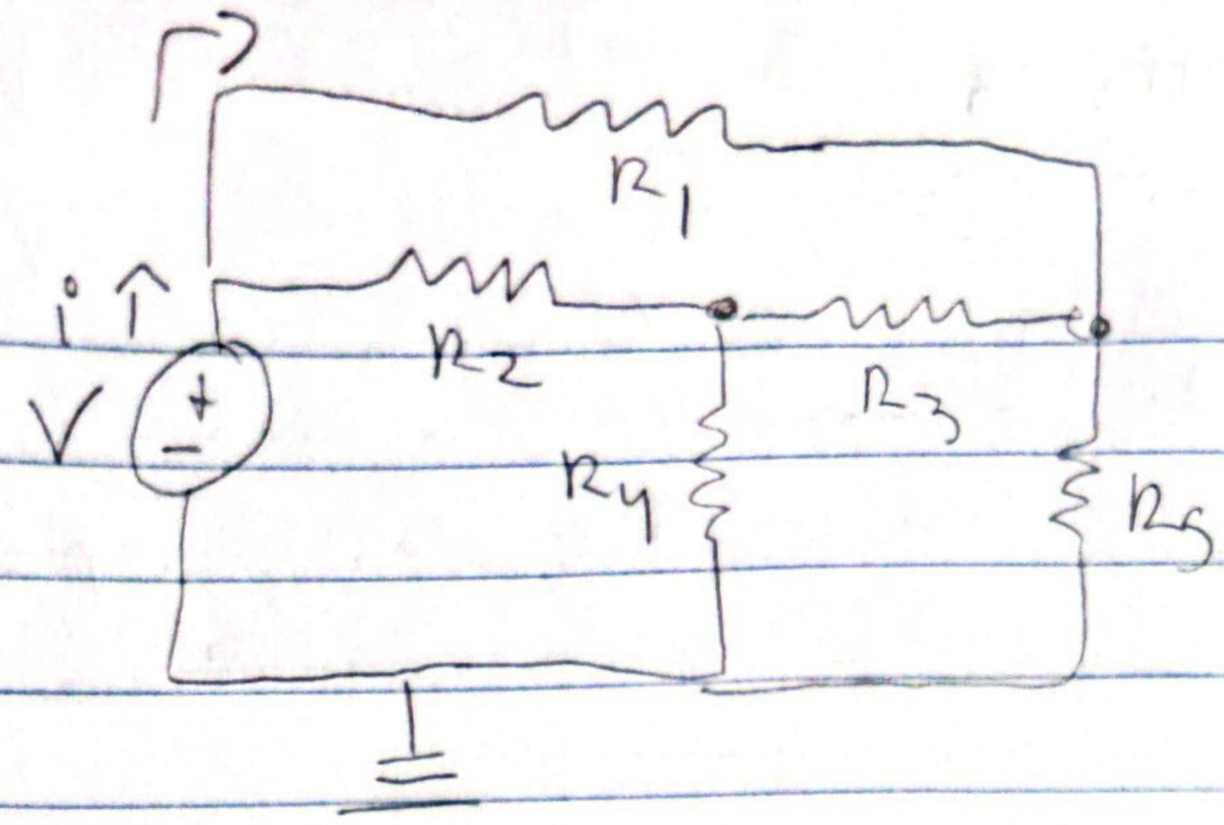
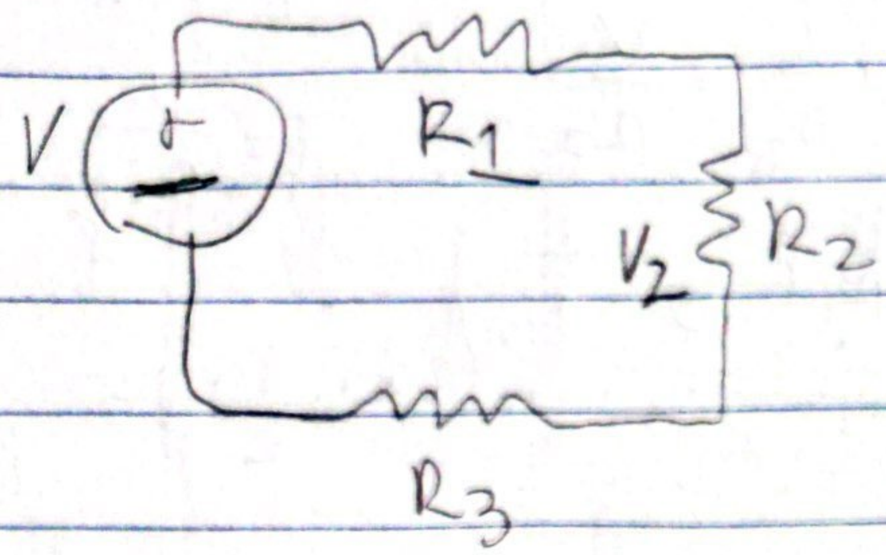
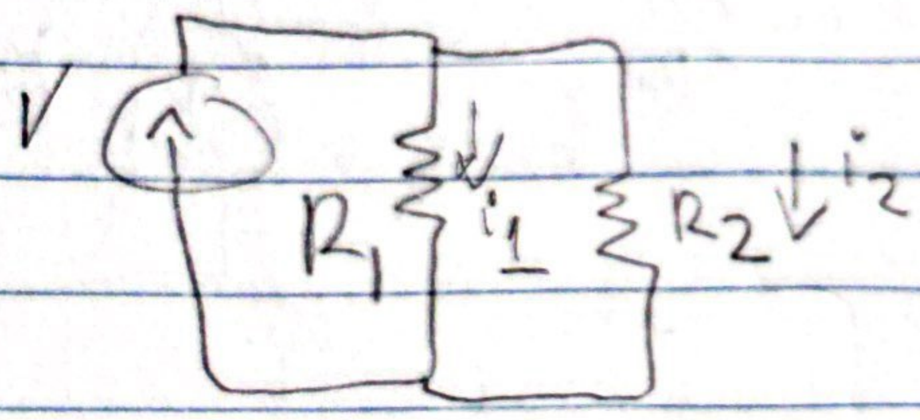
Ex:




$$i = \frac{V}{R_1 + R_2 + R_3}$$

$$V_2 = iR_2 = \frac{R_2}{R_1 + R_2 + R_3} V$$




$$V = \frac{R_1 R_2}{R_1 + R_2} i$$

$$i_1 = \frac{V}{R_1} = \left(\frac{R_1 R_2}{R_1 + R_2}\right)\frac{1}{R} V$$

$$= \frac{R_2}{R_1 + R_2} V$$

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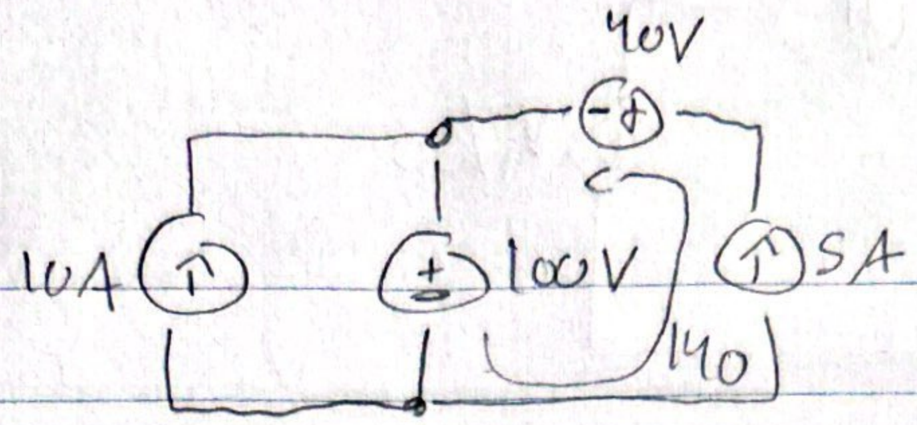
circuits
HW 1

2.1)



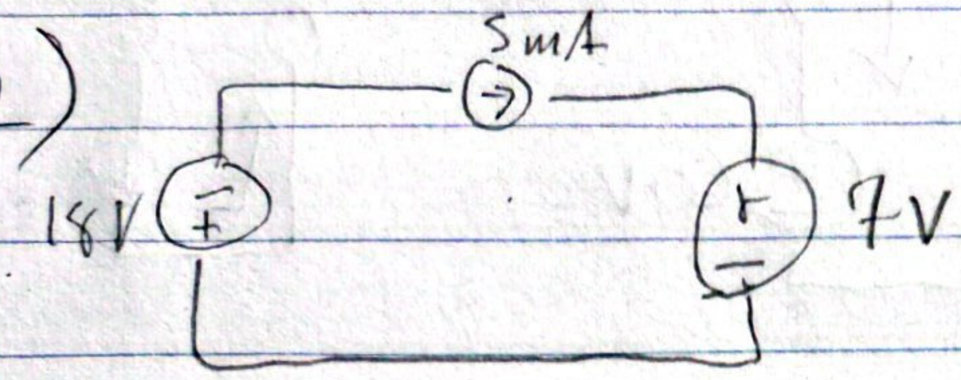

Yes the interconnection is valid because each source is charged independently

right side 5A · 40V = 200W

left side 10A + 5A (100V) = 1500W

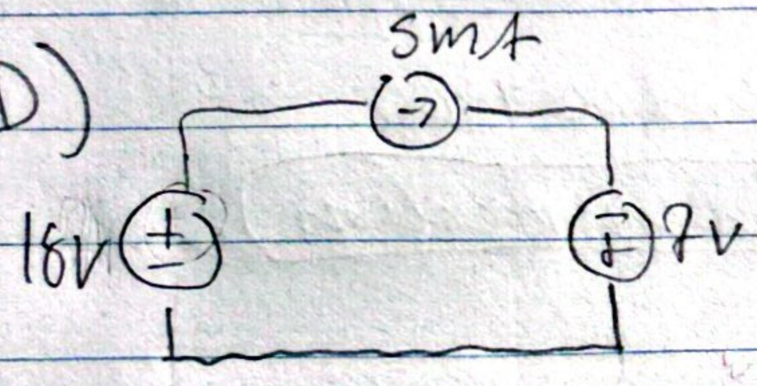
$\boxed{\text{total absorbs or generates 1700W}}$

2.2)




a) yes interconnection is valid because each source is charged independently & circuit is in series

D)




B) 5mA is delivering
18V is absorbing
7V is absorbing

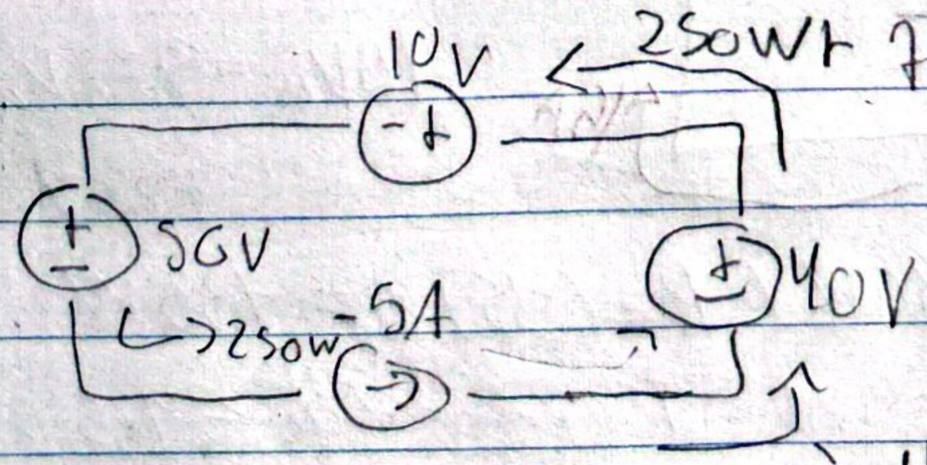
18V becomes the developer

C) 5x18 = 90W -> to charge 7V

18V(-5mA) = -90mW ⇒ pushes power into 7 volts (18-7)·5 = $\boxed{55}$

7V absorbs 18
7V absorbs the 5mA
5x18 = 90
7x5 = 35
} $\boxed{125V}$

2.4)




connection is valid because each source charges independently

50V · 5A = 250W

40V · 5A = 200W

10 · 5A = 50W

250 + 50 = $\boxed{300W \text{ total power}}$

V=IR

I = V/R

R = V/I

P = V · I

P = V² R

V = √PR

P = I² · R

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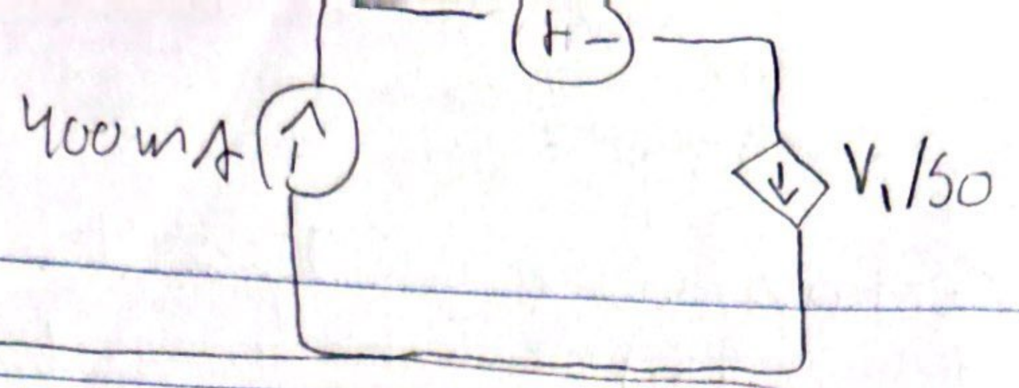
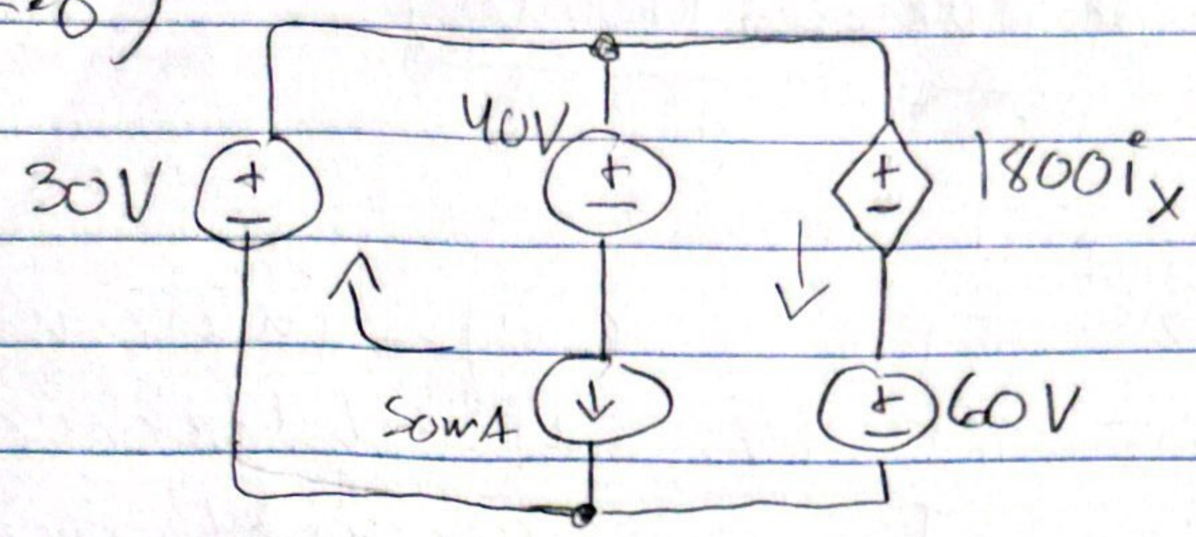
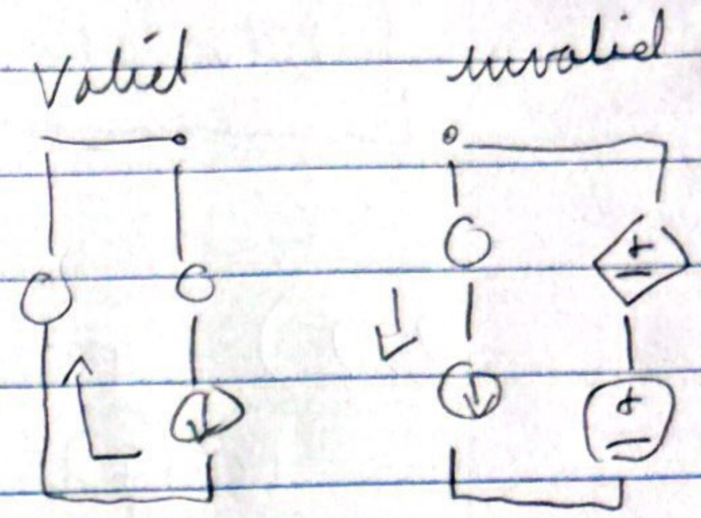



a) $V_1 = 0.4(50) = 20\,W$

B) $P_{absorbed} = 20(0.4A) = 8\,W$

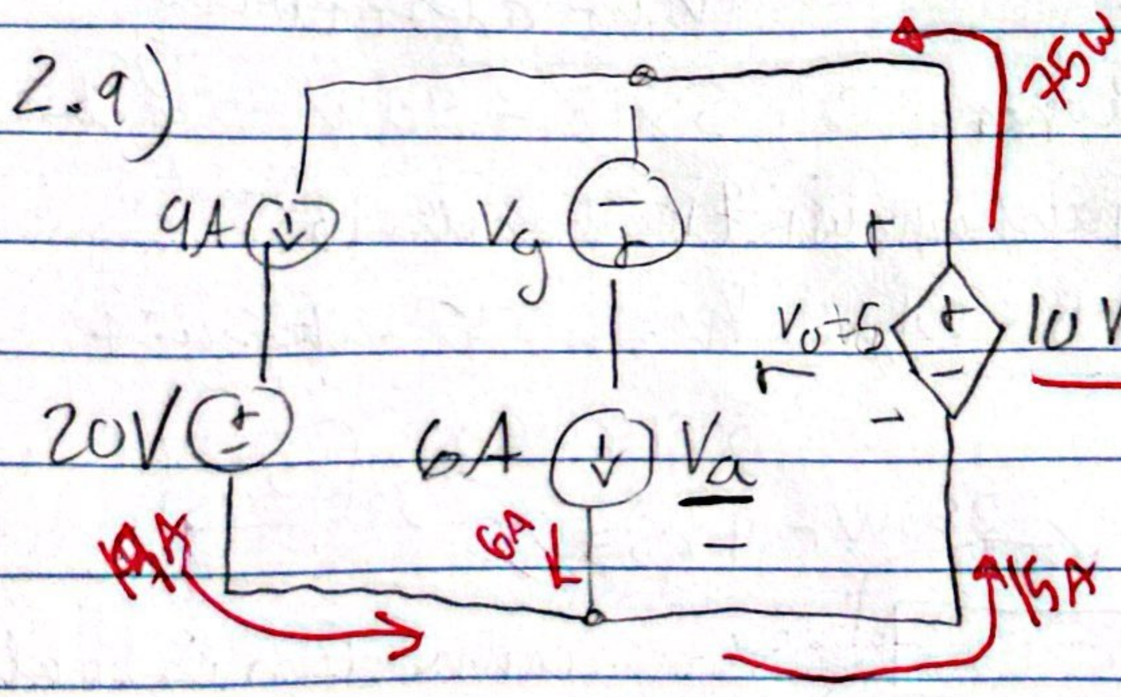
2.8)




Right side can zero out & give 10V difference
left side can't zero out & produce 1800
therefore invalid interconnection

2.9)




find the power developed

9A ↓ 6A ↓

20V ± $10V_a$

$V_0 = 5V$

$10V_a = 5 \Rightarrow V_a = 0.5V$

+5V +20V 5 − 0.5 = 4.5 across

$P = V \cdot i$ $P = 20 \times 9 = 180W$ $P = (-15) \cdot 9 = -135W$

$P = V \cdot i$ $P = 0.5V \times 6A = 3W$ Top V across middle = 4.5 × 6 = 27

9+6 I-dependent (no load) dependent vop = 5·(−15) = −75W

I dependent = 15A

$P = V \cdot i$ $5 \times (-15) = -75W$

total absorbed = 180+3+27 = 210W

total delivered = 135+75 = 210W

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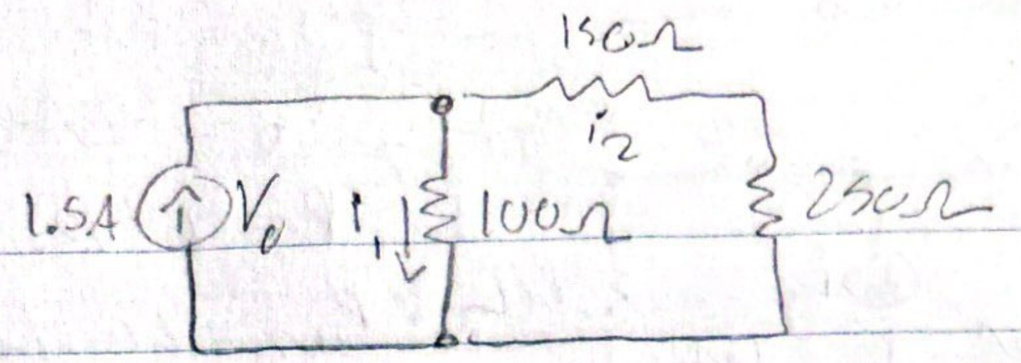
circuits HW2

2.17




$150+250=400\Omega$

$100\Omega \| 400\Omega$

$R_{eq} = \frac{100\cdot 400}{100+400} = \frac{40000}{500}$

$\boxed{R_{eq}=80\Omega}$

$V_0 = I \cdot R_{eq} = 1.5\times 80 = 120V$

$i_1 = \frac{V_0}{100} = \frac{120}{100} = \boxed{1.2A}$ $\frac{120}{400} = 0.3A = i_2$

$1.5\times 120 = \boxed{180W}$

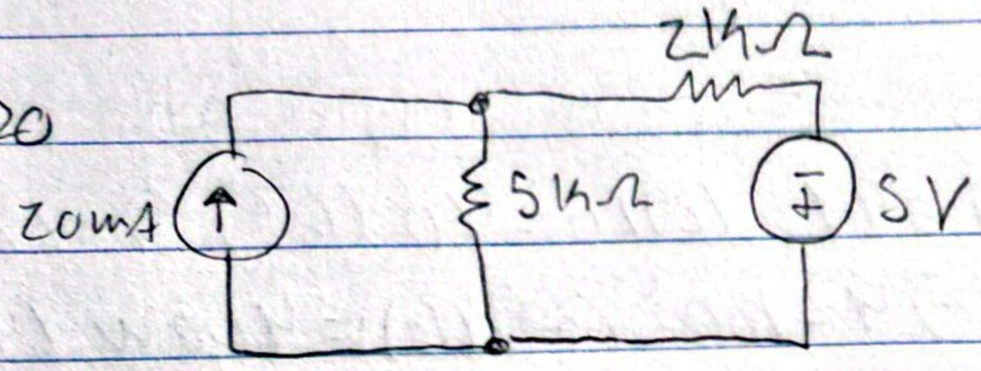
$100\Omega: (1.2)^2\cdot 100 = 144W$

$150\Omega: (0.3)^2\cdot 150 = 13.5W$

$250\Omega: (0.3)^2\cdot 150 = 22.5W$

$\boxed{180W}$

2.20




a) find $V_0$ b) verify $V_0$

$\frac{V_0}{5k} + \frac{V_0-(-5)}{2k} = 20mA$

$\times 1000$

$2V_0 + 5(V_0+5)$ $2V_0+5V_0+25 = 7V_0+25 = 200$ $\boxed{V_0 = 25V}$

$I_{5k} = 25/5000 = 5mA$ $I_{2k} = (25+5)/2000 = 15mA$

$P = 20mA\cdot 25V = 0.500W$

$2k\Omega: I^2R = (15mA)^2\cdot 2k = 0.450W$

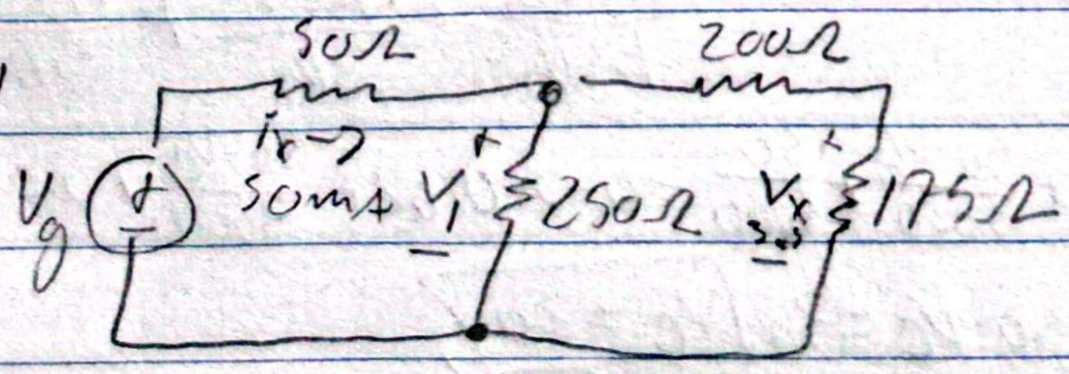
$5k\Omega: V^2/R = 25^2/5000 = 0.125W$

5V 15mA $\rightarrow$ a $-5 \rightarrow p = -0.075$ (75mW)

$0.500 + 0.075 = .575W$

$0.450 + 0.125 = 0.575W$

2.21




$i_x = 50mA$ $V_x = 3.5V$

$50+200+250 = 500$

$V = 3.5/175 = 0.02A = \boxed{20mA = i_1}$

$V_1 = 200\Omega\cdot I_1 = 200\cdot 0.2 = 4V$

so $4+3.5 = \boxed{7.5V}$

$V_g = V_1 = 7.5V$

$p = v_2\cdot i_x = 10\cdot 0.05 = \boxed{0.5W}$

$V_2 = 50\Omega\ 50mA = 0.05\cdot 50 = 2.5V$

$V_2 = V_1 + 2.5 = 7.5 + 2.5 = \boxed{10V}$

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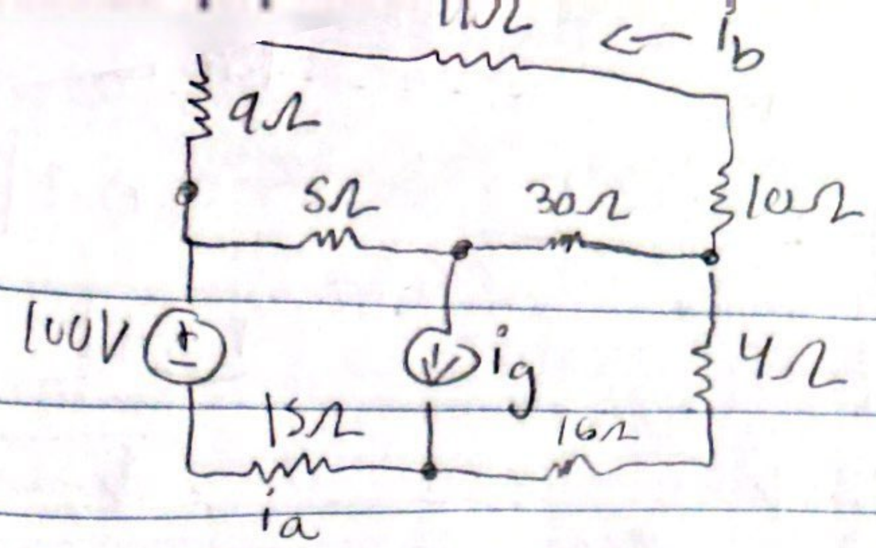



$i_a = 4A$

$i_b = -2A$

$P = I^2R$

$P_{11\Omega} = 44 \Rightarrow |I_{11}| = \sqrt{44/11} = 2A$

$P_{10\Omega} = 40 \Rightarrow |I_{10}| = \sqrt{40/10} = 2A$

$P_{4\Omega} = 100 = |I_4| = 5A$ $\quad P_{15\Omega} = 240\ |I_{15}| = 4$

$P_{16\Omega} = 400 = |I_{16}| = 5A$ $\quad P_{9\Omega} = 36\ |I_9| = 2A$

$P_{5\Omega} = 180 = |I_5| = 6A$

$P_{30\Omega} = 270 = |I_{30}| = 3A$

$i_g = -(6+3) = -9A$

$V_g$

$11\Omega = 11 \cdot 2 = 22V$

$10\Omega = 10 \cdot 2 = 20V$

$4\Omega = 5 \cdot 4 = 20V$

$16\Omega = 5 \cdot 16 = 80V$

$15\Omega = 4 \cdot 15 = 60V$

Loop node $= 190V$

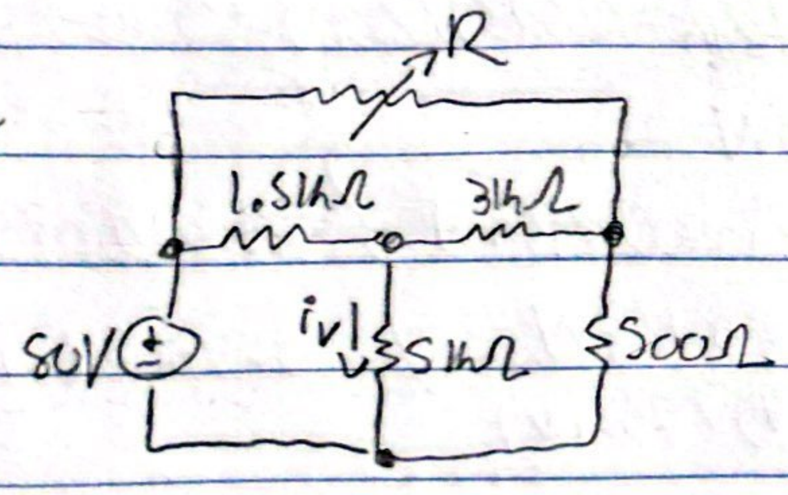
$(2^2)(9) = 36$ $\quad (2^2)11 = 44$ $\quad (2^2)10 = 40$ $\quad (6^2)5 = 180$

$(3^2)30 = 270W$ $\quad (5^2)4 = 100$ $\quad (5^2)(16) = 400W$ $\quad (4^2)15 = 240W$

$IR = 6 \cdot 5 = 30$ $\quad 30 \cdot 3 = 90$ $\quad V_g = 190$

$36 + 44 + 40 + 180 + 270 + 100 + 400 + 240 = 1310$

2.27




$i_o \downarrow 10mA$ $\quad R$ $\quad V_A = +80V$

$i_o = \frac{V_B - 0}{5k\Omega} = 10mA = V_B = (10 \times 10^{-3}) \cdot 5000$

$= \boxed{50V}$

$\frac{V_B - V_A}{1.5k} + \frac{V_B - V_C}{3k} + \frac{V_B - 0}{5k} = 0$

$V_A = 80$ $\quad V_B = 50$ $\quad \frac{-30}{1500} + \frac{50 - V_C}{3000} + \frac{50}{5000} = 0 \Rightarrow -0.02 + \frac{50 - V_C}{3000} + 0.01 = 0$

$\frac{50 - V_C}{3000} = 0.01 \Rightarrow 50 - V_C = 30$ $\quad \boxed{V_C = 20}$

$\frac{V_C - V_B}{3k} + \frac{V_C - V_A}{R} + \frac{V_C - 0}{500} = 0$ $\quad \frac{-30}{3000} + \frac{-60}{R} + \frac{20}{500} = 0$

$V_C = 20$ $\quad V_B = 50$ $\quad V_A = 80$

$-0.01 - \frac{60}{R} + 0.04 = 0$

$0.03 = \frac{60}{R}$ $\quad R = \frac{60}{0.03} = \boxed{2000\Omega}$

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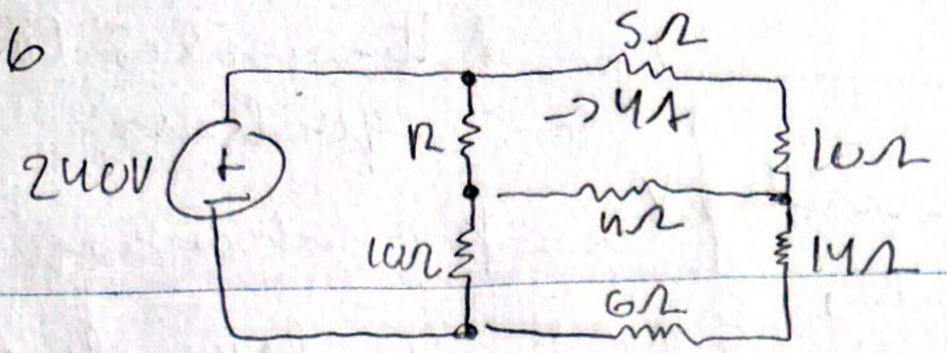
circuits HW 1

2.26




$A = +240V$

$C = 0V$

$B = ?$

$D \to E = 10\Omega$ $E-F = 14\Omega$ $A \leftrightarrow D = 5\Omega$ $I_{AD} = \frac{V_A - V_D}{5} = 4$

$A \to B : R$, $B \to C = 10\Omega$ $B \leftrightarrow E = 4\Omega$ $V_D = V_A - 20 = 240 - 20$

$C \leftrightarrow F = 6\Omega$ $\boxed{= 220V}$

$$\frac{V_D - V_A}{5} + \frac{V_D - V_E}{10} = 0 \Rightarrow \frac{220-240}{5} + \frac{220 - V_E}{10} = 0 \Rightarrow -4 + \frac{220 - V_E}{10} = 0$$

$$220 - V_E = 40 = \boxed{180 = V_E}$$

$$\frac{V_F - V_E}{14} + \frac{V_F - 0}{6} = 0 \quad \frac{V_F - 180}{4} + \frac{V_F}{6} = 0$$

$$\times 12 : 3(V_F - 180) + 2V_F = 0 \Rightarrow 10V_F = 540 \Rightarrow \boxed{V_E = 54V}$$

$$\frac{V_E - V_D}{10} + \frac{V_E - V_B}{4} + \frac{V_E - V_F}{14} = 0$$

$$(-40)/10 + (180 - V_B)/4 + (126)/14 = 0$$

$$-4 + \frac{180 - V_B}{4} + 9 = 0 \Rightarrow \frac{180 - V_B}{4} = -5 \Rightarrow 180 - V_B = -20 \boxed{V_B = 200V}$$

$$\to 4\Omega = \frac{V_B - V_E}{4} = \frac{200 - 180}{4} = 5A \quad I_{A \to B} = \frac{V_A - V_B}{R} = \frac{240 - 200}{R} = \frac{40}{R}$$

$$\to 10\Omega \ \frac{V_B - 0}{10} = 20A \downarrow \quad \frac{40}{R} = 5 + 20 = 25 = R = \frac{40}{25} = \boxed{1.6\Omega}$$

$$P_{supplied} = |V| \cdot |I| = 240 \times 29 = \boxed{6.96kW}$$

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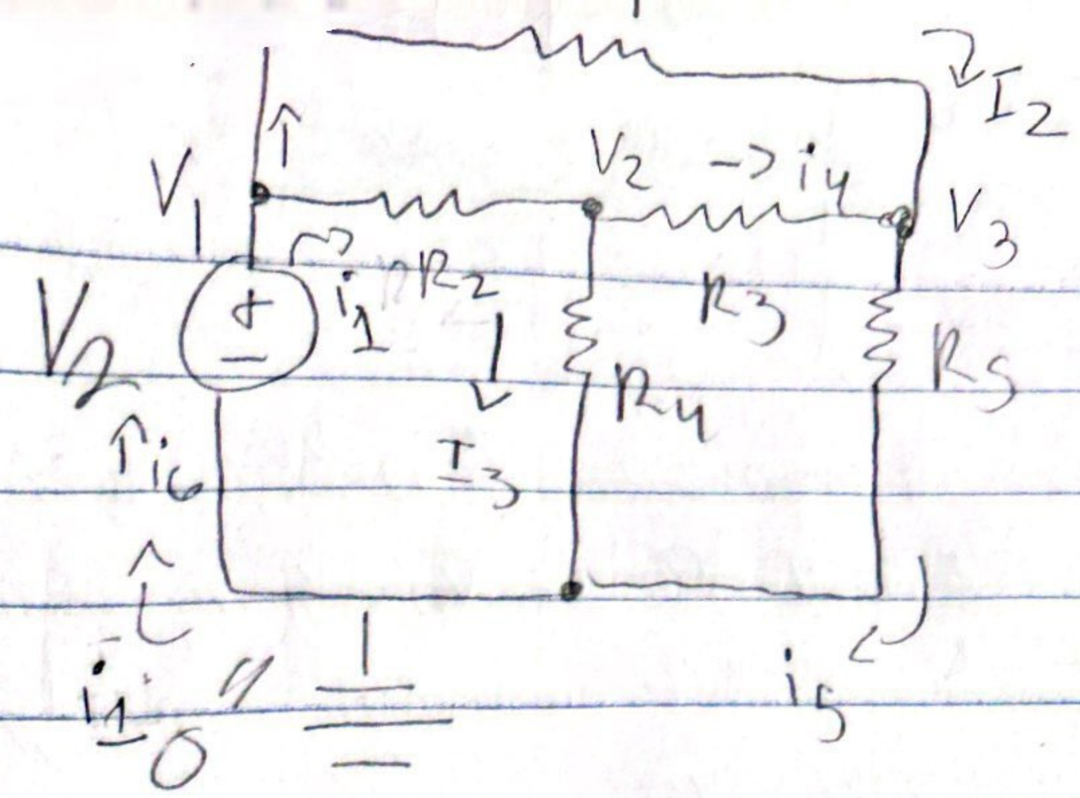


* the goal is to produce equations
* combine as many independent equations into one
* each equation represents different information because it comes from different parts

n-dimension

4-amount of work

$$i_1 = \frac{V_1 - V_2}{R_2} \qquad V_1 = V_2$$

$$i_2 = \frac{V_1 - V_3}{R_1}$$

$$i_3 = \frac{V_2}{R_4}$$

$$i_4 = \frac{V_2 - V_3}{R_3}$$

$$i_5 = \frac{V_3}{R_5}$$

$$i_6 = i_1 + i_2$$

node 1 ($V_1$)

$$i_6 = i_1 + i_2 = \frac{V_1 - V_2}{R_2} + \frac{V_1 - V_3}{R_1} = i_6$$

node 2 ($V_2$)

$$i_1 = i_3 + i_4 = \frac{V_2}{R_4} + \frac{V_2 - V_3}{R_3} = \frac{V_1 - V_2}{R_2}$$

node 3 ($V_3$)

$$i_2 + i_4 = i_5 \rightarrow \frac{V_1 - V_3}{R_1} + \frac{V_2 - V_3}{R_3} = \frac{V_3}{R_5}$$

node 1 ($V_1$)

$\Longrightarrow$

$$3x_1 + 5x_2 + 7x_3 = 3$$
$$4x_1 + 37x_2 - 10x_3 = 4$$
$$5x_1 + \quad - 3x_3 = 7$$

$$\underbrace{\begin{bmatrix} 3 & 5 & 7 \\ 4 & 37 & -10 \\ 5 & 0 & -3 \end{bmatrix}}_{A} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \underbrace{\begin{bmatrix} 3 \\ 4 \\ 7 \end{bmatrix}}_{b = C}$$

$AB \neq BA$

$AB = AC$

if $B = C$

$Ab = C$

$A^{-1}Ab = A^{-1}C$

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node 1 $(V_1) = \frac{V_1}{R_1} - \frac{V_2}{R_2} + \frac{V_1}{R_1} - \frac{V_3}{R_1} = i_6$

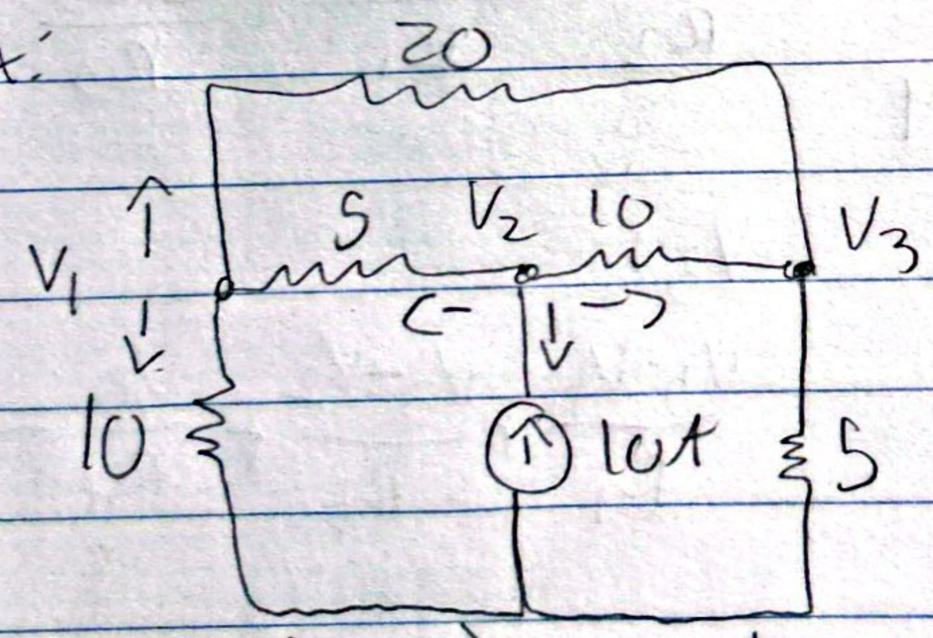
$$V_1\left(\frac{1}{R_2} + \frac{1}{R_1}\right) - V_2\left(\frac{1}{R_2}\right) - V_3\left(\frac{1}{R_1}\right) = i_6$$

node 2 $(V_2) = -V_1 \cdot \frac{1}{R_2} + V_2\left(\frac{1}{R_4} + \frac{1}{R_3} + \frac{1}{R_2}\right) + V_3\left(\frac{1}{R_3}\right) = 0$

node 3 $(V_3) = V_1\left(\frac{1}{R_1}\right) + V_2\left(\frac{1}{R_3}\right) + V_3\left(\frac{-1}{R_1} - \frac{1}{R_3} - \frac{1}{R_5}\right) = 0$

$$\begin{bmatrix} \frac{1}{R_1} + \frac{1}{R_2} & -\frac{1}{R_2} & 0 \\ -\frac{1}{R_2} & \frac{1}{R_2} + \frac{1}{R_4} + \frac{1}{R_3} & -\frac{1}{R_4} \\ 0 & -\frac{1}{R_4} & \frac{1}{R_4} + \frac{1}{R_5} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \begin{bmatrix} i_2 \\ 0 \\ i_2 \end{bmatrix}$$

Ex:




$V_1: \frac{V_1}{10} + \frac{V_1 - V_2}{5} + \frac{V_1 - V_3}{20} = \emptyset$

$V_2: \frac{V_2 - V_1}{5} + \frac{V_2 - V_3}{10} - 10 = \emptyset$

$V_3: \frac{V_3 - V_1}{20} + \frac{V_3 - V_2}{10} + \frac{V_3}{5} = \emptyset$

$V_1\left(\frac{1}{10} + \frac{1}{5} + \frac{1}{20}\right) + V_2\left(-\frac{1}{5}\right) + V_3\left(\frac{-1}{20}\right) = 0 \Rightarrow .35V_1 - .2 - .05V_3 = 0$

$V_1\left(\frac{-1}{5}\right) + V_2\left(\frac{1}{5} + \frac{1}{10}\right) + V_3\left(\frac{-1}{10}\right) = 10 \Rightarrow .2V_1 + .3V_2 - .1V_3 = 10$

$V_1\left(\frac{-1}{20}\right) + V_2\left(\frac{-1}{10}\right) + V_3\left(\frac{1}{20} + \frac{1}{10} + \frac{1}{5}\right) = \emptyset \Rightarrow -.05V_1 - .1V_2 + .35V_2 = \emptyset$

$$\begin{bmatrix} .35 & -.20 & -.05 \\ -.20 & -.3 & -.10 \\ -.05 & -.10 & .35 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \begin{bmatrix} 0 \\ 10 \\ 0 \end{bmatrix} = \begin{bmatrix} 45.45 V_1 \\ 72.72 V_2 \\ 27.27 V_3 \end{bmatrix}$$

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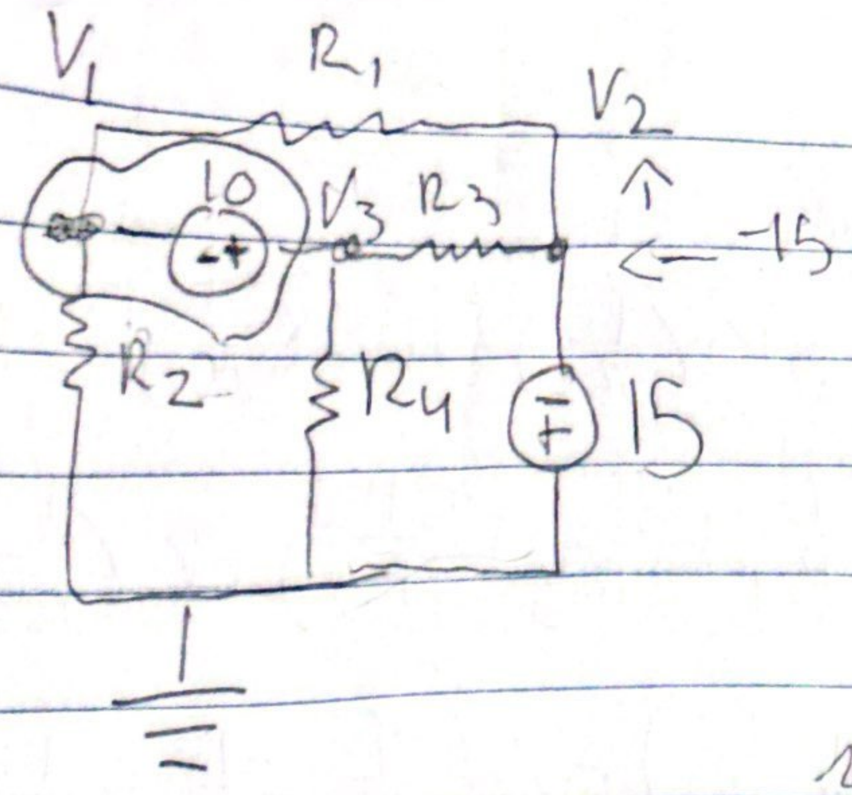
hd
ll current
ne closed area
must equal 0




V1: $\frac{V_1}{R_2} + \frac{V_1 - V_2}{R_1} + ?$

V2:

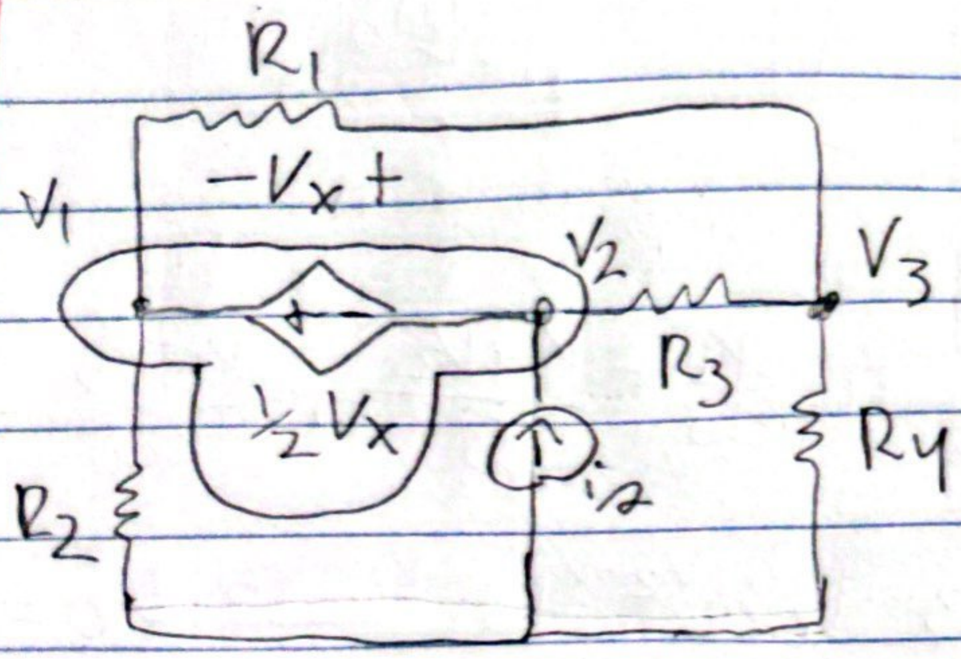
$V_2 = -15V$

supernode:

$$\frac{V_1}{R_2} + \frac{V_1 - V_2}{R_2} + \frac{V_2 - V_3}{R_3} + \frac{V_3}{R_4} = 0$$

3rd eqn:

$V_1 + 10 = V_3$




supernode

$$\frac{V_1}{R_2} + \frac{V_1 - V_3}{R_1} + \frac{V_2 - V_3}{R_3} - i_3 = 0$$

$V_3$:

$$\frac{V_3 - V_1}{R_1} + \frac{V_3 - V_2}{R_3} + \frac{V_3}{R_4} = 0$$

$V_3 - V_1 = V_x$

$V_1 - V_2 = \frac{1}{2}V_x$

$V_1 - V_2 = \frac{1}{2}(V_3 - V_1)$

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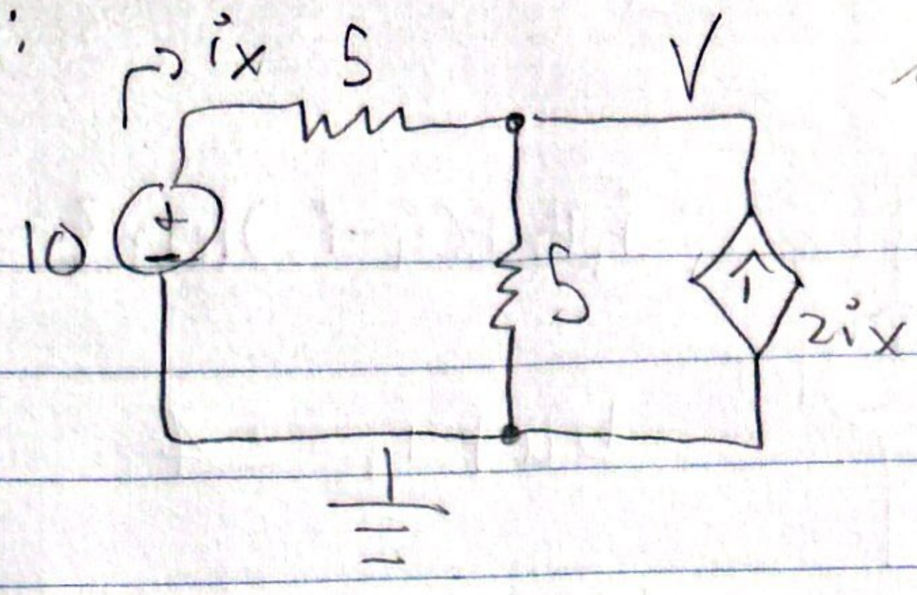
circuits
09/02/25

ex 1:



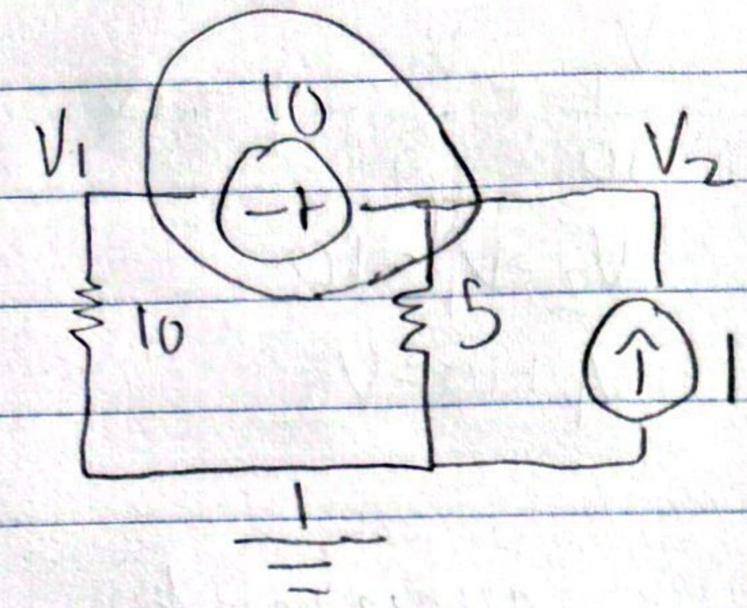

supernodes

V:

$$\frac{V-10}{5} + \frac{V}{5} - 2i_x = 0$$

$$\frac{10-V}{5} = i_x$$

ex 2:

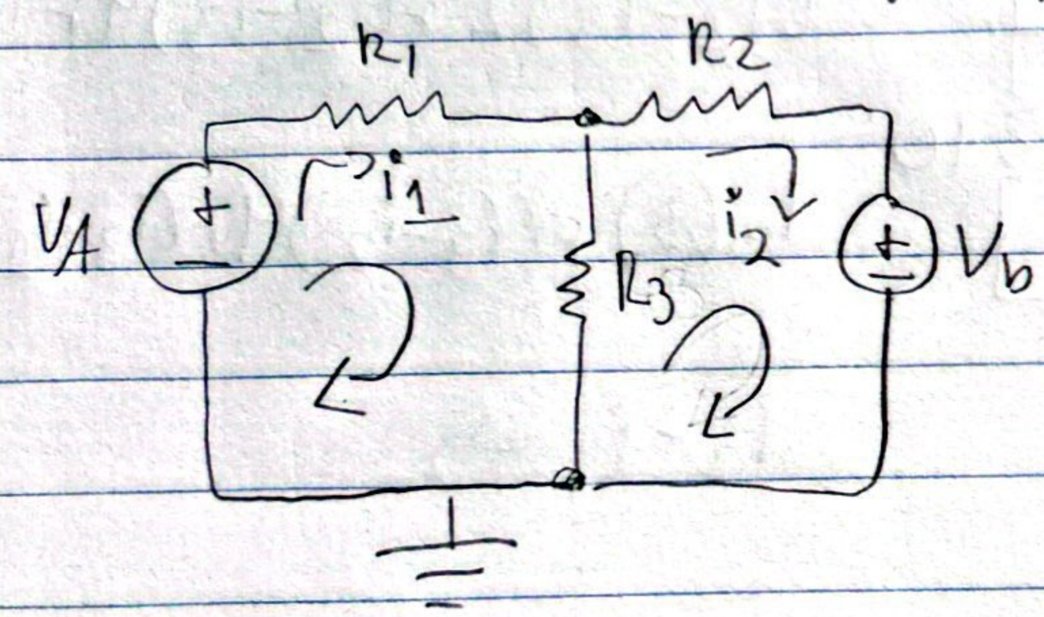



supernode:

$$\frac{V_1}{10} + \frac{V_2}{5} - 1 = 0$$

$$V_2 - V_1 = 10$$

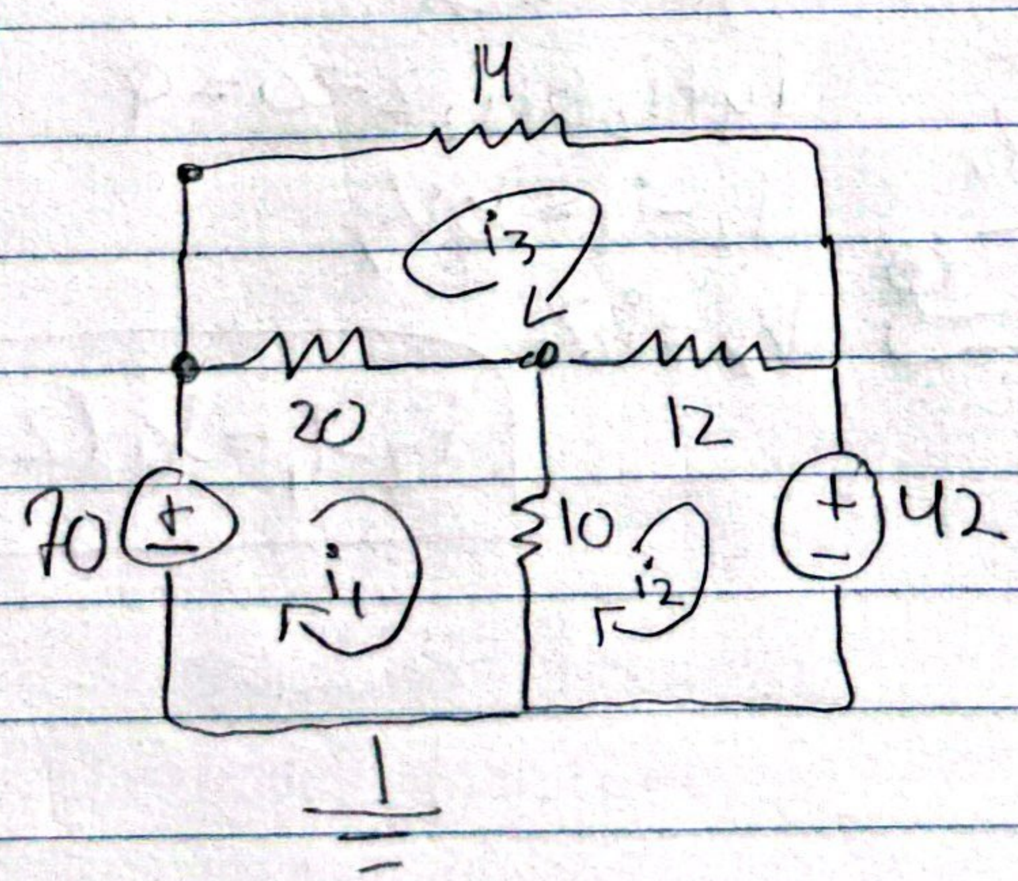
loops




$$i_1 R + i_3 R_3 - V_a = 0$$

$$i_2 R_2 + V_b - i_3 R_3 = 0$$

$$i_2 + i_3 = i_1$$




$i_3$:

$$i_3 14 + (i_3 - i_2)12 + (i_3 - i_1)20 = 0$$

$$i_1: (i_1 - i_3)20 + (i_1 + i_2)10 - 70 = 0$$

$$i_2: (i_2 - i_3)12 + 42 + (i_2 - i_1)10 = 0$$

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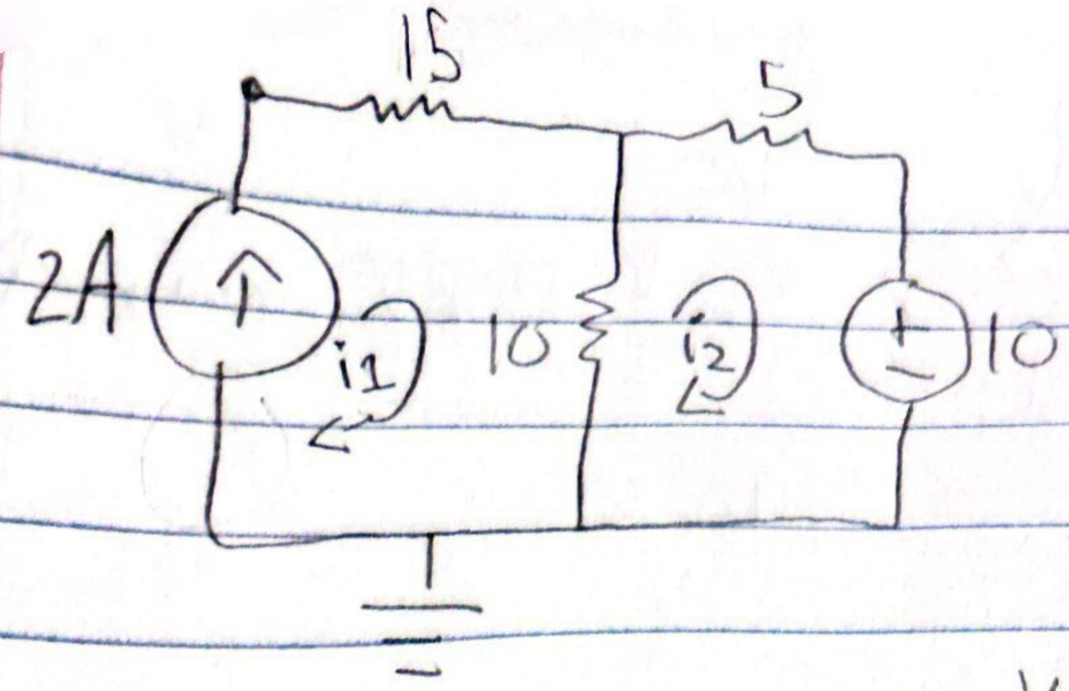



$i_1 15 + (i_1 - i_2)10 + 3 = \phi$

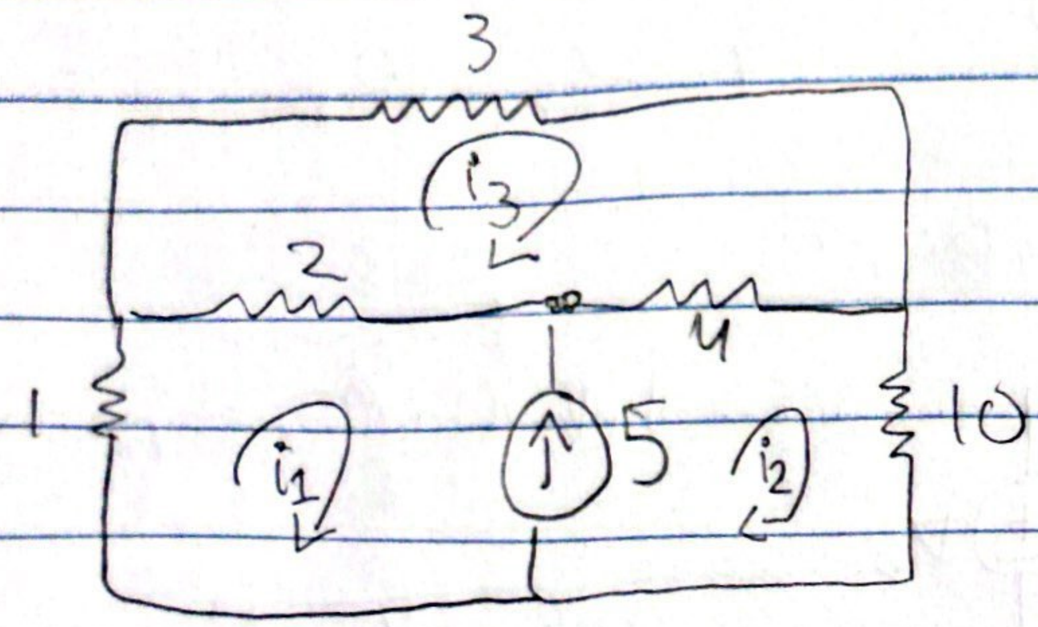
but $i_1 = 2A$

$i_2(5) + 10 + (i_2 - i_1)10 = \phi$

$\frac{V_1}{10} + \frac{V_2}{5} - 1 = \phi$

$V_2 - V_1 = 10$

$V_1 + 10 = V_2$

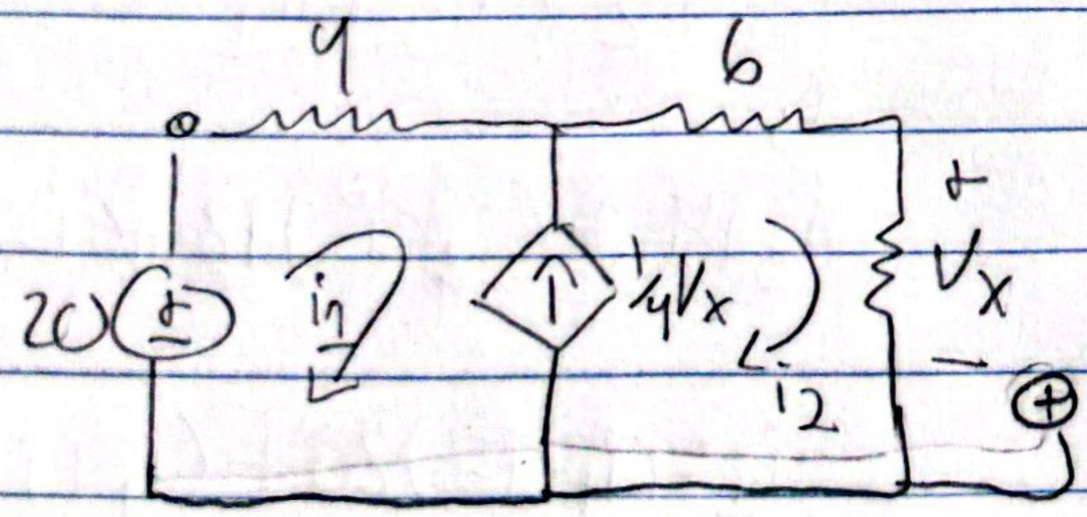



supermesh

$(i_2 - i_3)2 + (i_2 - i_3)4 + i_2 10 + i_1(1)$

$i_3(3) + (i_3 - i_2)4 + (i_3 - i_1)2 = \phi$

$i_2 - i_1 = 5$




supermesh

$i_4 + i_2 6 + i_2 2 - 20 = \phi$

$i_2 - i_1 = \frac{1}{4}V_x$

$V_x = i_2 2$

$\boxed{i_2 - i_1 = \frac{1}{4}(2i_2)}$

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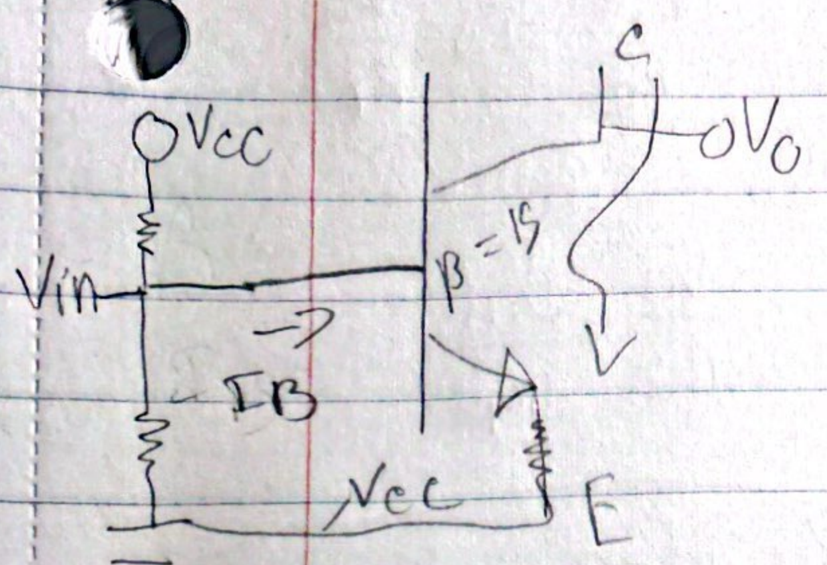
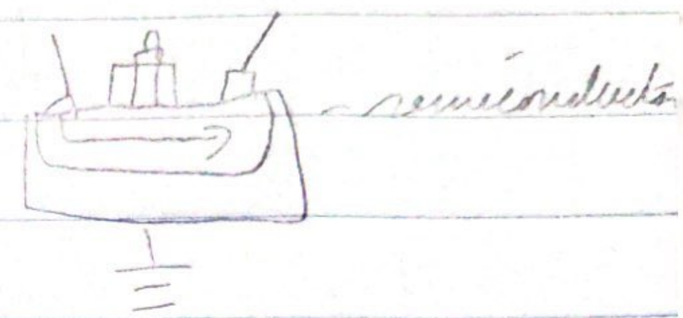
circuits day 4

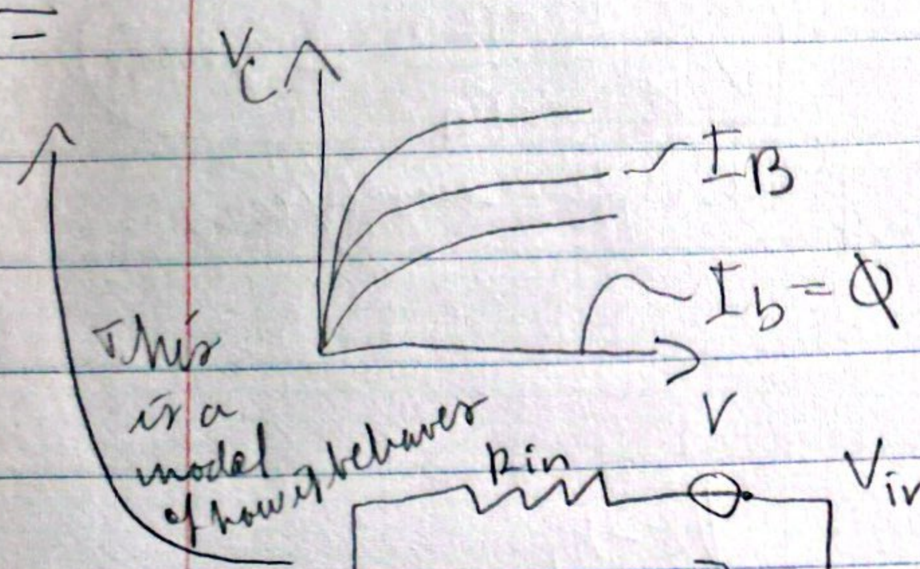
# transistors and op amps

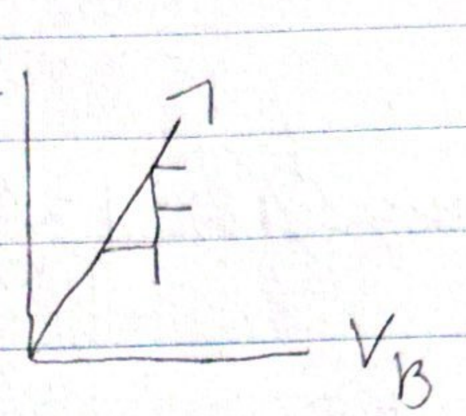
09/09/25



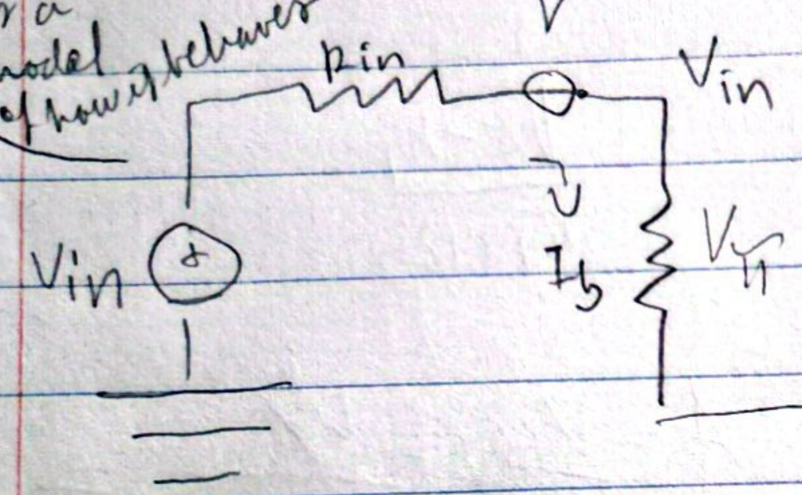

× current goes down which means electrons go up

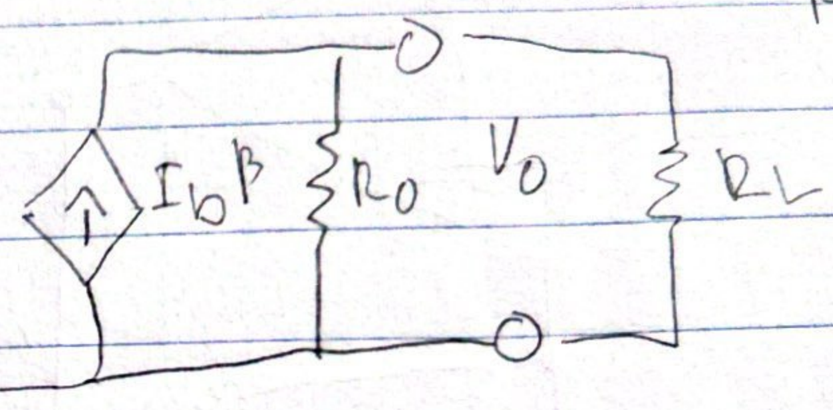


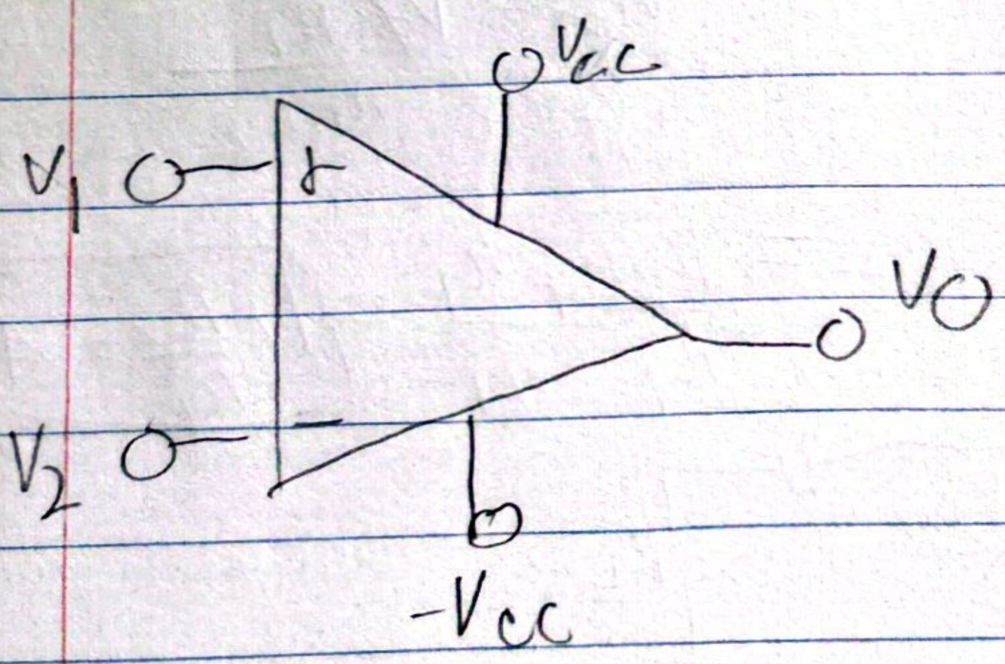

β = current



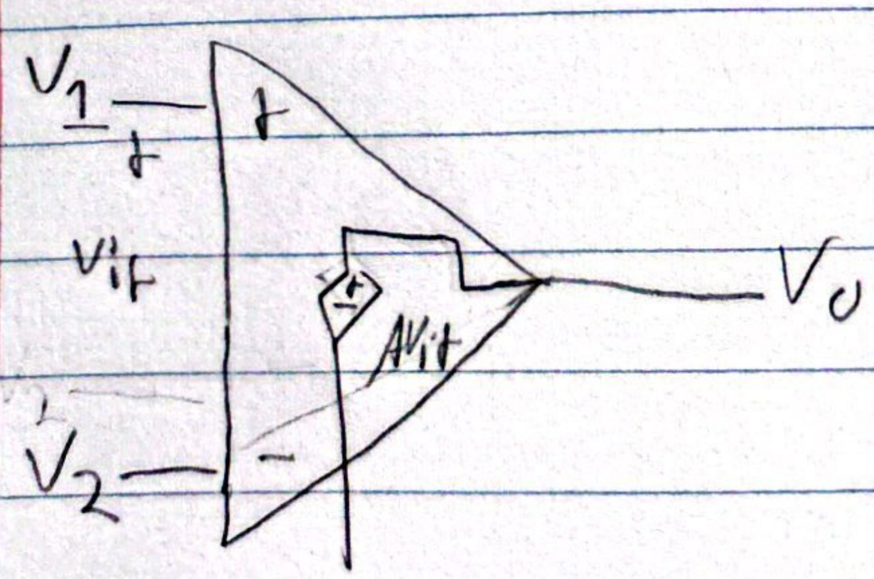

$Z_{in} = \infty$ $A = \infty$

$R_o = 0$ $A_{cm} = 0$




$v_{cm} = \frac{V_1 + V_2}{2}$

should be 0

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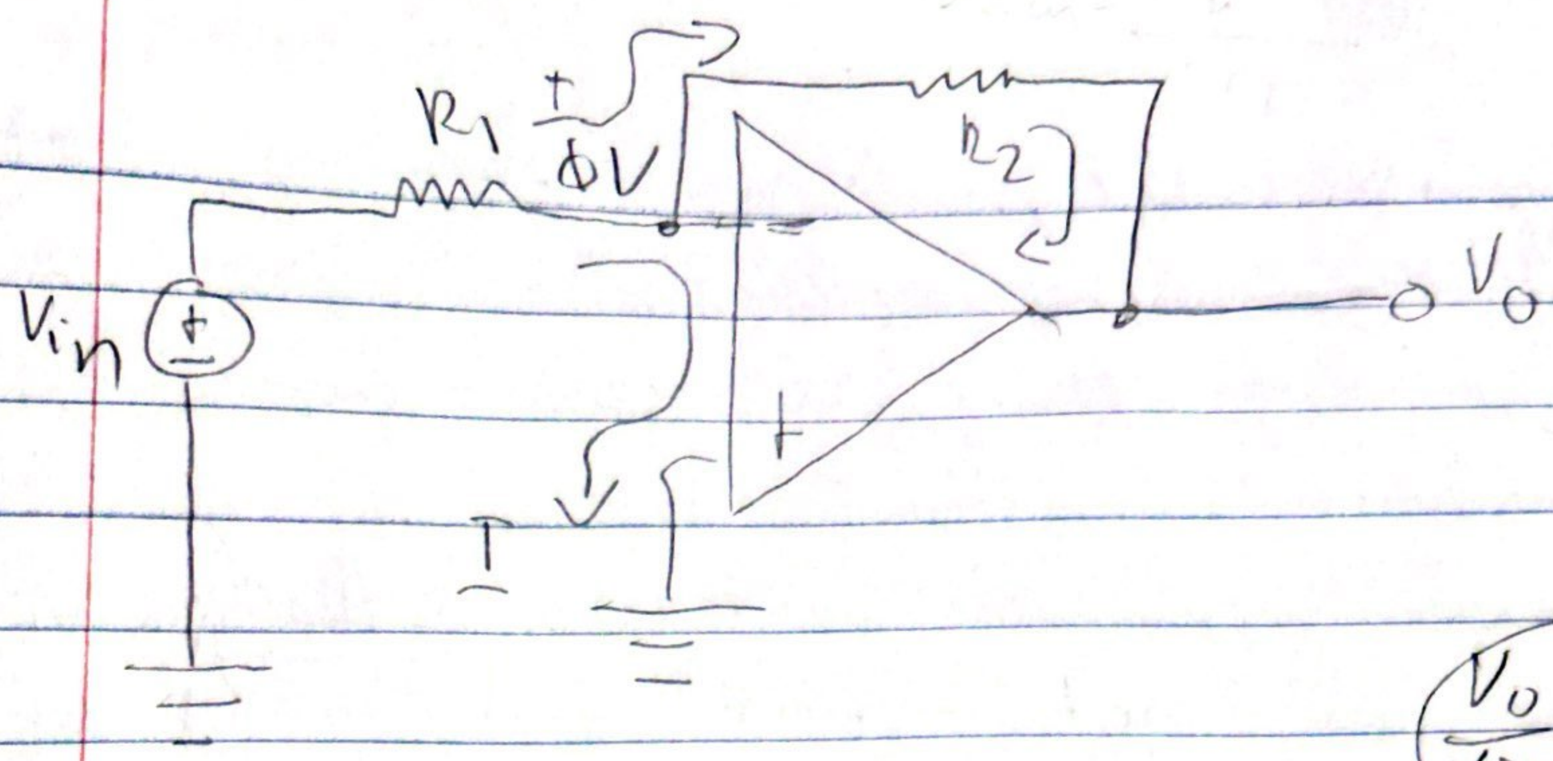
$-in = \frac{Vin}{R_1} - \phi$



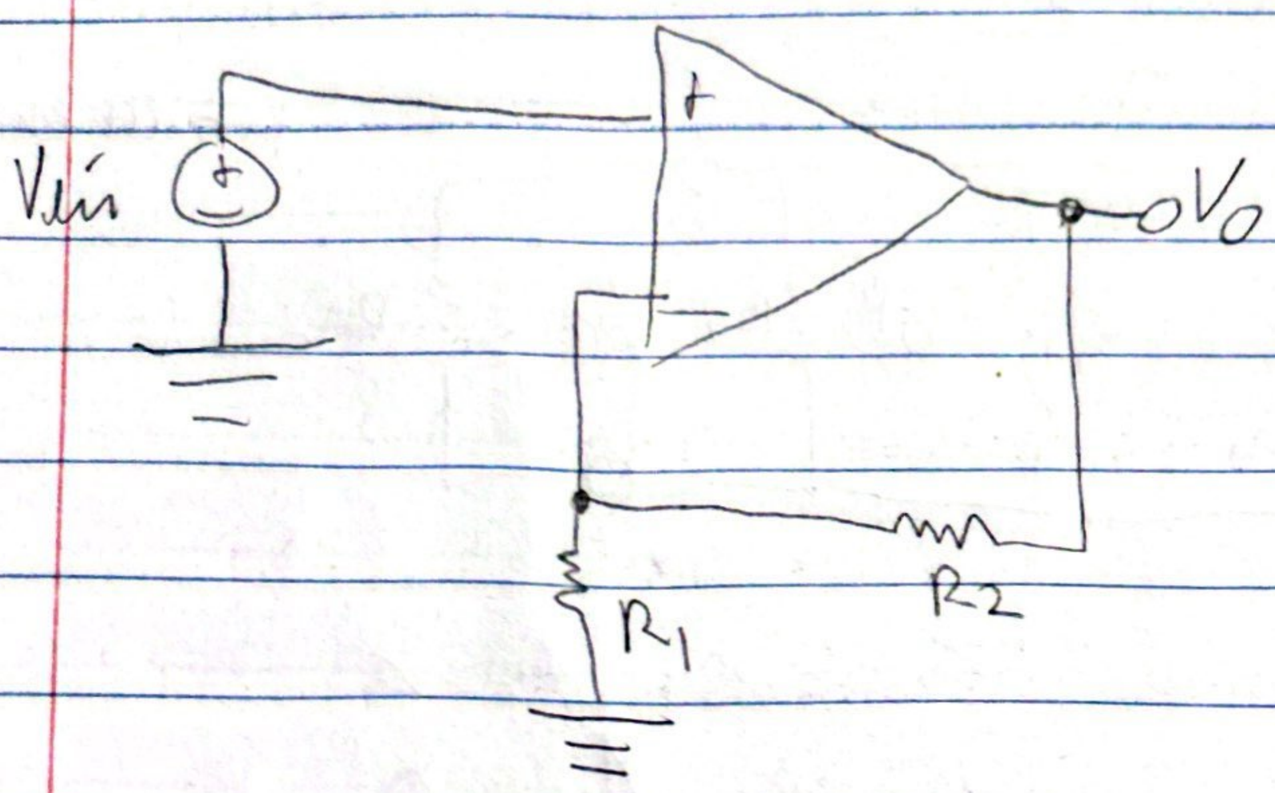

$\frac{\phi - V_o}{R_2} = I_n = \frac{V_{in}}{R_1}$

$\frac{V_o}{R_2} = \frac{V_{in}}{R_1}$

$\frac{V_o}{V_{in}} = \frac{-R_2}{R_1} = \text{gain}$

↳ inverting amplifiers

non inverting amplifier: $A = \frac{V_o}{V_{in}} = \frac{R_2}{R_1} = A$

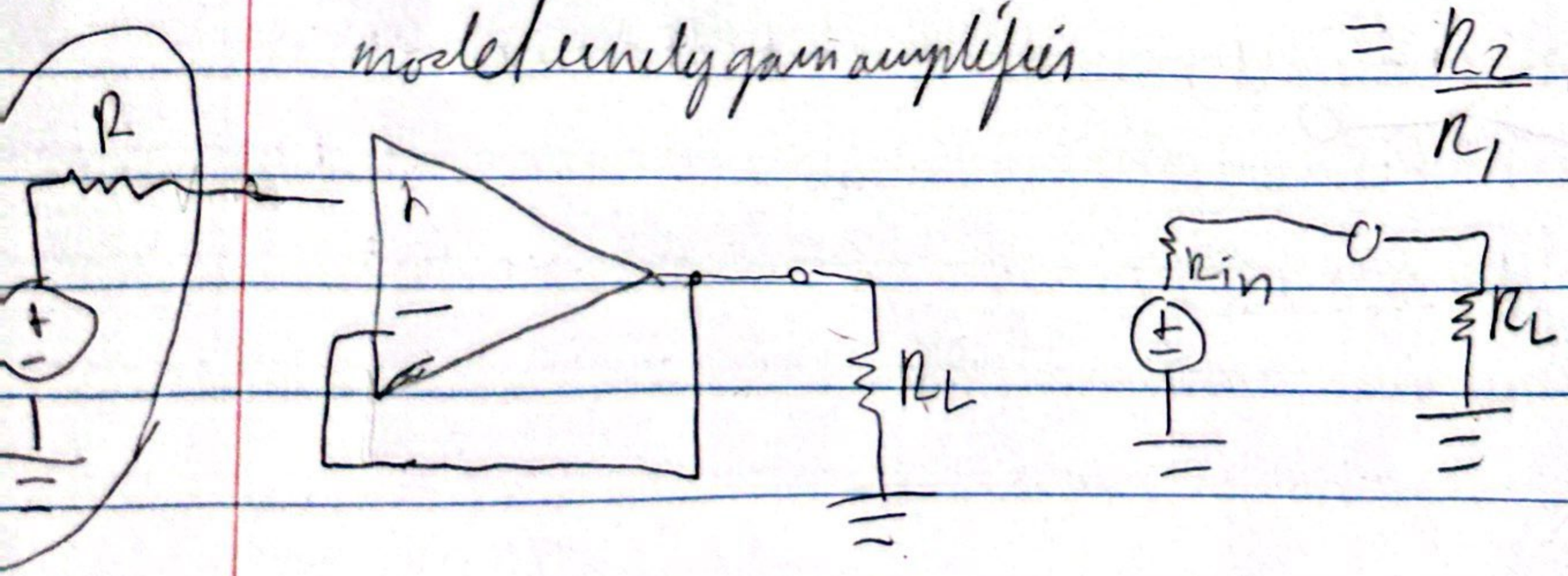



$\frac{V_o - R_1}{R_1 + R_2}$

$A = \frac{V_o}{V_{in}} = \frac{V_\phi}{V_\phi \frac{R_1}{R_1 + R_2}} =$

$= \frac{R_2}{R_1} + \frac{R_1}{R_1} = \boxed{1 + \frac{R_2}{R_1} = A}$

model unity gain amplifier

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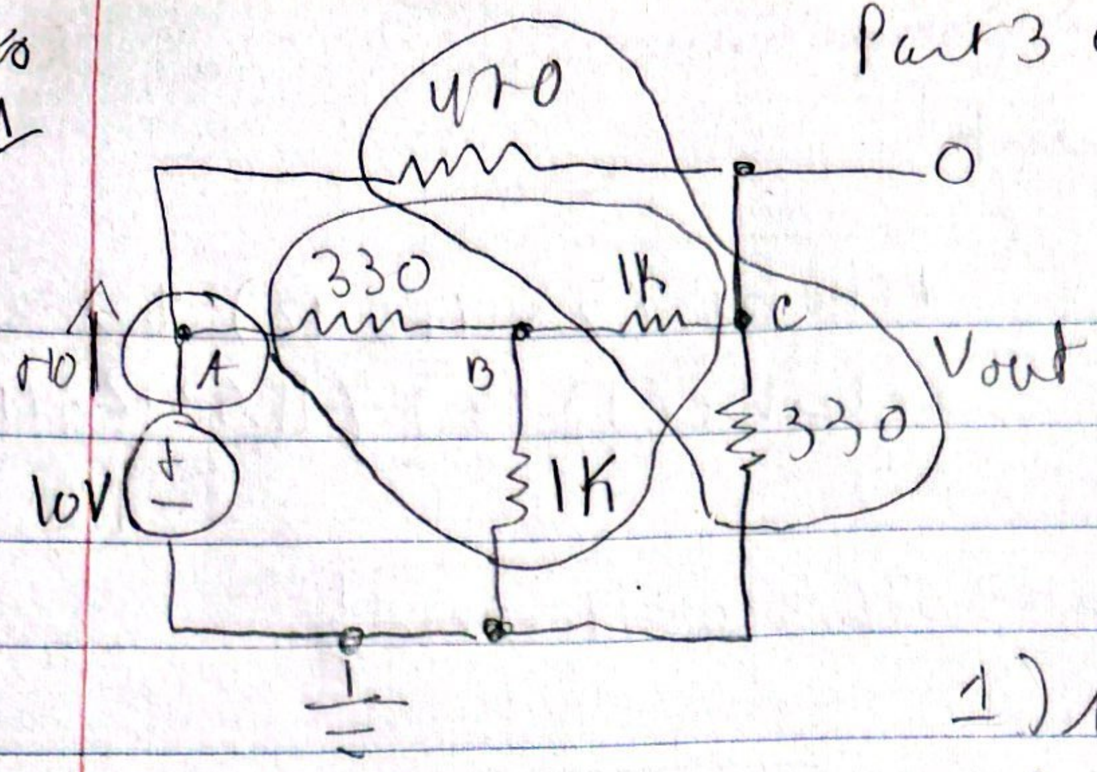
circuits part 1

# Part 3 circuit analysis




node A: loop of the 10V source fixed at $V_A = 10V$

node B: middle junction (330 & 1kΩ)

node C: right junction (470, 1kΩ, 330)

1) node voltage analysis $V_B = 6.92$ $V_C = 4.58$

$V_A = +10$ ↑

ground = 0V

**Resistors:**

A - B : 330Ω

B - C : 1kΩ

A - C : 470Ω

B - ground: 1kΩ

C - ground 330Ω

**KCL at node B:**

$$\frac{V_B - V_A}{330} + \frac{V_B - V_C}{1000} + \frac{V_B - 0}{1000}$$

$$\frac{V_B - 10}{330} + \frac{V_B - V_C}{1000} + \frac{V_B - 0}{1000} \quad (\times 1000)$$

$$\frac{1000}{330}(V_B - 10) + (V_B - V_C) + V_B = 0$$

$$(3.0303 + 2)V_B - V_C = 30.30303$$

$$\boxed{5.030303 V_B - V_C = 30.30303}$$

2) **KCL at node C:**

$$\frac{V_C - V_A}{470} + \frac{V_C - V_B}{1000} + \frac{V_C - 0}{330} = 0$$

$$(\times 1000) \quad \frac{V_C - 10}{470} + \frac{V_C - V_B}{1000} + \frac{V_C}{330} = 0$$

$$\frac{1000}{470}(V_C - 10) + (V_C - V_B) + \frac{1000}{330} V_C = 0$$

$$-V_B + (2.127 + 1 + 3.0303)V_C = 21.2765$$

$$\boxed{-V_B + 6.157963 V_C = 21.276596}$$

3) **Solving (B) - (C):**

(C) $V_B = 6.1579 \; V_C - 21.2765$

put into B

$5.0303(6.1579 V_C - 21.276) - V_C = 30.$

$(30.9764 - 1)V_C - 107.02 = 30.30$

$29.976422 V_C = 137.3$ $\boxed{V_C = 4.}$

$V_B = 6.157(4.58) - 21.27 = \boxed{6.92}$

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Lab 1

Part 3 analysis

2) currents in every element

$I = \frac{V_{left} - V_{right}}{R}$

* checks B $(2.344 + 6.92) - 9.33 = 0V$ ✓
* checks C $(13.88) - (11.53 + 2.344) = 0V$ ✓

through A-B (330Ω)

$\Delta V = 10 - 6.92 = 3.076V \rightarrow I_{AB} = 3.076/330 = \boxed{9.33mA}$

through B-C (1kΩ)

$\Delta V = 6.92 - 4.58 = 2.344V \rightarrow I_{BC} = \boxed{2.344mA}$

through A-C (470Ω)

$\Delta V = 10 - 4.58 = 5.421V \rightarrow I_{AC} = 5.421/470 = \boxed{11.53mA}$

B to ground (1kΩ) $I_{B\downarrow} = V_B/1000$ $6.92/1000 = \boxed{6.92mA}$

C to ground (330Ω) $I_{C\downarrow} = V_C/330 = \boxed{13.88mA}$

3) Power dissipated $P = \frac{(\Delta V)^2}{R}$

- 330Ω (A-B) $P_{AB} = (3.076)^2/330 = \boxed{28.7mW}$
- 1kΩ (B-C) $P_{BC} = (2.344)^2/1000 = \boxed{5.50mW}$
- 470Ω (A-C) $P_{AC} = (5.421)^2/470 = \boxed{62.6mW}$
- 1kΩ (B-G) $P_{B\downarrow} = (6.92)^2/1000 = \boxed{47.9mW}$
- 330Ω (C-G) $P_{C\downarrow} = (4.58)^2/1000 = \boxed{63.6mW}$

$\boxed{\Sigma P = 208.3mW}$

4) $I_{source} = I_{AB} + I_{AC} = 9.33mA + 11.53mA = \boxed{20.86mA}$

$P_{source} = 10V \times 0.02086A = \boxed{208.6mW}$

5) error calculation (done in the lab

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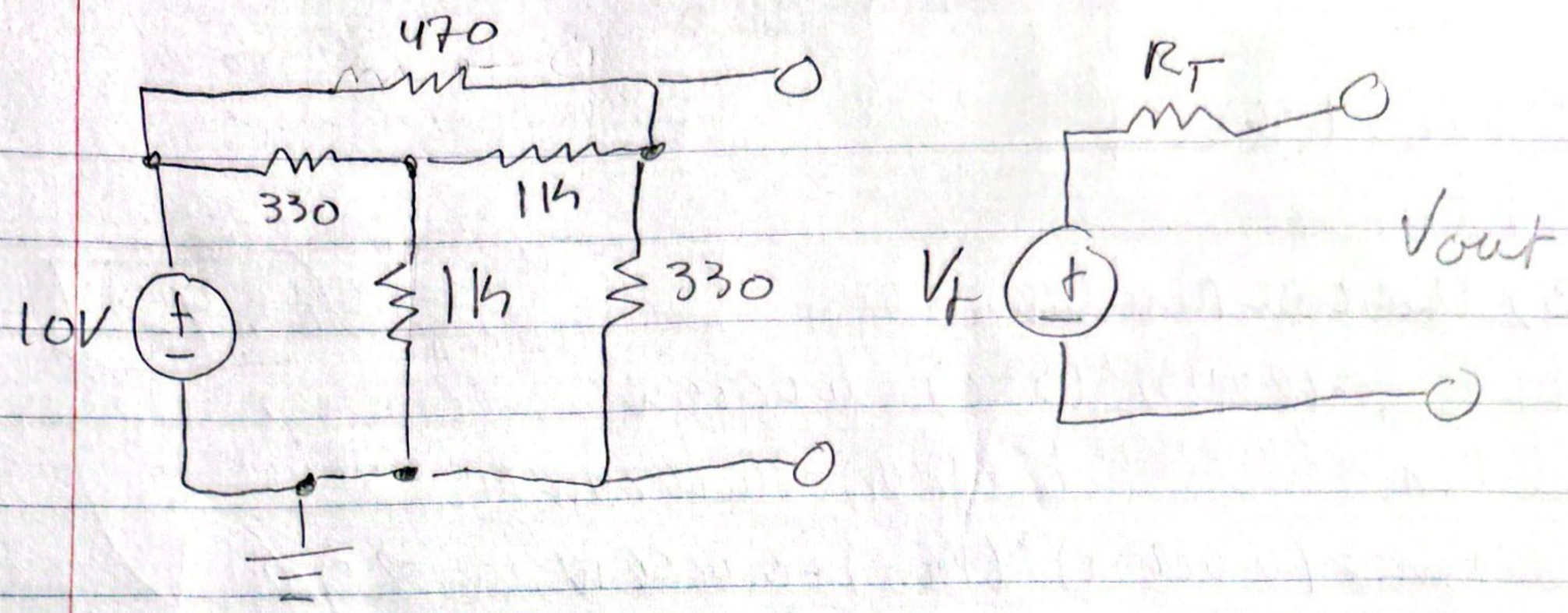
Circuits lab 1 Part 4 Thevenin equivalent circuits




- ground (bottom rail) = 0V
- node A = top of the source → $V_A = 10V$
- node B = middle junction (330Ω, 1kΩ, 1kΩ↓)
- node C = right terminal (joins 470Ω from A, 1kΩ from B, 330Ω)
  → Vout

Resistors: A-B: 330Ω; B-C: 1kΩ, A-C: 470Ω, B-G: 1kΩ, C-G: 33

open circuit Voltage $V_{oc}$ ($V_{Th}$)

1) KCL at B-C

node B: $\frac{V_B-10}{330} + \frac{V_B-V_C}{1000} + \frac{V_B}{1000} = 0$ $\boxed{V_B = 6.934V}$

$V_{oc} = V_{Th} = 4.518$

node C: $\frac{V_C-10}{470} + \frac{V_C-V_B}{1000} + \frac{V_C}{330} = 0$ $\boxed{V_C = 4.581V}$

2) Short circuit current $I_{sc}$

$\frac{V_B-10}{330} + \frac{V_B}{1000} + \frac{V_B}{1000} = 0$ $\boxed{V_B = 6.024096V}$

$I_{sc} = \frac{10-0}{470} + \frac{V_B-0}{1000} = 0.0212766 + 0.0060241 \approx \boxed{0.0273007A = 27m}$

3) Thevenin resistance $R_{Th} = \frac{V_{oc}}{I_{sc}} \approx \frac{4.581293}{0.0273007} \approx \boxed{167.809\Omega}$

1. 330Ω (C-G) 2. 470Ω (C-A=G)

3. 1kΩ (330 || 1000) $R_3 = 1000 + (330 \parallel 1000) = 1000 + 248.12 = \boxed{1248.12}$

$R_{eq} = (1/330 + 1/470 + 1/1248)^{-1} = \boxed{167.809\Omega}$

$\boxed{\text{Verify } I = V_{Th}/R_{Th} = 4.518/167.809 = 27mA}$

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Circuits Lab 1

Part 4 actual

1) $V_{oc} = 4.56$

2) $I_x = 2.8$

3) Thevenin Resistance: $R_{TN} = \frac{V_{oc}}{I_x} = \frac{4.56}{0.028} = \boxed{163.4\,\Omega}$

4) $P_{gm} = (0.0093)^2(330) = 0.0285W$

$P_{g1} = (0.01157)^2(470) = 0.0629W$

$P_{m1} = (0.00237)^2(1000) = 0.0056W$

$P_{m6} = (0.00693)^2(1000) = 0.0480W$

$P_{R6} = (0.01382)^2(330) = 0.0630W$

Total $= 0.208W$

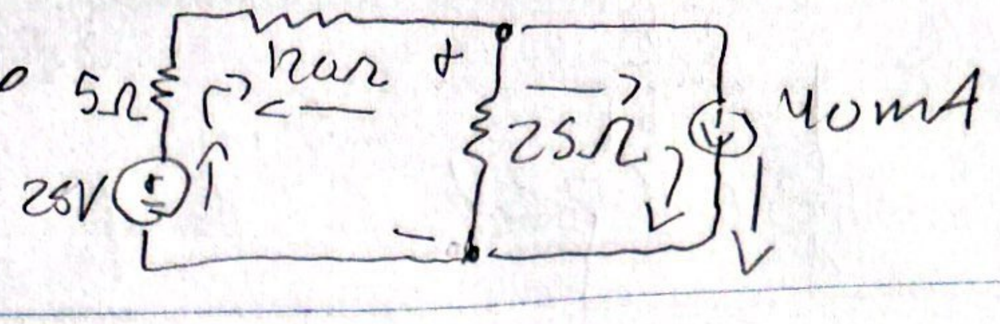
$I_2 = I_{gm} + I_{g1} \approx \boxed{20.87mA}$

5) Power $V_2 \cdot I_2 = (0.46)(0.02087) = \boxed{0.2087W}$

a very small difference can be seen. largely because this circuit is following the laws of the conservation of energy

Circuits
HW 2

4.6




$V_a = (5\Omega \,\&\, 120\Omega)$

$V_b = (25\Omega)\ V_0 = V_b$

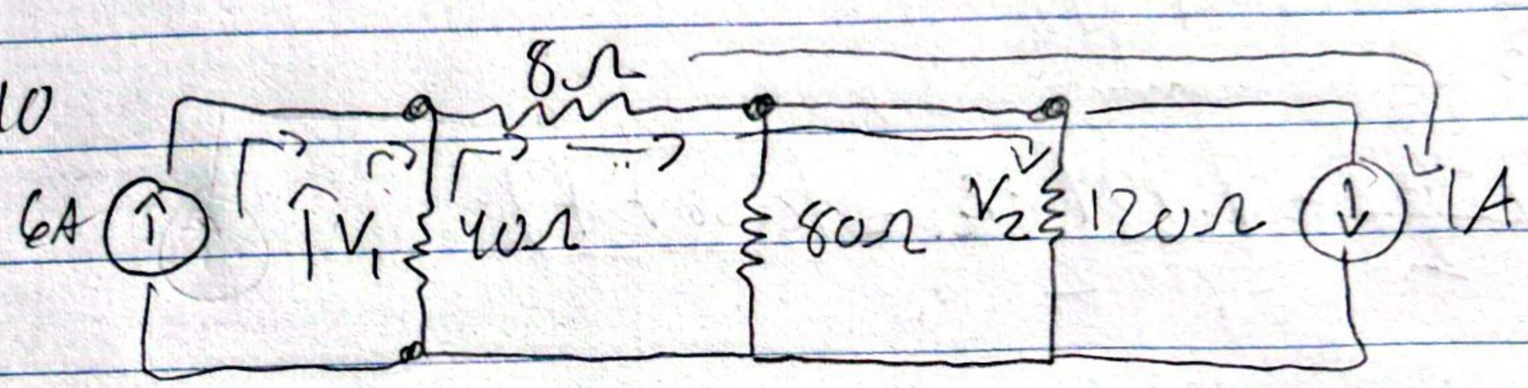
KCL at $V_a$: $\frac{V_a - V_b}{120} + \frac{V_a - 25}{5} = 0$

KCL at $V_b$: $\frac{V_b - V_a}{120} + 0.040 + \frac{V_b}{25} = 0$

$\frac{V_a - V_b}{120} = \frac{V_a - 25}{5} \Rightarrow V_a = \frac{362}{15} = 24.133\,V$

$V_b = 10/3 = \boxed{3.333V}$

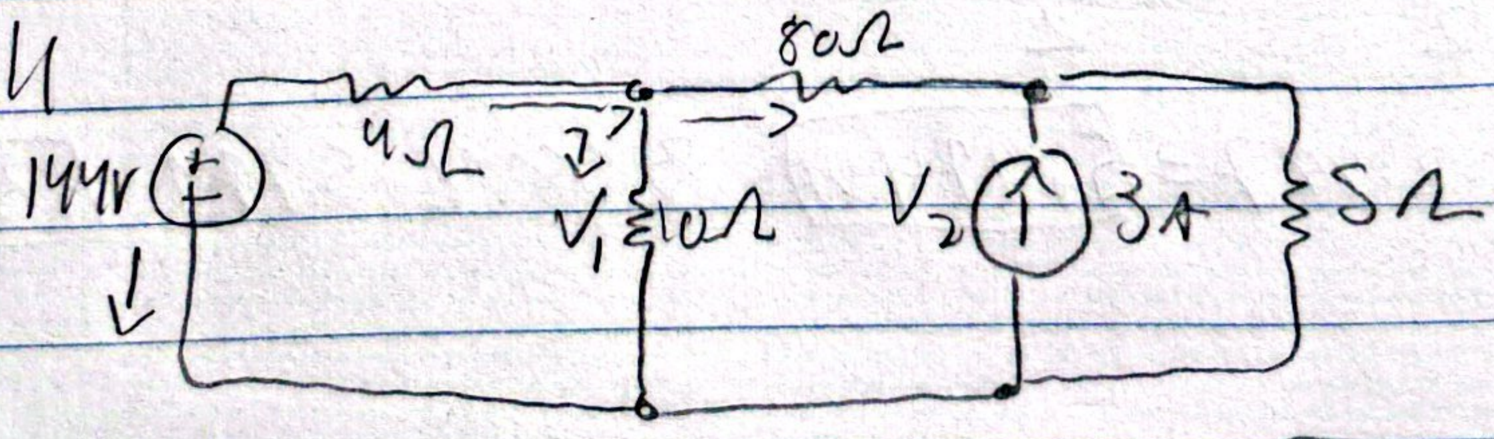
4.10




KCL at $V_1$: $\frac{V_1}{40} + \frac{V_1 - V_2}{8} - 6 = 0$ $\boxed{V_1 = 120V}$

KCL at $V_2$ $\frac{V_2}{80} + \frac{V_2}{120} + \frac{V_2 - V_1}{8} + 1$ $\boxed{V_2 = 96V}$

4.11




$\frac{V_1 - (-144)}{4} + \frac{V_1 - V_2}{80} + \frac{V_1}{10} = 0$ $\boxed{V_1 = 100V}$

$\frac{V_2 - V_1}{80} + \frac{V_2}{5} + 3 = 0$ $\boxed{V_2 = 20V}$

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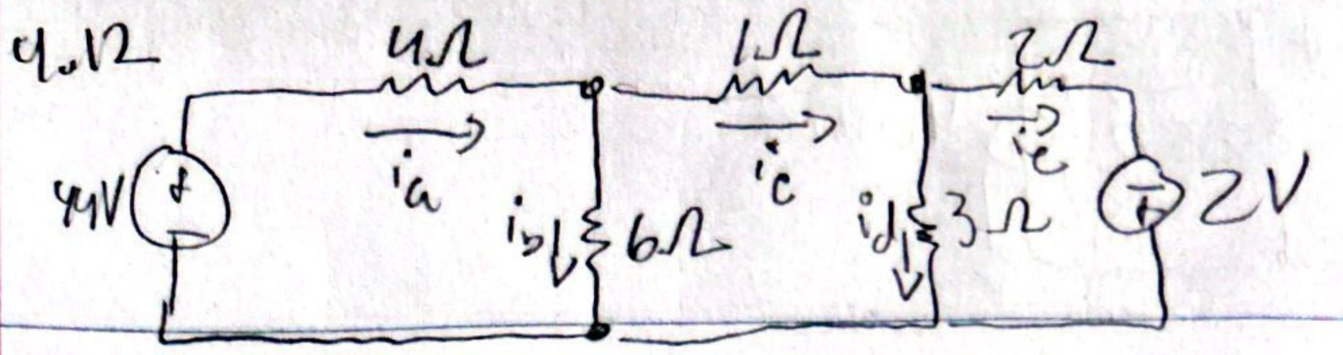
circuits
Hw 2

4.12




$V_y = +44V$

$V_3 = +2V$

Nodal at $V_1$: $\frac{V_1 - V_y}{4} + \frac{V_1 - V_2}{1} + \frac{V_1}{6} = 0$ $\boxed{V_1 = \frac{1524}{115} = 13.25V}$

Nodal at $V_2$: $\frac{V_2 - V_1}{1} + \frac{V_2 - V_3}{2} + \frac{V_2}{3} = 0$ $\boxed{V_2 = \frac{894}{115} = 7.774V}$

a) $i_a = \frac{V_y - V_1}{4} = \frac{44 - 13.52}{4} = \boxed{7.68A}$

$i_b = V_1/6 = \boxed{2.209A}$

$i_c = \frac{V_1 - V_2}{1} = \boxed{5.478A}$

$i_d = \frac{V_2}{3} = \boxed{2.591A}$

$i_e = \frac{V_2 - V_3}{2} = \frac{7.774 - 2}{2} = \boxed{2.887A}$

b) $P_R = i_a^2(4) + i_c^2(1) + i_e^2(2) + i_b^2(6) + i_d^2(3)$

$= \boxed{3.3245e^2 W}$

$P_{44V\,del} = 44 i_a = \boxed{338.2W}$

$I_{2V} = \frac{V_3 - V_2}{2} = \frac{2 - 7.774}{2} = -2.887A$

$P_{2V\,abs} = 2 \cdot 2.887 = \boxed{5.774W}$ $338.2 - 5.774 = \boxed{332.45W}$

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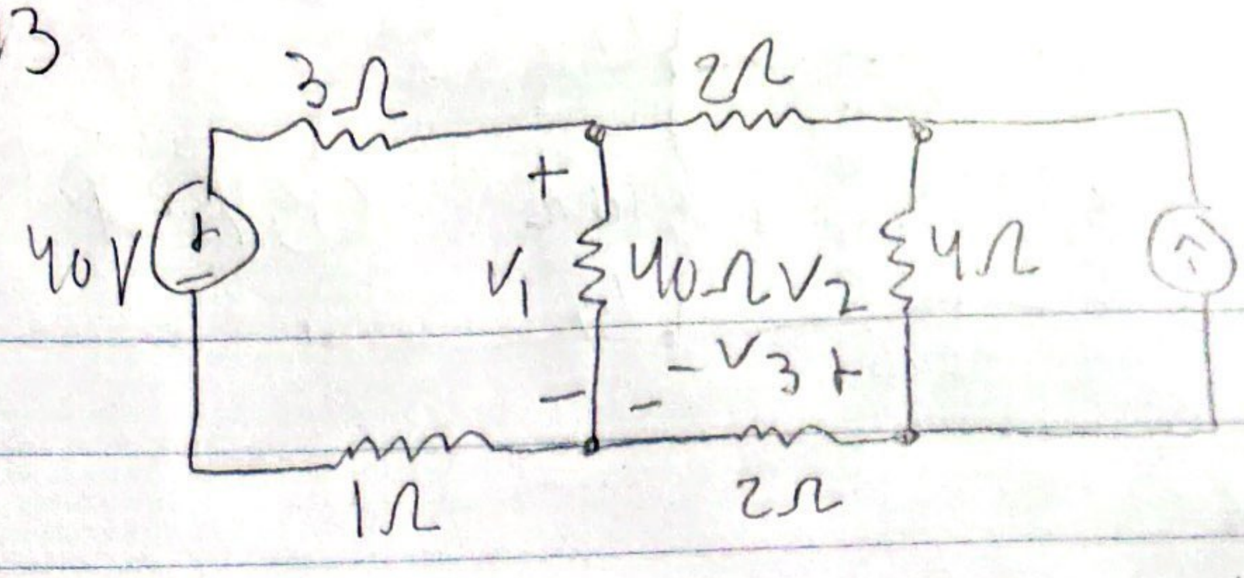
circuits HW 2

4.13




$V_1, V_2, V_3$

node $V_1$: $\frac{V_1-40}{3} + \frac{V_1}{1} + \frac{V_1-V_2}{\text{wire}} = 0 \Rightarrow \frac{V_1-40}{3} + V_1 = 0$

node $V_2$: $\frac{V_2-V_3}{2} + \frac{V_2}{2} + \frac{V_2-V_1}{\text{wire}} = 0 \Rightarrow \frac{V_2-V_3}{2} + \frac{V_2}{2} = 0$

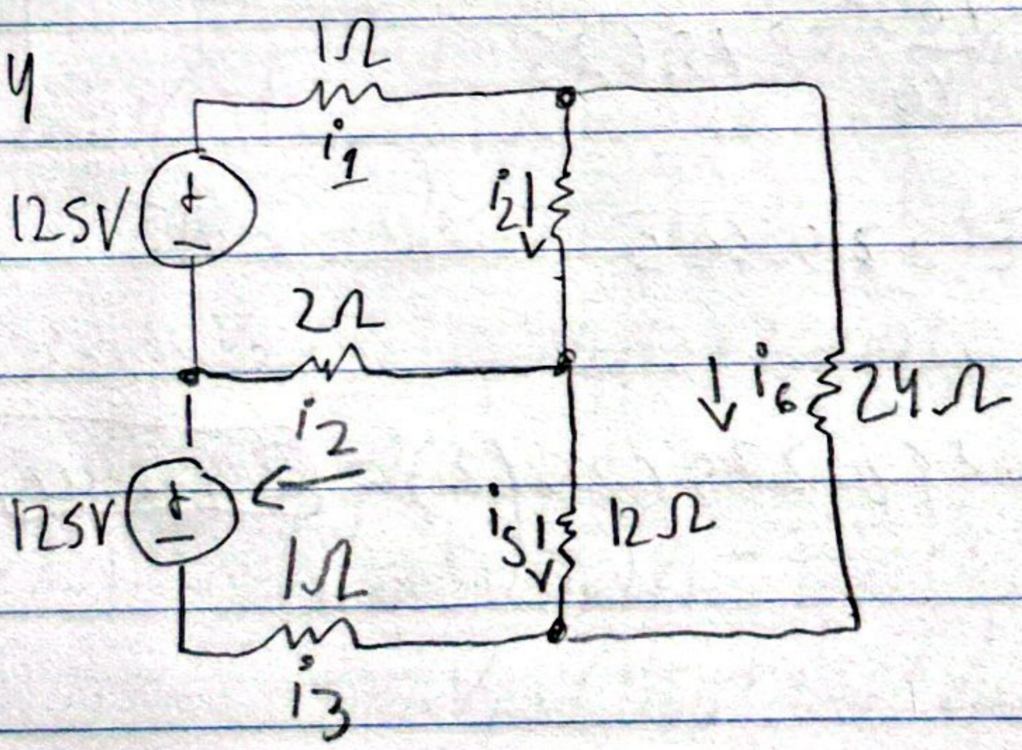
node $V_3$: $\frac{V_3-V_2}{2} \quad \frac{V_3}{4} - 28 = 0 \Rightarrow \frac{V_3-V_2}{2} + \frac{V_3}{4} = 28$

$\frac{V_1-40}{3} + V_1 = V_1 - 40 + 3V_1 \quad 4V_1 = 40 \quad \boxed{V_1 = 10V}$

$\frac{V_2-V_3}{2} + \frac{V_2}{2} = 0 \Rightarrow V_2 - V_3 + V_2 = \boxed{2V_2 = V_3}$

$\frac{V_3-V_2}{2} + \frac{V_3}{4} = 28 \overset{(21)}{\Rightarrow} \frac{V_3 - \frac{V_3}{2}}{2} + \frac{V_3}{4} = 28 = \frac{\frac{V_3}{2}}{2} + \frac{V_3}{4} = 28 \quad \frac{V_3}{2} = 28 \quad \boxed{V_3 = 56}$

4.14




$V_a = \frac{(V_a - 250)}{0}$

$V_b = 2V_a$

$\frac{V_a}{1} + \frac{V_a - V_b}{1} = 0 \Rightarrow 2V_a - V_b = 0$

$\frac{V_b - V_a}{1} + \frac{V_b}{2} + \frac{V_b}{1} - 24 = 0$

$(2V_a - V_a) + \frac{2V_a}{2} + 2V_a - 24 = 0 \quad V_a + V_a + 2V_a - 24 = 0 \quad 4V_a = 24$

$\boxed{V_a = 6V \quad V_b = 12V}$

$i_1 = \frac{250 - V_a}{1} \quad 250 - 6 = \boxed{244A}$ $\quad i_3 = \frac{V_a - V_b}{1} = 6 - 12 = \boxed{-6A}$ $\quad i_5 = \frac{V_b}{1} = \boxed{12A}$

$i_2 = \frac{V_a}{1} = \boxed{6A}$ $\quad i_4 = \frac{V_b}{2} = \boxed{6A}$ $\quad i_6 = i_1 - i_2 - i_3 - i_4 - i_5 = \boxed{226}$

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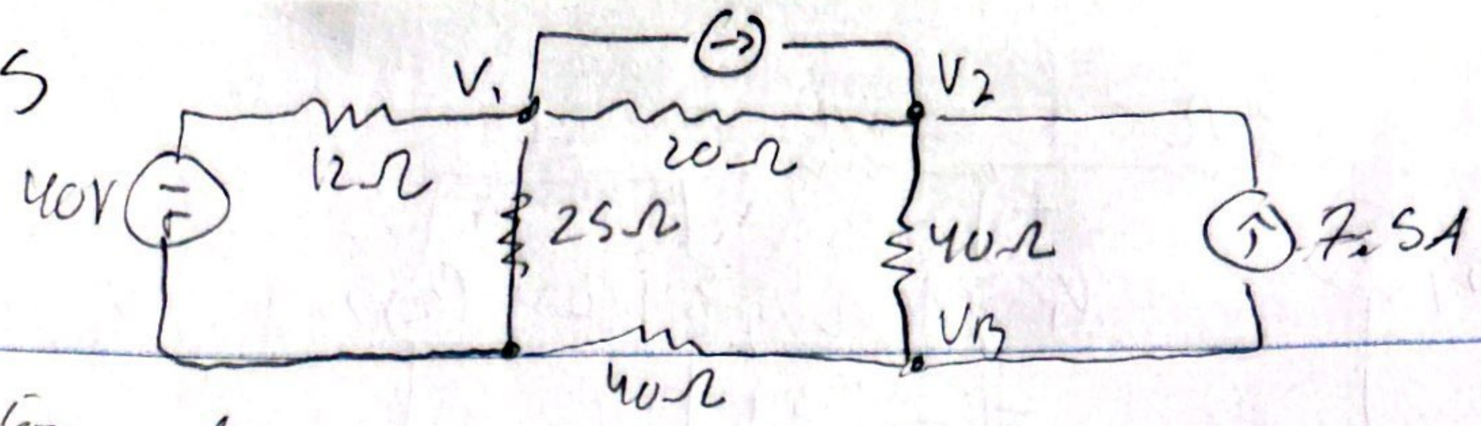
Circuits HW 2

4.15




$V_1$ = left node

$V_2$ = right top node

Nodes:

$$V_1 = \left(\tfrac{1}{12}+\tfrac{1}{20}+\tfrac{1}{25}\right)V_1 - \tfrac{1}{20}V_2 = \tfrac{1}{12}(-40)+(-5)$$

$$V_2 = -\tfrac{1}{20}V_1 + \left(\tfrac{1}{20}+\tfrac{1}{40}\right)V_2 - \tfrac{1}{40}V_B = (+5)+(+7.5) = 12.5$$

$$V_B = -\tfrac{1}{40}V_2 + \left(\tfrac{1}{40}+\tfrac{1}{40}\right)V_B = 0$$

$$\boxed{V_1 = 12.5V \quad V_2 = 210V \quad V_B = 105V}$$

$$P_{12} = \frac{(V_1-(-40))^2}{12} = \frac{(52.5)^2}{12} = 229.687S$$

$$P_{20} = \frac{(V_1-V_2)^2}{20} = \frac{(197.5)^2}{20} = 1950.312S$$

$$P_{25} = \frac{V_1^2}{25} = \frac{(12.5)^2}{25} = 6.25$$

$$P_{current} = \frac{(V_2-V_B)^2}{40} = \frac{105^2}{40} = 275.625$$

$$P_{voltage} = \frac{V_B^2}{40} = \frac{105^2}{40} = 275.625$$

$$P_{total} = 229+1950+6.25+275.625(2) = \boxed{2736W}$$

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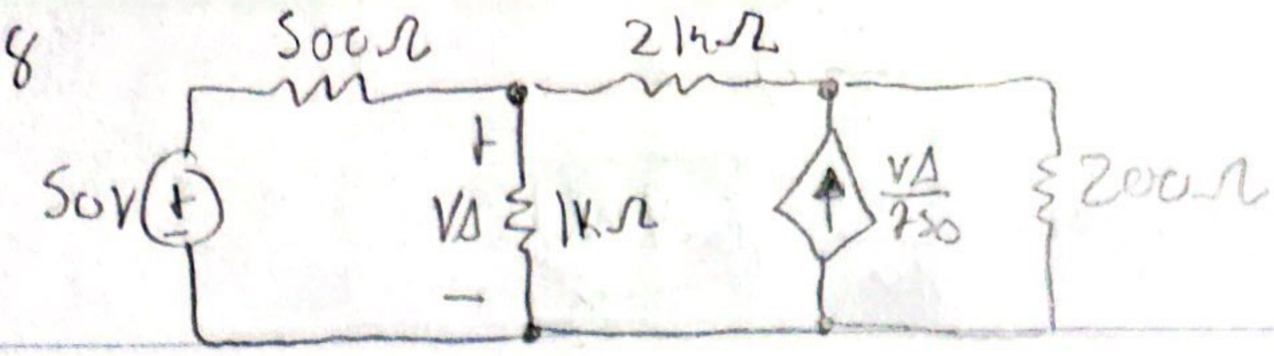
circuits
Hw 2

4.18




$$I_d = \frac{V_\Delta}{750} = \frac{V_a}{750}\ (A)$$

$$(1)\ \frac{V_a - 50}{500} + \frac{V_a - V_b}{2000} + \frac{V_a}{1000} = 0 \quad (2)\ \frac{V_b - V_a}{2000} + \frac{V_b}{200} - \frac{V_a}{750} = 0$$

$$(1')\ \times 2000 \rightarrow 4(V_a - 50) + (V_a - V_b) + 2V_a = 0 \Rightarrow 7V_a - V_b - 200 = 0$$

$$(2')\ \times 6000 \rightarrow 3(V_b - V_a) + 30V_b - 8V_a = 0 \Rightarrow -11V_a + 33V_b = 0$$

$$(2)\ V_a = 3V_b \rightarrow 7(3V_b) - V_b - 200 = 0 \quad 20V_b - 200 = 0 \quad \boxed{V_b = 10\,V}$$

$$V_a = 3(10V) = \boxed{30V}$$

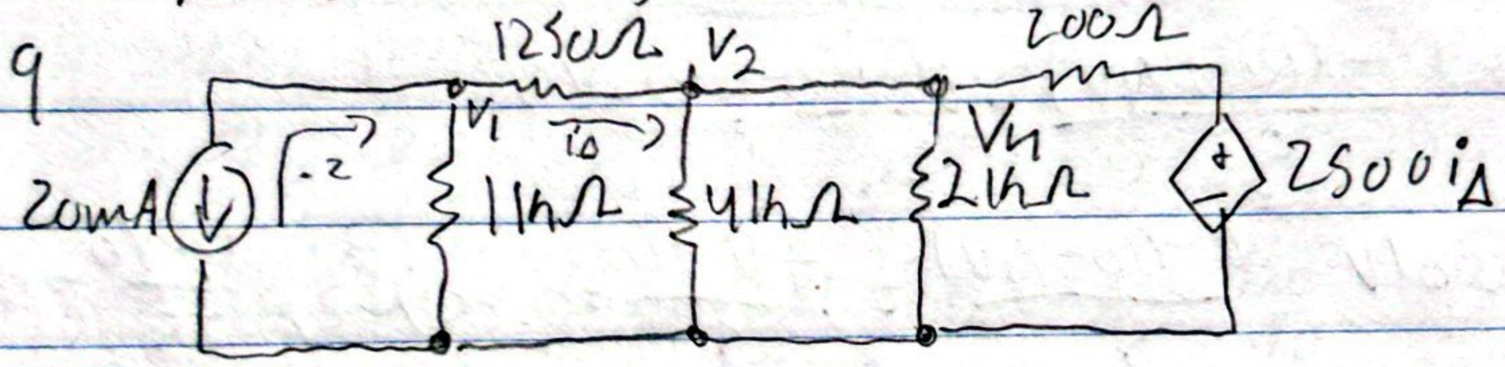
$$I_{500} = \frac{50-30}{500} = 0.04A \quad P_{50} = (50)(0.04) = 2.0\,W$$

$$V_b = 10V \quad I_d = \frac{V_a}{750} = \frac{30}{750} = \boxed{0.04A}$$

$$P_{dep} = (+10) \times (\text{current entering}) = 10 \times (-0.04) = -0.4W$$

$$P_{sup} = P_{50} + (0.4W) = 2.4W$$

4.19




$$i_\Delta = \frac{V_2 - V_1}{1250}, \quad V_4 = +2500 i_\Delta = 2500\,\frac{V_2 - V_1}{1250} = 2(V_2 - V_1)$$

Ind: 1) $V_1$: $\left(\frac{1}{1000} + \frac{1}{1250}\right)V_1 - \frac{1}{1250}V_2 = -0.02$

2) $V_2$: $-\frac{1}{1250}V_1 + \left(\frac{1}{1250} + \frac{1}{4000} + \frac{1}{2000} + \frac{1}{200}\right)V_2 - \frac{1}{200}V_4 = 0$

3) $V_4 = 2(V_2 - V_1)$

$\frac{1}{1250} = 0.008,\ \frac{1}{1000} = 0.001,\ \frac{1}{4000} = 0.00025,\ \frac{1}{2000} = 0.0005,\ \frac{1}{200} = 0.005$

1) $0.0018V_1 - 0.008V_2 = -0.02$

2) $-0.008V_1 + 0.00655V_2 - 0.005V_4 = 0$

3) $V_4 = 2V_2 - 2V_1$

$-0.008V_1 + 0.00655V_2 - 0.005(2V_2 - 2V_1)$

$0 \Rightarrow 0.0092V_1 - 0.00345V_2$

$V_2 = \frac{0.0092}{0.00345}V_1 = \boxed{\frac{8}{3}V_1}$

$0.0018V_1 - 0.008\left(\frac{8}{3}V_1\right) = -0.02 \Rightarrow (0.0018 - 0.002133)V_1 = -0.02$

$-\frac{1}{3000}V_1 = -0.02 \quad \boxed{V_1 = 60V} \quad V_2 = \frac{8}{3} \cdot 60 = 160V \quad V_4 = 2(160 - 60) =$

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4.14 continued $\left(P = \frac{V^2}{R}, \frac{\Delta V^2}{R}\right)$

$P_{1k} = \frac{60^2}{1000} = \boxed{3.6W}$ $P_{4k} = \frac{160^2}{4000} = \boxed{6.4W}$

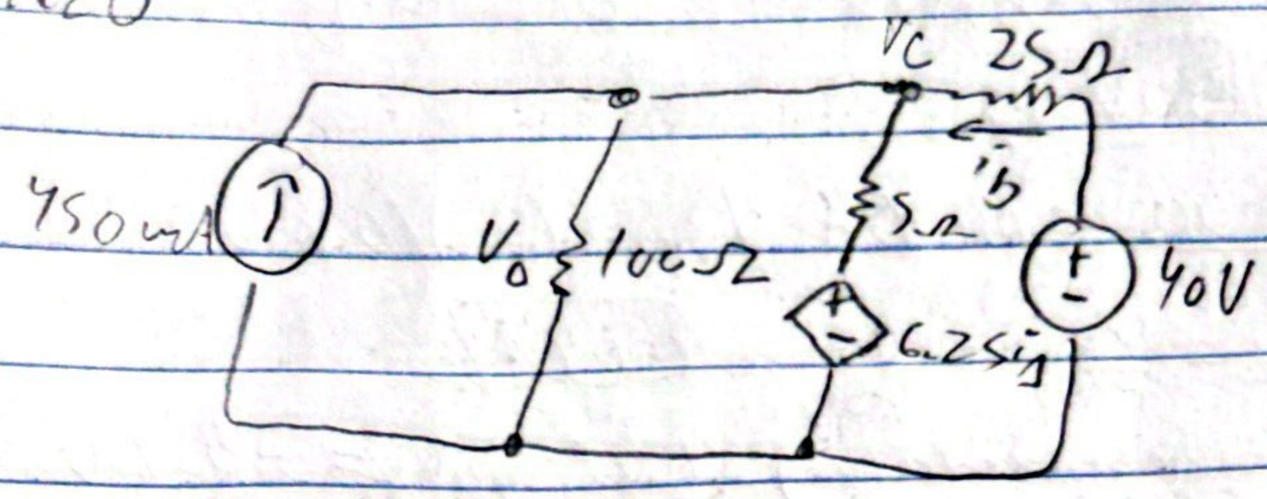
$P_{2k} = \frac{160^2}{2000} = \boxed{12.8W}$ $P_{1250} = \frac{(160-60)^2}{1250} = \boxed{8W}$

$P_{200} = \frac{(160-200)^2}{200} = \boxed{8W}$ $\Sigma P = 38.8W$

$I_{dep} = (V) = -\frac{V_4 - V_2}{200} = -\frac{200-160}{200} = -0.2A$

$P = V \cdot I = 200 \times (-0.2) = \boxed{-40W}$ $P_{20mA} = +60(0.02) = \boxed{1.2W}$

4.20




$i_\Delta = \frac{40-V}{25}$

$i_\Delta = V_c = +6.25i_\Delta = 6.25\frac{40-V}{25}$

$= 10 - \frac{1}{4}V$

$\frac{V}{100} + \frac{V-V_c}{5} + \frac{V-40}{25} = 0.45$

$\frac{V}{100} + \frac{V-(10-\frac{1}{4}V)}{5} + \frac{V-40}{25} = 0.45$

$\frac{V}{100} = 0.01V$ $\frac{V-(10-\frac{1}{4}V)}{5} = \frac{\frac{5}{4}V-10}{5} = 0.25V-2$, $\frac{V-40}{25} = 0.04V-1.6$

$\Sigma\ 0.01V + (0.25V-2) + (0.04V-1.6) = 0.45 \Rightarrow 0.30V-3.6 = 0.45$

$\boxed{V = V_o = 13.5V}$

$V_o = V = 15V$ $V_c = 10 - \frac{1}{4}(15) = 10 - 3.75 = 6.25V$

$i_{dep} = \frac{V-V_c}{5} = \frac{15-6.25}{5} = 1.75A$

$P_{dep} = V_c \cdot i_{dep} = 6.25 \times 1.75 = \boxed{11.25W}$

$\boxed{i_{25} = \frac{40-15}{25} = 1A \text{ to the left}}$

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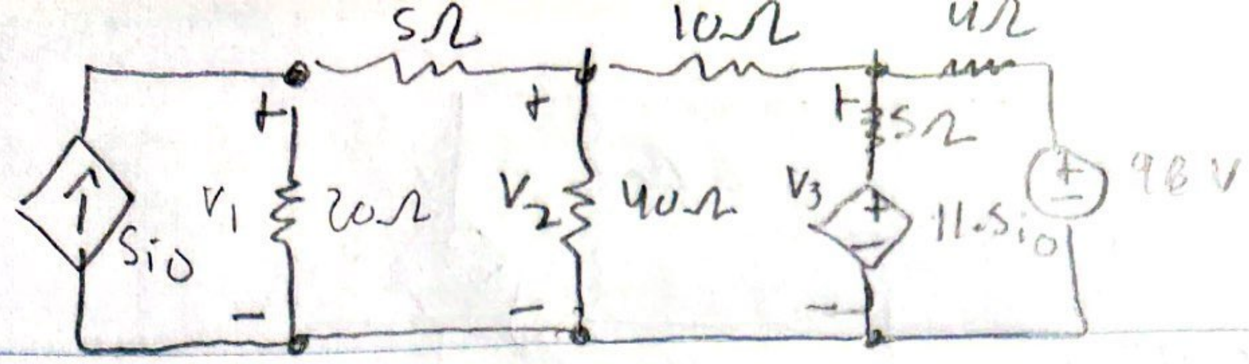
Circuits HW 2

4.21




find $V_1, V_2, V_3$
total power dissipated

$$i_o = \frac{V_2}{40} \quad 5i_o = \frac{5V_2}{40} = \frac{V_2}{8} \quad 11.5 i_o = 11.5\frac{V_2}{40}$$

KCL: $V_1$: $\frac{V_1 - V_2}{5} + \frac{V_1}{20}$ injection $= \frac{V_2}{8}$ $(\times 20)$

$V_2$: $\frac{V_2 - V_1}{5} + \frac{V_2 - V_3}{10} + \frac{V_2}{40} = 0$ $(\times 40)$

$$V_3 = +11.5\frac{V_2}{40} = \frac{23}{80}V_2$$

1) $4(V_1 - V_2) + V_1 = \frac{20}{8}V_2 = 5V_1 - 4V_2 = 2.5V_2 = (5V_1 = 6.5V_2) = \boxed{V_1 = \frac{13}{10}V_2}$

2) $8(V_2 - V_1) + 4(V_2 - V_3) + V_2 = 0 \Rightarrow (-8V_1 + 13V_2 - 4V_3 = 0)$

$-8\left(\frac{13}{10}V_2\right) + 13V_2 - 4\left(\frac{23}{80}V_2\right) = 0 \Rightarrow \left(-\frac{104}{10} + 13 - \frac{92}{80}\right)V_2 = 0$

$-10.4 + 13 - 1.15 = 1.45 = 1.45V_2 = 0$

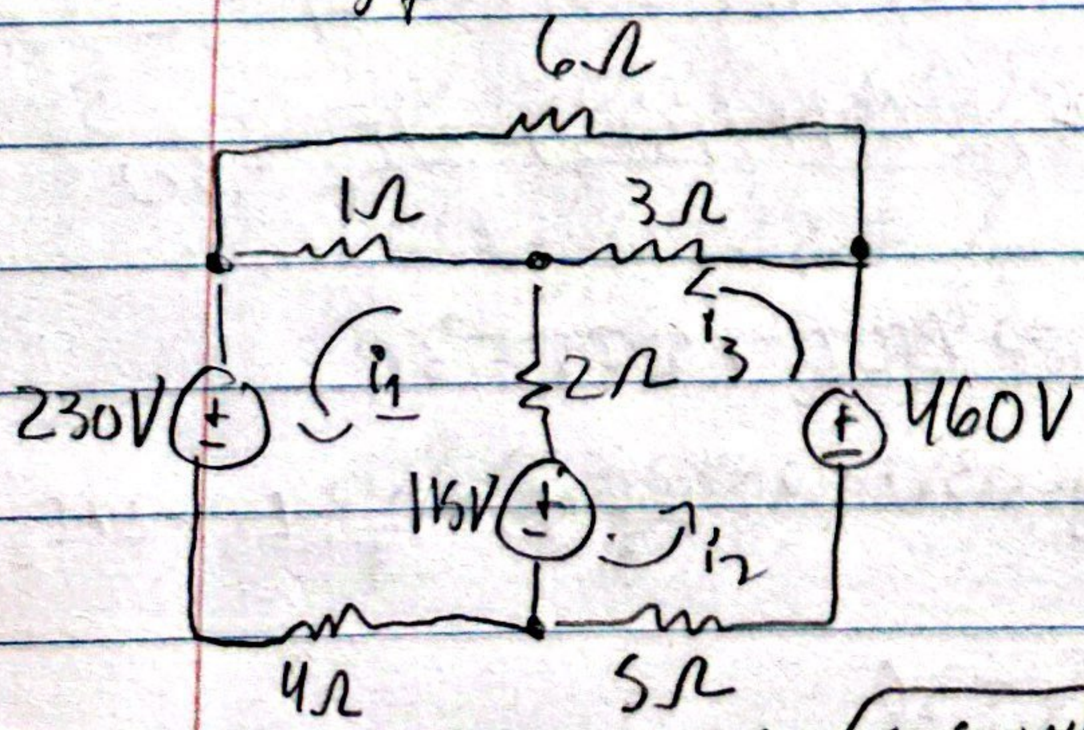
$\boxed{V_1 = 156\text{ V} \quad V_2 = 120\text{ V} \quad V_3 = 78\text{ V}}$

$P_{20} = \frac{V_1^2}{20} = \frac{156^2}{20} = \boxed{1216.8\text{ W}}$ $P_5 = \frac{(V_1 - V_2)^2}{5} = \frac{36^2}{5} = \boxed{259.2\text{ W}}$

$P_{10} = \frac{(V_2 - V_3)^2}{10} = \frac{42^2}{10} = \boxed{176.4}$ $P_{40} = \frac{V_2^2}{40} = \frac{120^2}{40} = \boxed{360\text{ W}}$

$P_5 = \frac{V_3^2}{5} = \frac{78^2}{5} = \boxed{1216.8\text{ W}}$ $\Sigma P = \boxed{2772\text{ W}}$

4.37




left: $4I_1 + 1(I_1 - I_2) + 6(I_1 - I_3) = -230$

middle: $1(I_2 - I_1) + 3(I_2 - I_3) + 2I_2 = 115$

right: $5I_3 + 3(I_3 - I_2) + 6(I_3 - I_1) = +460$

$(4 + 1 + 6)I_1 - 1I_2 - 6I_3 = -230$

$-1I_1 + (1 + 3 + 2)I_2 - 3I_3 = 115$

$-6I_1 - 3I_2 + (5 + 3 + 6)I_3 = +460$

$$\begin{bmatrix} 11 & -1 & -6 \\ -1 & 6 & -3 \\ -6 & -3 & 14 \end{bmatrix}\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} -230 \\ 115 \\ 460 \end{bmatrix}$$

$\boxed{\begin{aligned} I_1 &= -35\text{A} \\ I_2 &= -5\text{A} \\ I_3 &= +40\text{A} \end{aligned}}$

$P_{230} = 230 \times -35 = \boxed{-8050\text{ W}}$

$P_{115} = 115(5) = \boxed{575\text{ W}}$

$P_{460} = 460(40) = \boxed{18400}$

$\boxed{\Sigma P = -17940\text{ W}}$

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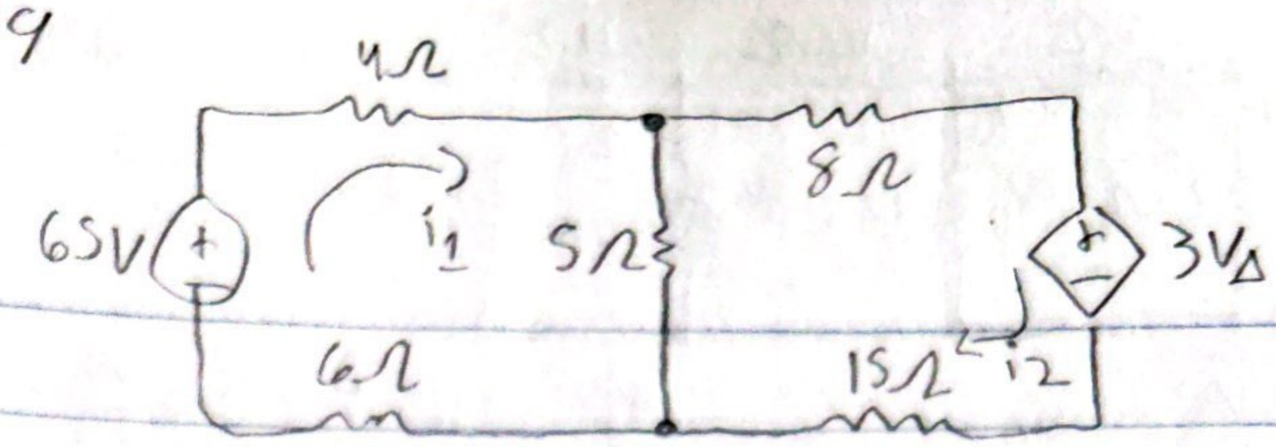
Thu 2

4.39




$V_\Delta = 4(I_1 - I_2)$ dependent source $= +3V_\Delta$

(left) KVL: $65 - 4(I_1 - I_2) - 6I_1 = 0 \Rightarrow (10)I_1 - 4I_2 = 65$

(right) KVL: $8I_2 + 3 \cdot 4(I_1 - I_2) + 15I_2 + 5I_2 = 0$

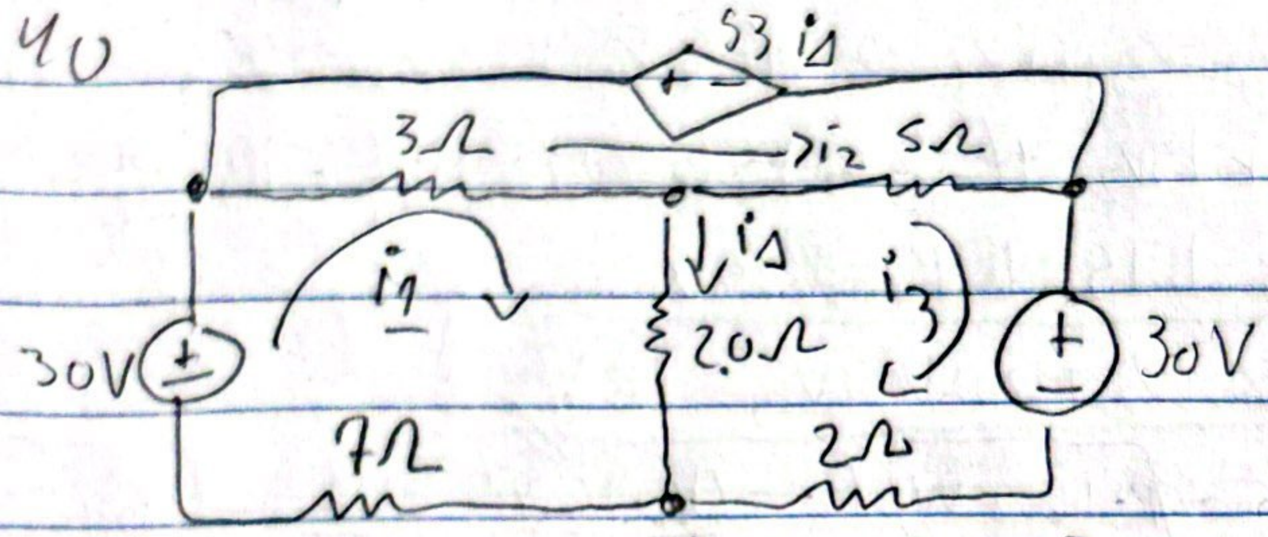
$8I_2 + 12I_1 - 12I_2 + 15I_2 + 5I_2 = 0 \Rightarrow 12I_1 + 16I_2$

$10(-\frac{4}{3}I_2) - 4I_2 = 65 \Rightarrow -\frac{40}{3}I_2 - 4I_2 = 65 \Rightarrow -\frac{52}{3}I_2 = 65$

$\boxed{I_2 = -\frac{195}{52} \approx -3.75A}$ $\boxed{I_1 = -\frac{4}{3}(-3.75) = 5A}$

$P_{15} = I_2^2(15) = (3.75)^2 \cdot 15 = \boxed{15W}$

4.40




$3\Omega = I_1 - I_2$

$20\Omega = I_2$

$5\Omega = I_2 - I_3$

Center $\underbrace{[3(I_1 - I_2) + 5(I_2 - I_3)]}_{V_f - V_p} = \frac{53 i_\Delta}{53 I_2}$

left $30$ (voltage rise) $= 3(I_1 - I_2) + 20I_2 + 7I_1 \Rightarrow 30I_1 - 20I_2 = 30$

right $30 = 5(I_2 - I_3) + 20I_2 + 2I_3 \Rightarrow -20I_1 + 27I_2 - 5I_3 = 30$

Center $= 3I_1 - 3I_2 + 5I_2 - 5I_3 = 53I_2 \Rightarrow 3I_1 - 5I_3 = 51I_2$ $I_1 = \frac{51I_2 + 5I_3}{3}$

$\Rightarrow 30\left(\frac{51I_2 + 5I_3}{3}\right) - 20I_2 = 30 \Rightarrow 10(51I_2 + 5I_3) - 20I_2 = 30$

$(510 - 20)I_2 + 50I_3 = 30 \Rightarrow 490I_2 + 50I_3 = 30$

$-20\left(\frac{51I_2 + 5I_3}{3}\right) + 27I_2 - 5I_3 = 30 \Rightarrow -\frac{1020}{3}I_2 - \frac{100}{3}I_3 + 27I_2$

$(-340 + 27)I_2 + (-\frac{100}{3} - 5)I_3 = 30$

$-313I_2 - \frac{115}{3}I_3 = 30 \Rightarrow -939I_2 - 115I_3 = 90$

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4.40 continued

$50I_3 = 30 - 490I_2 \Rightarrow I_3 = \frac{30-490I_2}{50}$

$-939I_2 - 115\left(\frac{30-490I_2}{50}\right) = 90 \Rightarrow -939I_2 + \frac{115 \cdot 490}{50} I_2 = 90$

$\frac{3450}{50} = 69 \quad \frac{115 \cdot 490}{50} = 1127$

$(-939+1127)I_2 - 69 = 90 \Rightarrow 188I_2 = 159 = I_2 = i_s = \frac{159}{188} = \boxed{0.846\,A}$

$I_3 = \frac{30-490\left(\frac{159}{188}\right)}{50} = \frac{30-413.7234}{50} = \boxed{-7.747\,A}$

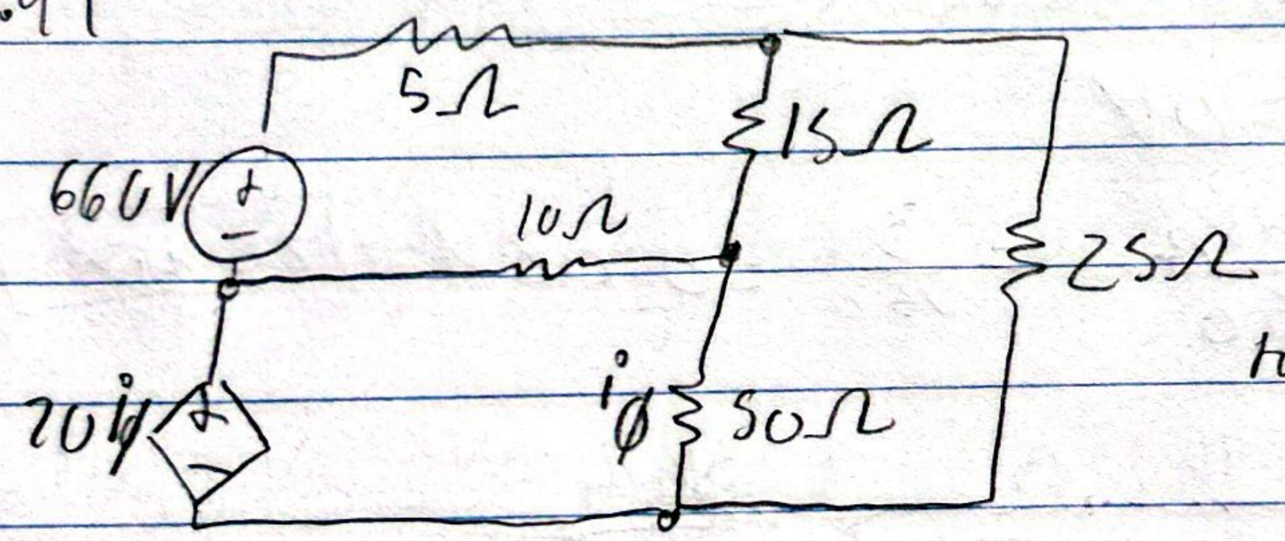
$I_1 = \frac{5I_2+5I_3}{3} = \frac{5(0.846)+5(-7.747)}{3} = \frac{43.187-38.735}{3} = \boxed{1.484}$

$V_{dep} = 53 i_s = 53 \times 0.846 = \boxed{44.878\,V}$

$I_{dep} = (I_1 - I_2) + (I_2 - I_3) = I_1 - I_3 = 1.484 - (-7.747) = \boxed{9.231\,A}$

$P_{dep} = V_{dep} I_{dep} = 44.878 \times 9.231 = \boxed{4.664e^4\,W}$

4.41




$i_\phi = \frac{V_b}{50}$

$20 i_\phi = 20 \frac{V_b}{50} = 0.4V_b$

top $= 0.4V_b$ bottom $= 0$

660V $\quad V_a = 0.4V_b + 660$

KCL at $V_a$: $\frac{V_a - V_b}{5} + \frac{V_a - V_b}{10} = 0 \Rightarrow \left(\frac{1}{5} + \frac{1}{10}\right)(V_a - V_b) = 0 \; V_a =$

$V_a = 0.4V_b + 660 \Rightarrow V_b = 0.4V_b + 660 = 0.6V_b = 660 \Rightarrow \boxed{V_b = 1100}$

$\boxed{i_\phi = \frac{V_b}{50} = 22\,A}$

$I_{dep} = \frac{V_a - V_b}{5} + \frac{V_a - V_b}{10} = 0$

$V_{dep} = 0.4V_b = 0.4(1100) = \boxed{440\,V}$

$P_{dep} = V_{dep} I_{dep} = 440 \times 22 = \boxed{9680\,W \text{ absorbed}}$

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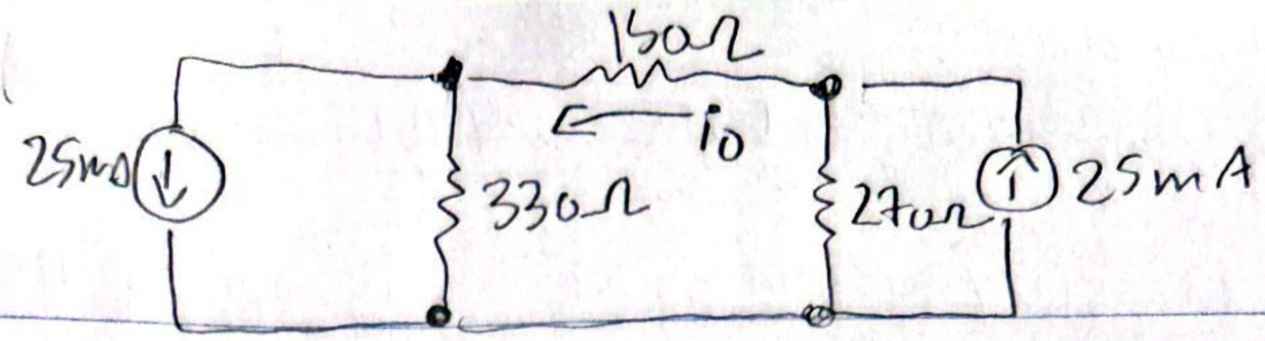
circuits
9 tw 2

4.59




$V_{Th,L} = IR = 25\,mA \times 330\,\Omega = 8.25\,V$

$R_{Th,L} = 330\,\Omega$

$V_{Th,R} = IR = 25\,mA \times 270\,\Omega = 6.75\,V$

$R_{Th,R} = 270\,\Omega$

$\boxed{330\,\Omega} - \boxed{150\,\Omega} - \boxed{270\,\Omega}$

$I_{series} = \frac{150}{330 \| 150 \| 270} = \frac{150}{750} = 2.0\,mA \quad i_o = 20\,mA$

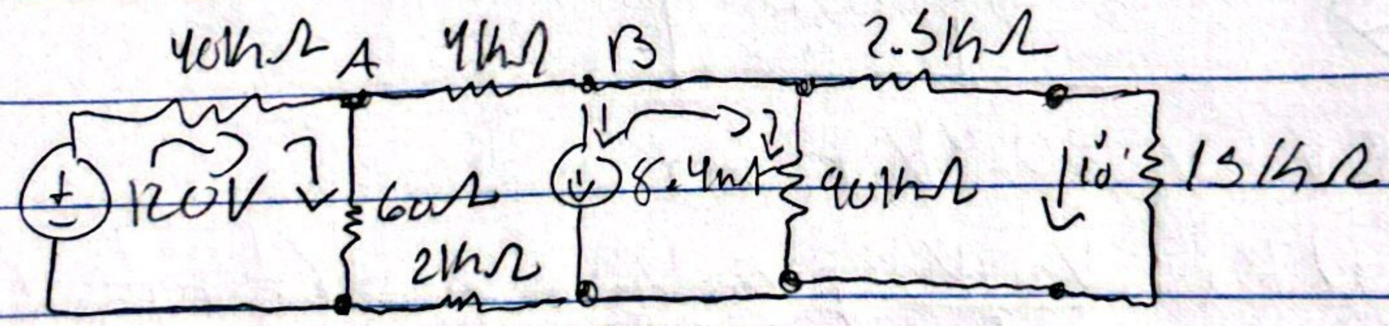
$\frac{V_L}{330} + \frac{V_L - V_R}{150} - 0.025 = 0$

$\frac{V_R}{270} + \frac{V_R - V_L}{150} - 0.025 = 0$

$V_L = 3V \quad V_R = 0V$

$i_o = \frac{V_L - V_R}{150} = \frac{3}{150} = 0.02A = \boxed{20\,mA}$

4.60




$60\,k\Omega \| 2\,k\Omega = \frac{60 \times 2}{60 + 2} \quad \frac{120}{62} = \boxed{1.935\,k\Omega}$

A Th A $V_{Th,A} = 120 \cdot \frac{1.935}{40 \| 1.935} = 120 \cdot \frac{1.935}{41.935} = \boxed{5.54\,V} \quad R_{Th,A} = 40 \| 1.935 = \frac{40 \cdot 1.935}{40 + 1.935} = \boxed{1.846\,\Omega}$

Th B $I_N = 8.4\,mA \downarrow \quad R_N = 90 \quad V_{Th,B} \quad I_N \cdot R_N = 0.0084 \times 90{,}000 = 756\,V \quad R_{Th,B} = 90\,k\Omega$

$[V_{Th,A} + R_{Th,A}] - 4\,k\Omega - [V_{Th,B} + R_{Th,B}] - 2.5\,k\Omega - 15\,k\Omega$

$i_o = -4.5\,mA, \quad P_{120} = +120 \cdot (-3.315\,mA) = -0.3978\,W = \boxed{-397.8\,mW}$

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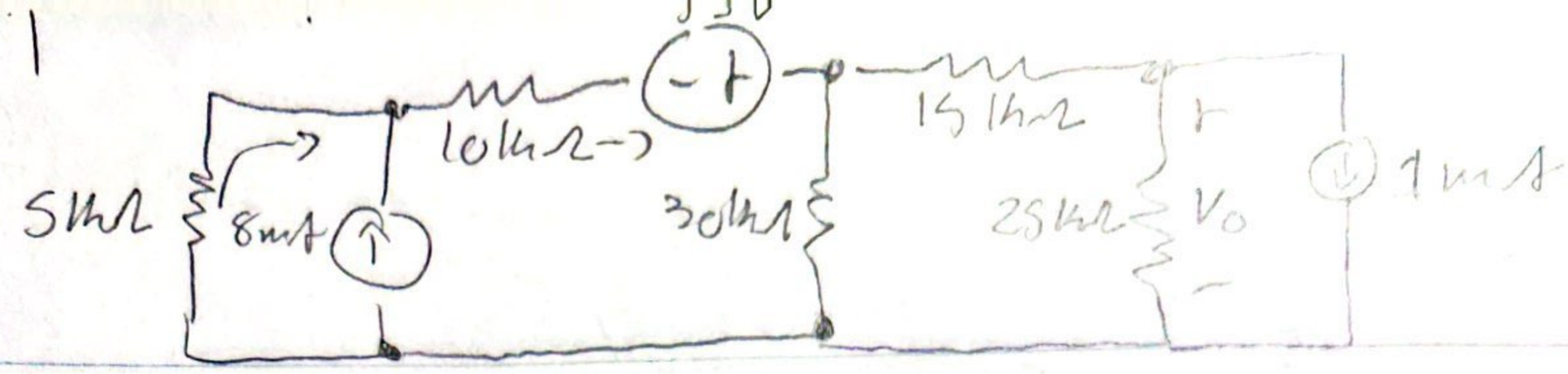
4.61



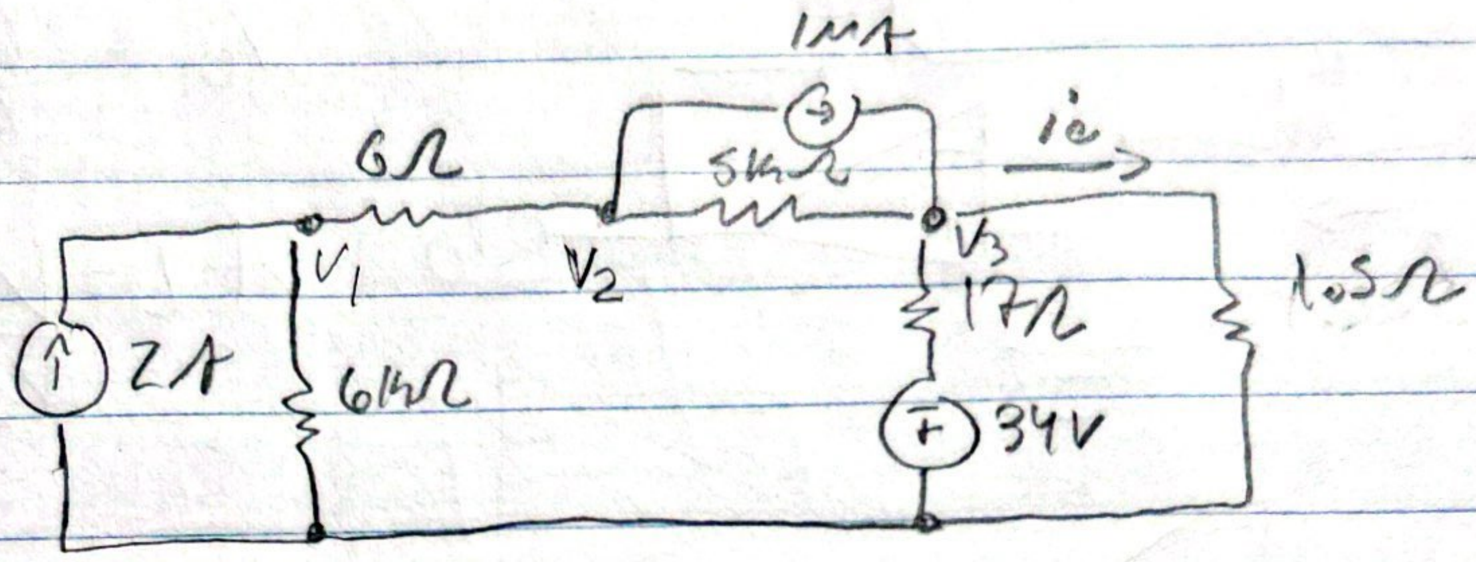

$V_{Th,L} = 8mA \times 5k\Omega = 40V$ $R_{ThL} = 5k\Omega$

$5k\Omega - 10k\Omega - (35V \text{ source}) - 15k\Omega - 25k\Omega$

$V_L - V_R = 35$ $V_R \approx 35 \parallel 15$

$V_o = 12.5V$

4.62




$V_x = -34V$

Incl $V_1$: $\frac{V_1}{6} + \frac{V_1 - V_2}{6} = 2$ $2V_1 - V_2 = 12$

Incl $V_2$: $\frac{V_2 - V_1}{6} + \frac{V_2 - V_3}{5} + 1 = 0 \Rightarrow 11V_2 - 5V_1 - 6V_3 = -30$

Incl $V_3$: $\frac{V_3 - V_2}{5} + \frac{V_3}{1.5} + \frac{V_3 - V_x}{17} - 1 = 0$

$V_x = -34$ $\frac{V_3 - V_2}{5} + \frac{2}{3}V_3 + \frac{V_3 + 34}{17} = 1$

(1) $V_2 = 2V_1 - 12$ $11(2V_1 - 12) - 5V_1 - 6V_3 = -30 \Rightarrow 17V_1 - 6V_3 = 102$

$\frac{V_3 - (2V_1 - 12)}{5} + \frac{2}{3}V_3 + \frac{V_3 + 34}{17} = 1$ $\times \text{Lcm}(5, 3, 17)$

$51(V_3 - 2V_1 + 12) + 170V_3 + 15(V_3 + 34) = 255$

$236V_3 - 102V_1 = -867$

$236V_3 - 102\left(\frac{102 + 6V_3}{17}\right) = -867 \Rightarrow 200V_3 = -255 \Rightarrow \boxed{V_3 = -1.2}$

$V_1 = \frac{102 + 6(-1.275)}{17} = 5.55V$ ; $V_2 = 2V_1 - 12 = -0.90V$

$i_o = \frac{V_3}{1.5} = \frac{-1.275}{1.5} = \boxed{-0.85A}$

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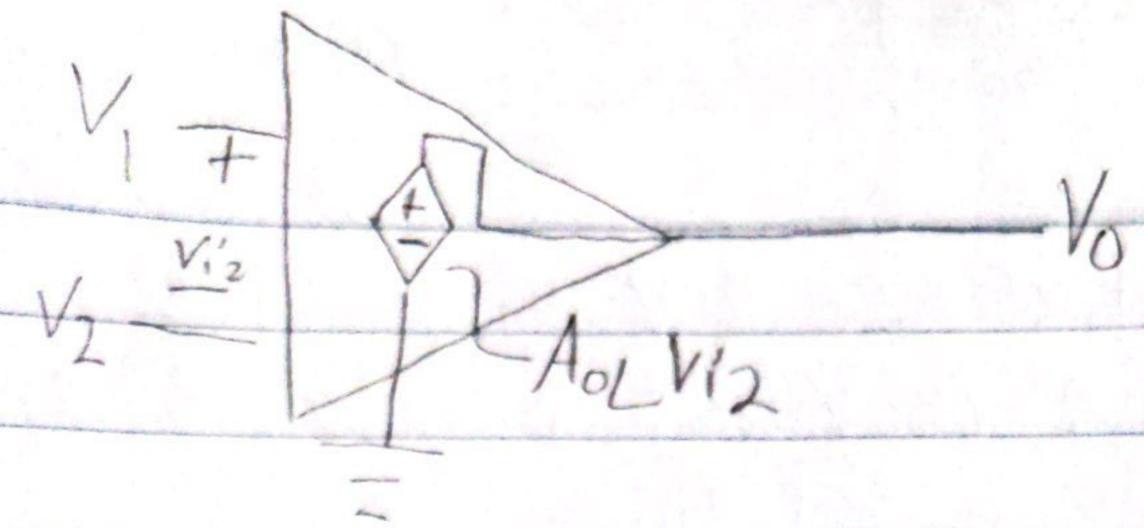
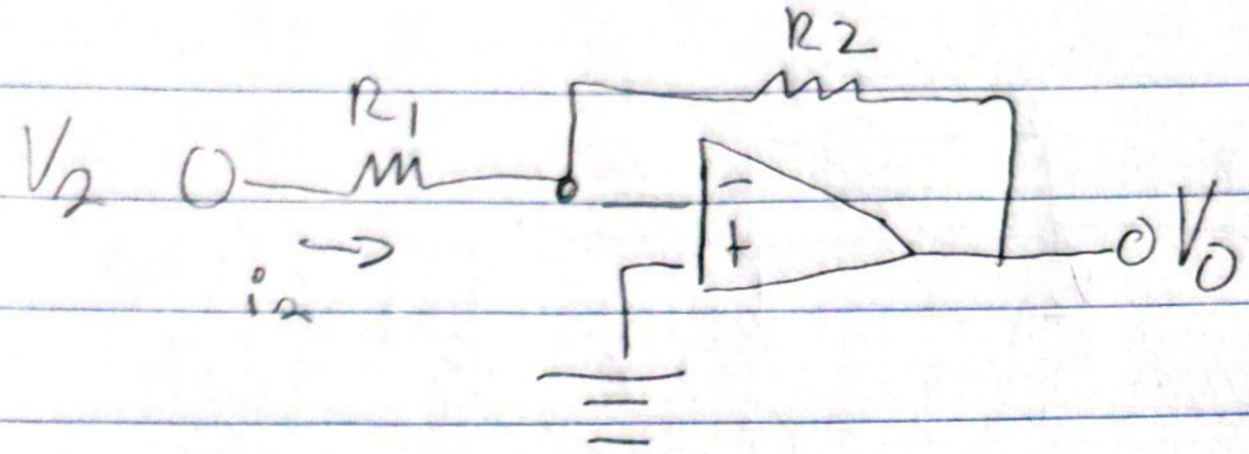
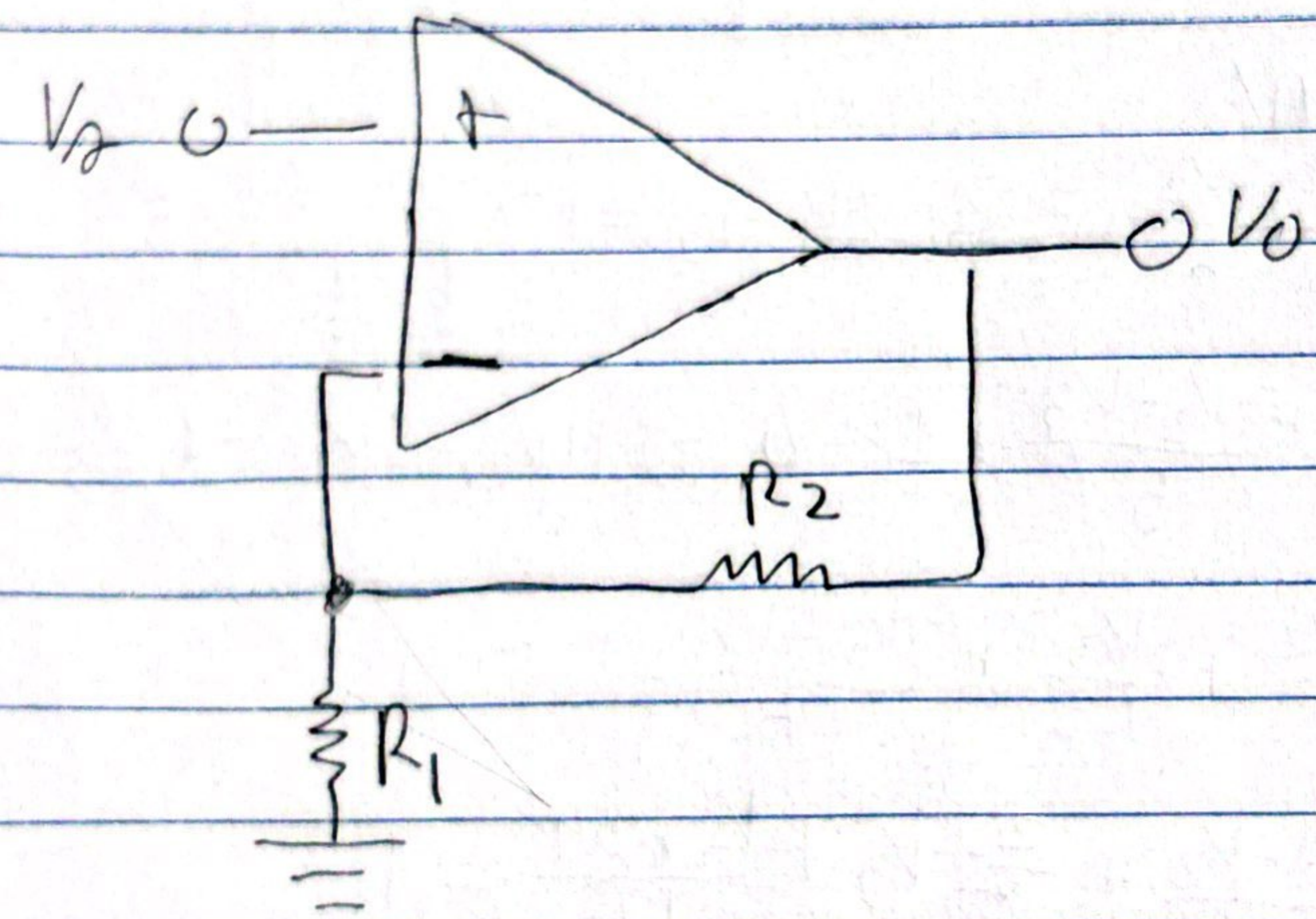
Lecture
09/16/25



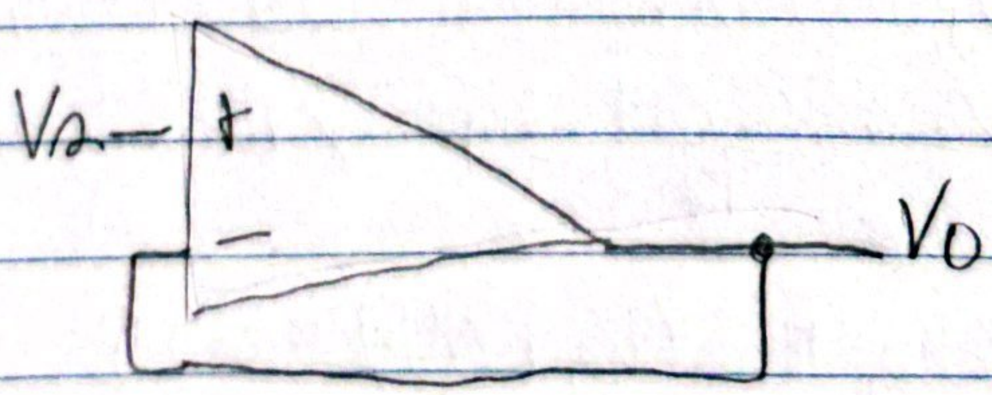

$$V_0 = \frac{-R_2}{R_1} V_2$$

$$A_{CL} = \frac{V_0}{V_2} = \frac{-R_2}{R_1}$$




$$V_0 = \left(1 + \frac{R_2}{R_1}\right) V_2$$

$$A_{CL} = \frac{V_0}{V_2} = 1 + \frac{R_2}{R_1}$$




$$V_0 = V_2$$

$$\frac{V_0}{V_2} = 1$$

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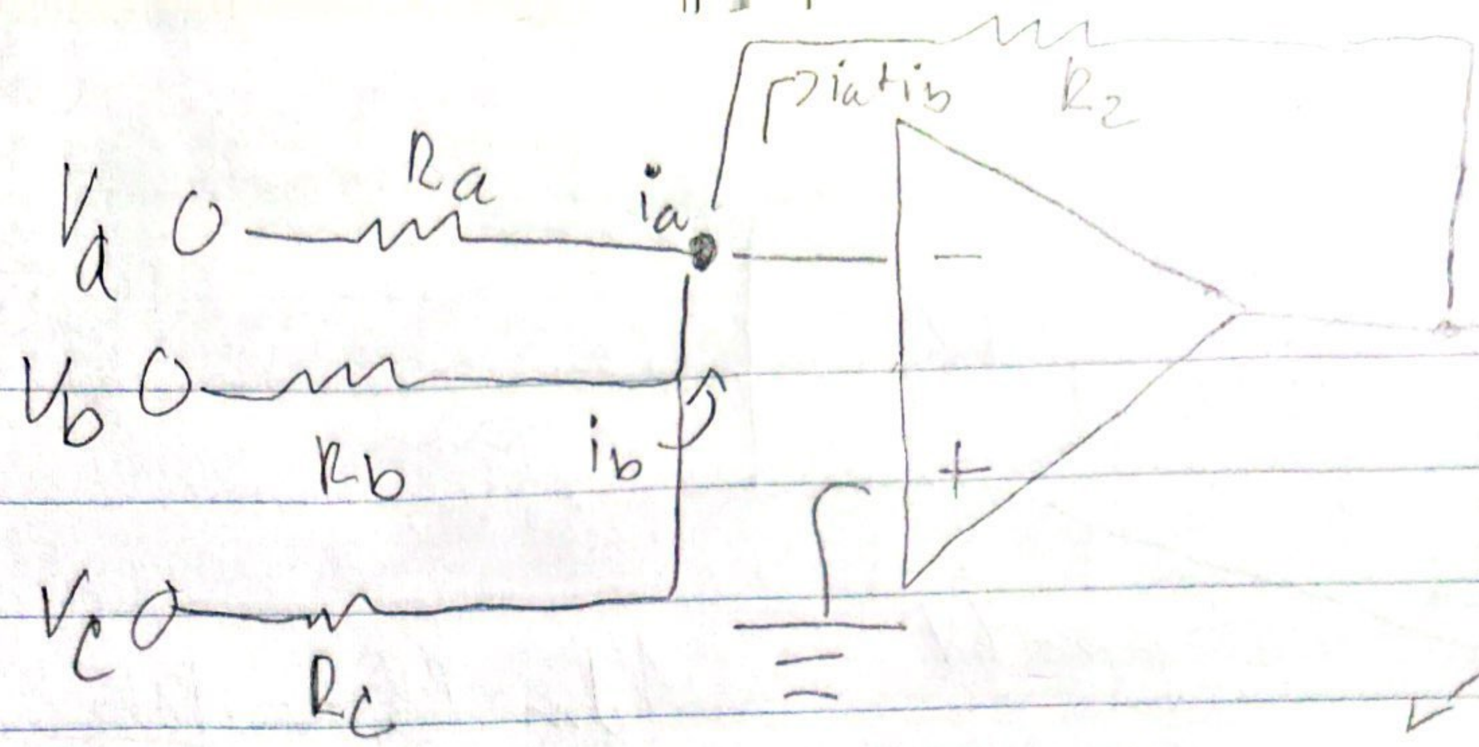
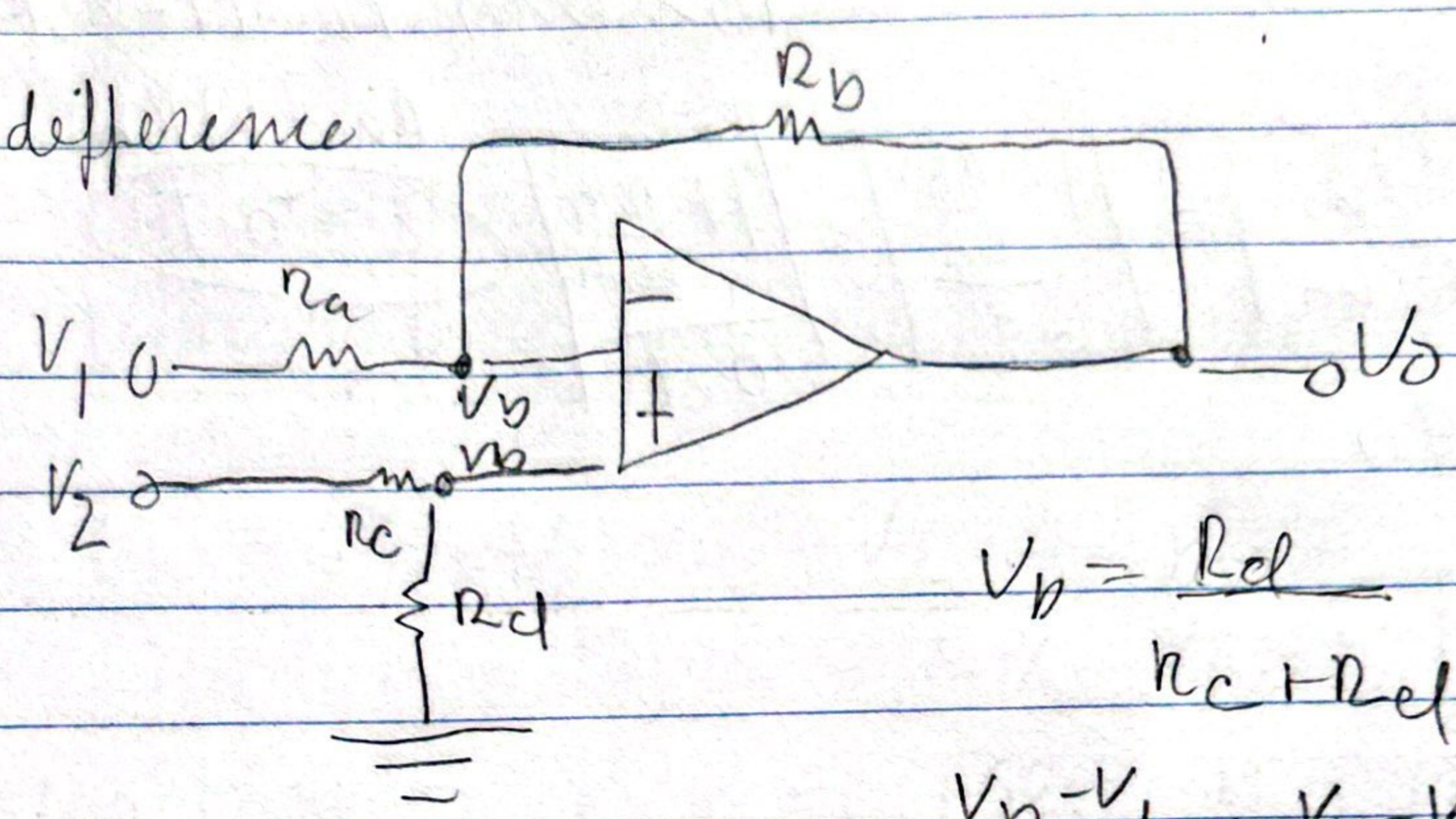
Circuits Lecture 09/16/25




$$= \frac{-R_2}{R_a} V_a - \frac{R_2}{R_b} V_b - \frac{R_2}{R_c} V_c = V_a - V_b - V_c = -(V_a + V_b + V_c)$$

difference




$$V_b = \frac{R_d}{R_c + R_d}$$

$$\frac{V_b - V_1}{R_a} + \frac{V_b - V_o}{R_b} = \phi$$

$$\frac{R_d}{R_c + R_d}\left(\frac{1}{R_a} + \frac{1}{R_b}\right) = \frac{V_1}{R_a} + \frac{V_o}{R_b}$$

$$V_b\left(\frac{1}{R_a} + \frac{1}{R_b}\right) = \frac{V_1}{R_a} + \frac{V_o}{R_b}$$

$$\frac{R_b}{R_c + R_2}\left(\frac{R_a + R_b}{R_a R_b}\right) - V_1 \frac{R_b}{R_a} = V_o$$

common mode

$R_a = R_c$ $\quad V_o = \frac{R_b}{R_a}(V_2$

$R_b = R_d$

$$V_o = V_2 \frac{R_a + R_b}{R_c + R_d} - V_1 \frac{R_b}{R_a}$$

$a_{cm} \Rightarrow 0$ $\quad a_{dm} = V_2 - V_1$ $\quad V_1 = V_{cm} - \frac{1}{2} V_{dm}$ $\quad$ * gain depends o the difference

$a_{dm} \Rightarrow \infty$ $\quad A_{cm} = \frac{V_1 + V_2}{2}$ $\quad V_2 = V_{cm} + \frac{1}{2} V_{dm}$

$$V_o = \frac{R_d(R_a + b)}{R_a(R_c + R_d)} V_2 - \frac{R_b}{R_a} V_1 \qquad V_o = \frac{R_a R_d - R_b R_c}{R_a(R_c + R_d)} V_{cm} + \frac{R_d(R_a + R_b) + R_b(R}{2R_a(R_c + R_d)}$$

$$= A_{cm} V_{cm} + A_{dm} V_{dm} \Rightarrow \frac{R_a}{R_b} = \frac{R_c}{R_d} \qquad V_o = \frac{R_b}{R_a}(V_2 - V_1)$$

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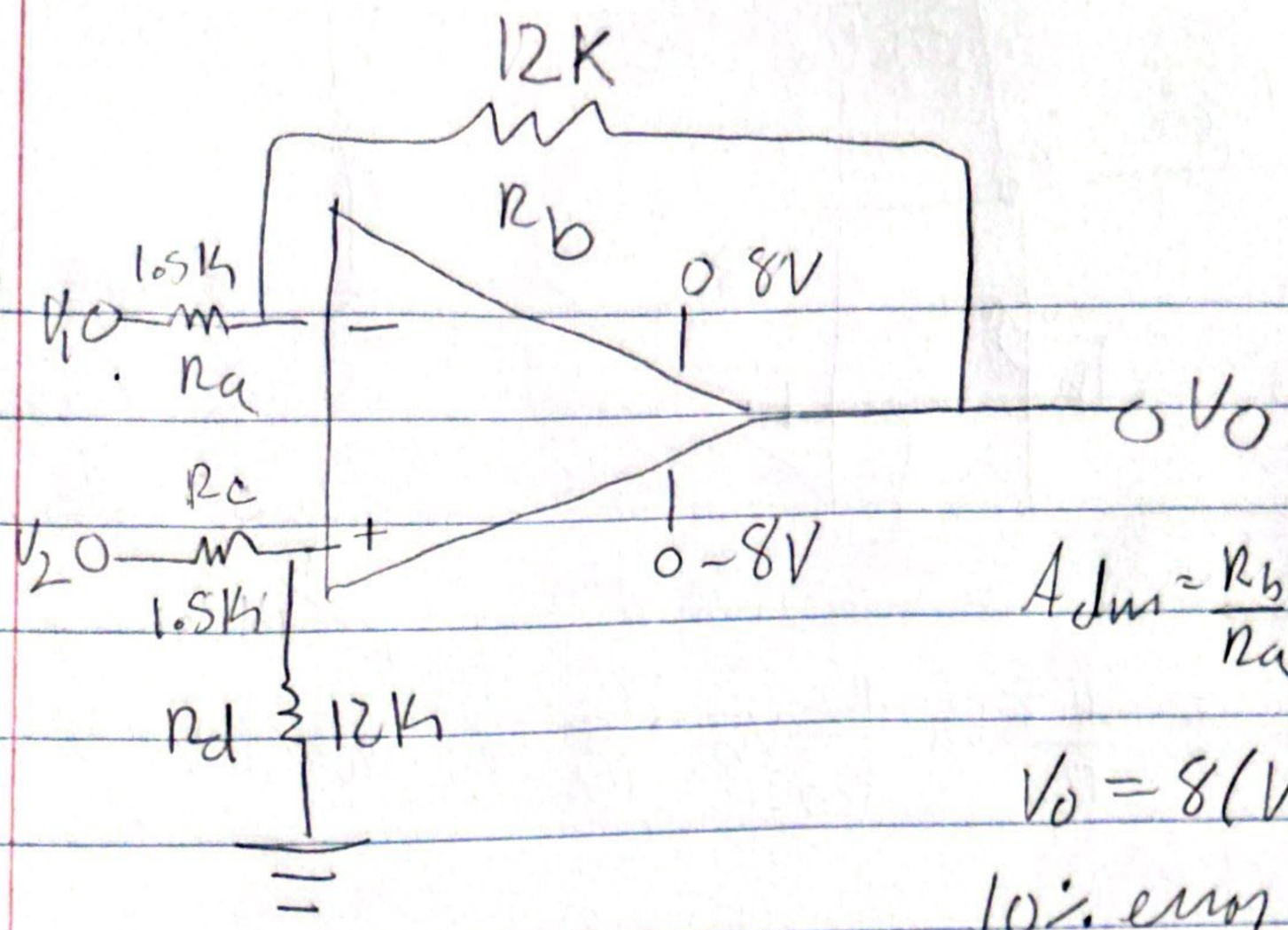
Circuito
Lecture
09/16/2024




$$A_{dm} = \frac{R_b}{R_a} = \frac{12K}{1.5K} = 8$$

$$V_0 = 8(V_2 - V_1)$$

10% error $R_a = (1-\varepsilon)R_b$

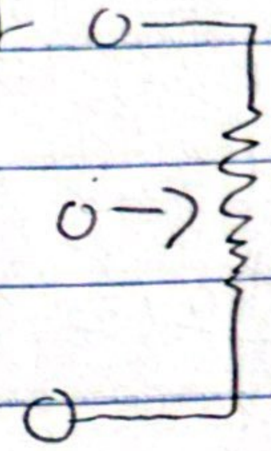
$R_a = 1.1 R_b$

$\varepsilon = 0.1$

$$CMRR = \left|\frac{A_{dm}}{A_{cm}}\right| = \left|\frac{1+\frac{R_b}{R_a}}{-\varepsilon}\right| = \left|\frac{1+\frac{12K}{1.5K}}{0.1}\right|$$

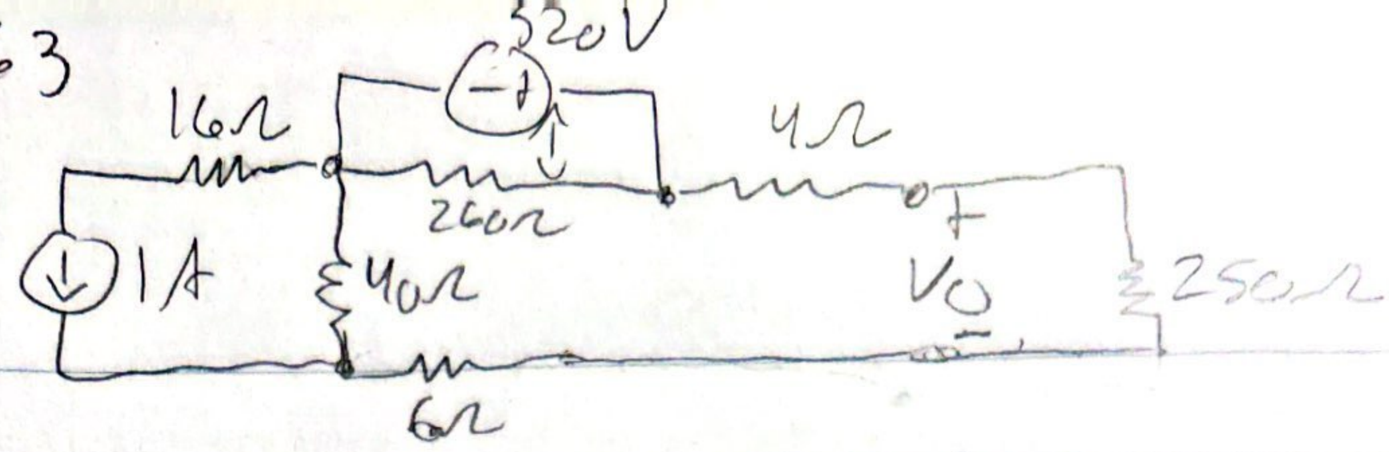
$= 90$

pot



circuits
HW

4.63




$V_{BL} = \frac{V_{BL}-0}{6} = 1 \quad V_{BL} = 6V$

$\frac{V_o - V_1}{16} + 1 = 0 \quad V_o = V_1 - 16V$

$V_2 - V_1 = 520$

$\frac{V_1 - V_o}{10} + \frac{V_1}{40} + \frac{V_2 - V_3}{4} = 0 \quad \frac{V_1}{40} + \frac{V_2 - V_3}{4} = -1$

$\frac{V_3 - V_2}{4} + \frac{V_3}{250} = 0 \Rightarrow (250)(V_3 - V_2) + 4V_3 = 0$

$V_3 = \frac{250}{254} V_2 = \frac{125}{127} V_2$

$V_2 - V_3 = V_2 - \frac{125}{127} V_2 = \frac{2}{127} V_2$ then $\frac{V_2 - V_3}{4} = \frac{V_2}{254}$

$\frac{V_1}{40} + \frac{V_2}{254} = -1 \quad V_2 = V_1 + 520 \quad \frac{V_1}{40} + \frac{V_1 + 520}{254} = -1$

$40 \cdot 254 = 10160$

$254V_1 + 40(V_1 + 520) = -10160 \Rightarrow 294V_1 = -30960$

$V_1 = \frac{-30960}{294} = -105.306V$

$V_2 = V_1 + 520 = 414.694V \quad V_3 = \frac{125}{127} V_2 = 408.16V$

$\boxed{V_o = 4.00e^2 V}$

$I_{260} = (V_2 - V_1)/260 = 520/260 = 2A$

$I_{520} = I_{right} - I_{260} = 3 - 2 = 1A$

$P_{520V} = -(520)(1) = -520W$

$P_{260} = I^2 \cdot R = 2^2 \cdot 260 = 1040W \quad -520 + 1040 = +520W$

$V_o - V_{BL} = (V_1 - 16) - 6 = -127.306V$

$P = I \cdot V = 1 \cdot (-127.306) \approx -127$

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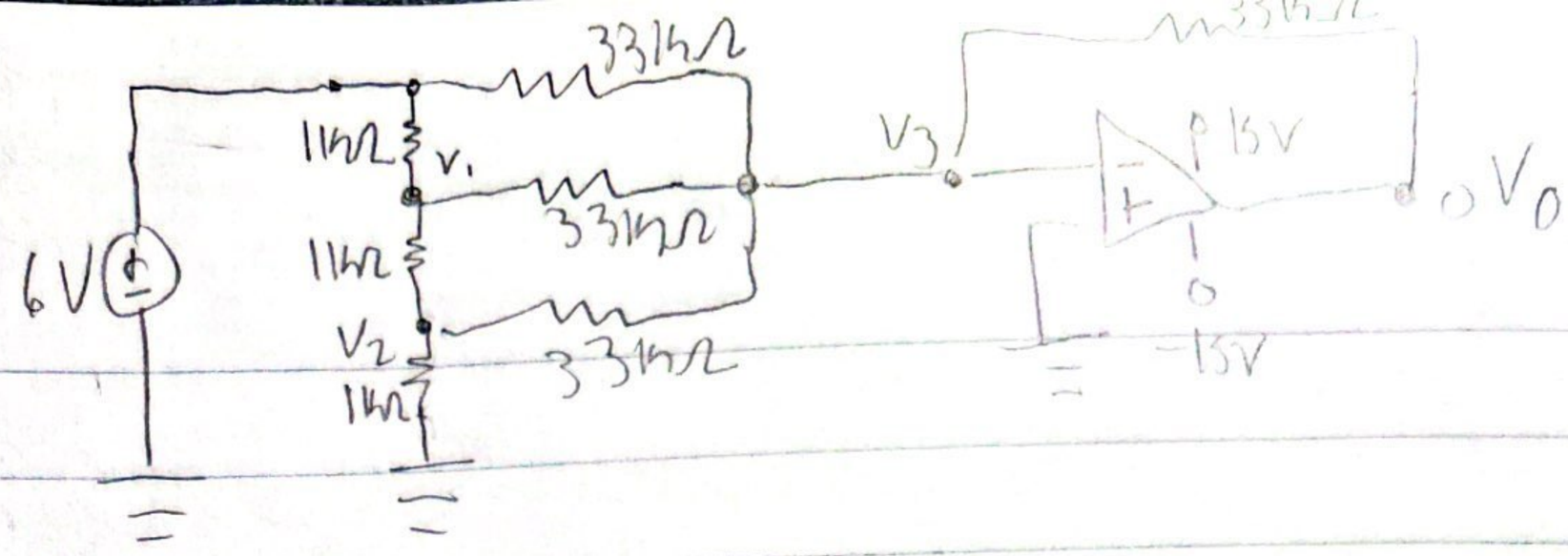
circuits lab 2

1)




step 1 analyze $V_1, V_2, V_3$ ($V_3 = 0$)

$1k + 1k + 1k = 3k\Omega$ $\quad I = \frac{6}{3k\Omega} = 2mA$

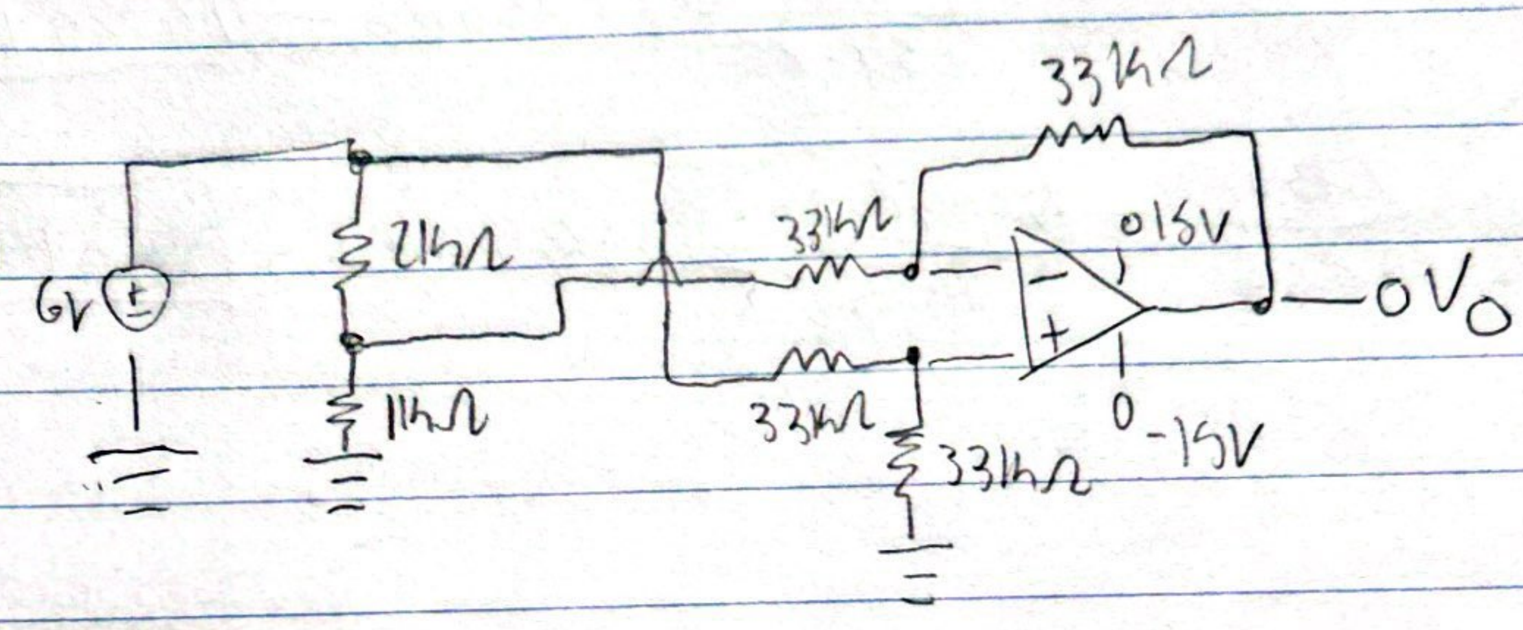
$V_1$: $V_1 = 6V - (1k\Omega \cdot 2mA) = 6V - 2V = \boxed{4V}$

$V_2$: $V_2 = 6V - 2k\Omega \cdot 2mA = 6V - 4V = \boxed{2V}$

step 2 $\rightarrow V_+ = 0$ $\quad V_- = V_3 = 0$

$V_0 = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$ $\quad V_0 = -33k\left(\frac{4}{33} + \frac{2}{33} + \frac{0}{33}\right) = -(4+2) = \boxed{-6V}$

2)




step 1 analyze node $V_1, V_2, V_3$

$V_1 = 6V \cdot \frac{1k\Omega}{2k\Omega + 1k\Omega} = 6 \cdot \frac{1}{3} = 2V$ $\quad \boxed{V_1 = 2V}$

$V_3 = V_1 \cdot \frac{33k\Omega}{33k\Omega + 33k\Omega} = 2 \cdot \frac{1}{2} = \boxed{1V}$

$V_2 = V_3 = 1V$

$\text{gain} = 1 + \frac{R_f}{R_{in}} = 1 + \frac{33k}{33k} = 1 + 1 = 2$

$V_0 = \text{gain} \cdot V_3 = 2 \cdot 1 = \boxed{2V}$

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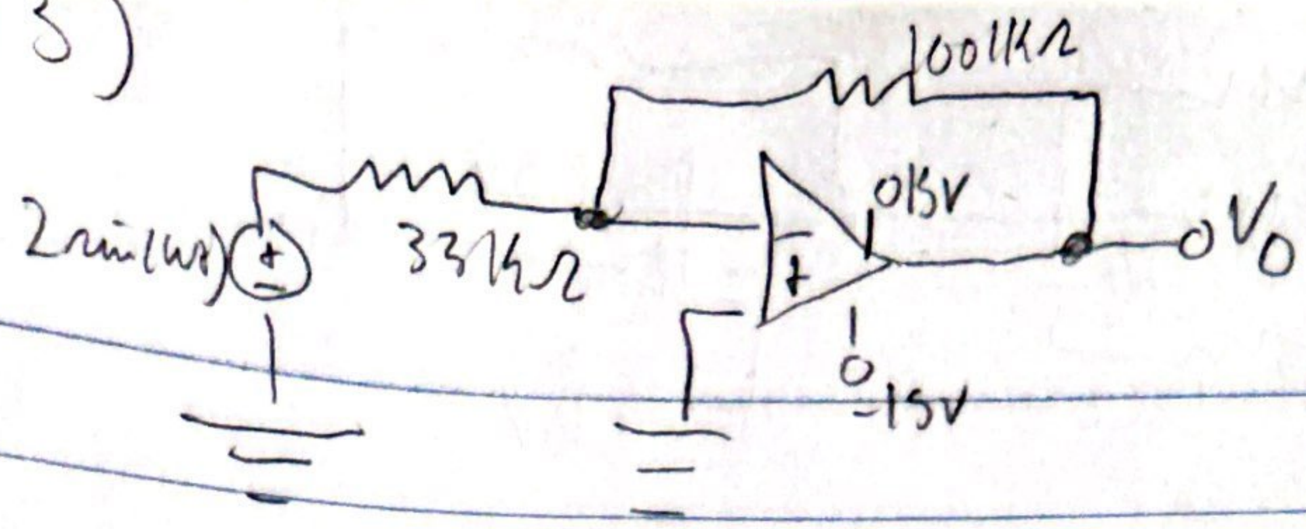
Tab 2

3)




$$f_H \geq 2\pi \cdot f_{FP} \cdot V_{pk} \quad \text{so,} \quad f_{FP} = \frac{f_H}{2\pi V_{pk}}$$

$$GBW = A_{CL} \cdot f_{CL} \quad \text{so,} \quad f_{CL} = \frac{GBW}{A_{CL}}$$

$$A_{CL} = \frac{R_f}{R_{in}} = \frac{100k\Omega}{33k\Omega} = \boxed{3.03}$$

$$f_{FP} = \frac{0.5e^6}{2\pi \cdot 6} \approx \frac{500{,}000}{37.7} = 13{,}250\,Hz \approx \boxed{13.25\,kHz}$$

$$f_{CL} = \frac{GBW}{A_{CL}} = \frac{1{,}000{,}000}{3.03} \approx 330{,}000\,Hz = \boxed{330\,kHz}$$

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circuits review

Ch. 1 introduction

energy

work

charge

$V = IR$

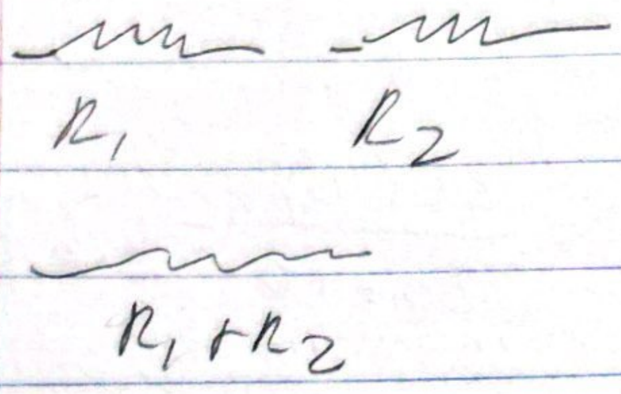
$P = IV$

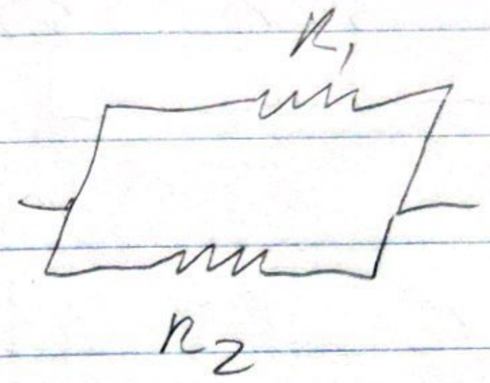
Ch. 2

KVL, KCL

Ch. 3

resistive circuits




$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$

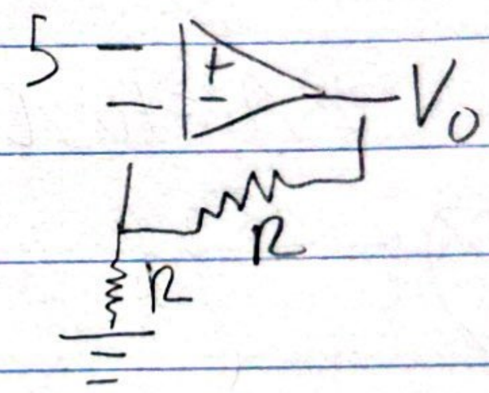
Ch. 4

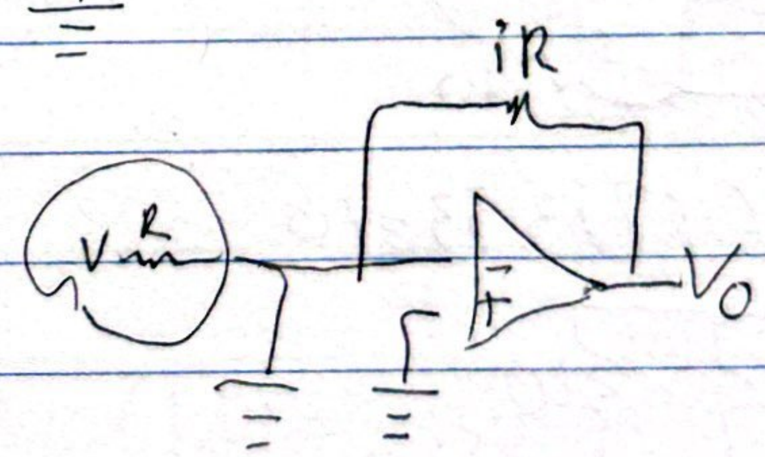
node analysis KCL

mesh analysis KVL

supernode

Ch. 5 op amps

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Circuits test 1

1) 2 amps at 5V to charge

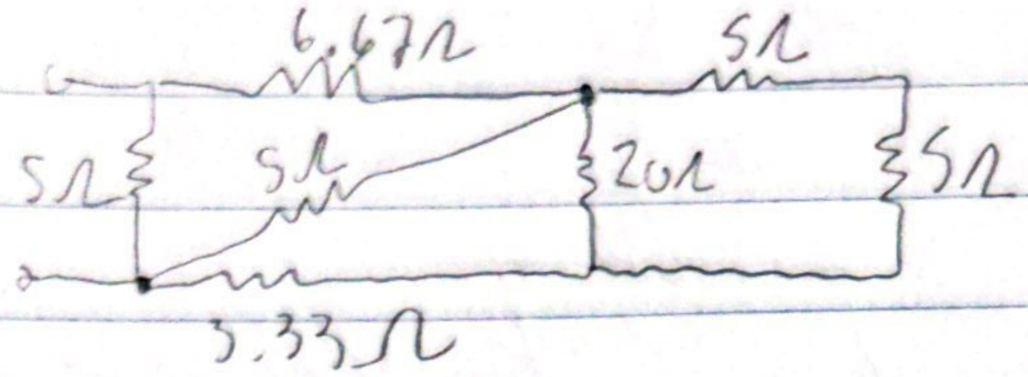
a) $P = VI = 5V \cdot 2A = 10W$

$E = 10W \cdot 1hour = 10W \cdot 3600 = 36{,}000Ws = \boxed{36{,}000J}$

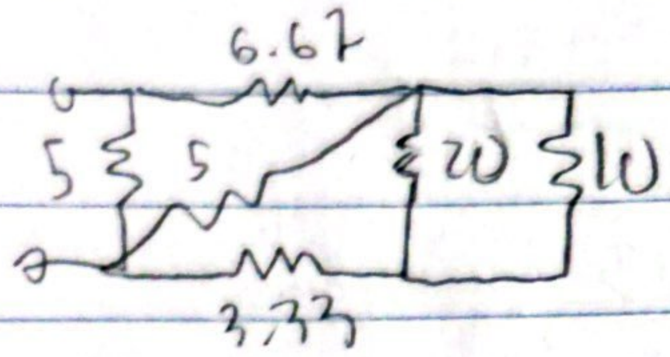
b) Charge $= 2A \cdot 1hr = 2A \cdot 3600s = 7200A \cdot s = \boxed{7{,}200 \text{ coulombs}}$

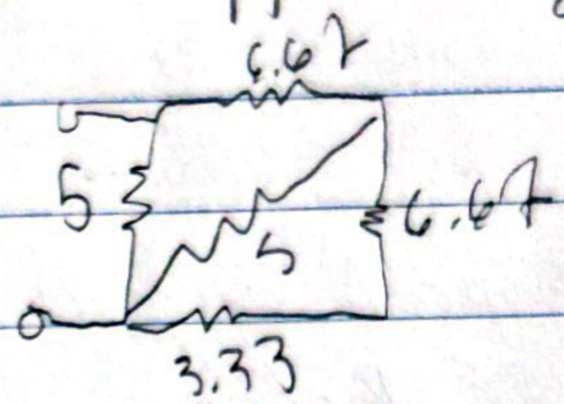
c) $C = \frac{Q}{V}$ $\frac{10Ah}{2A \cdot h} = 5$ times

2)

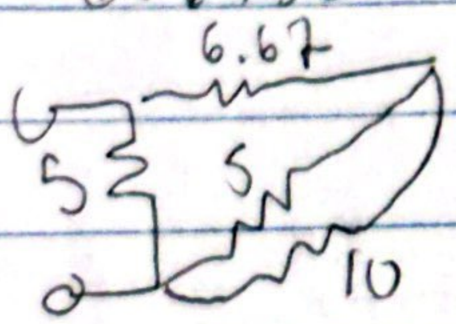


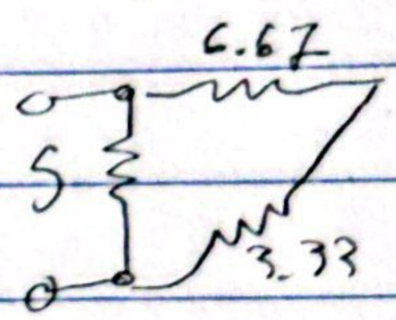

$5\Omega + 5\Omega = 10\Omega$ $\quad$ $20\Omega \| 10\Omega = \frac{20(10)}{20+10} = 6.67$



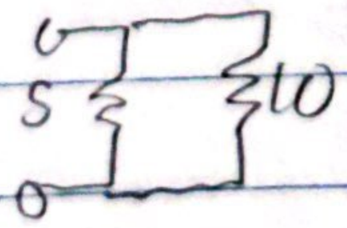



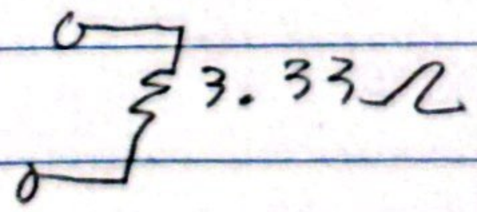

$6.67\Omega + 3.33\Omega = 10\Omega$ $\quad$ $5\Omega \| 10\Omega = \frac{5 \cdot 10}{5+10} = 3.33\Omega$




$6.67 + 3.33 = 10$ $\quad$ $5 \| 10 = \frac{5 \cdot 10}{5+10} = 3.33$




$R_{CB} = 20 \| 10 = \frac{20(10)}{20+10} = \frac{200}{30} = 6.667$

$R_{CB} = \left(\frac{1}{\frac{10}{3}} + \frac{1}{5} + \frac{1}{\frac{20}{3}}\right)^{-1} = (1.538\Omega)$

$R_{A-C-b} = \frac{20}{3} + \frac{20}{13} = 8.208$

$R_{eq} = 5 \| \frac{320}{39} = \frac{5 \cdot \frac{320}{39}}{5 + \frac{320}{39}} = \frac{\frac{1600}{39}}{\frac{515}{39}} = \frac{1600}{515} = \boxed{3.11\Omega}$

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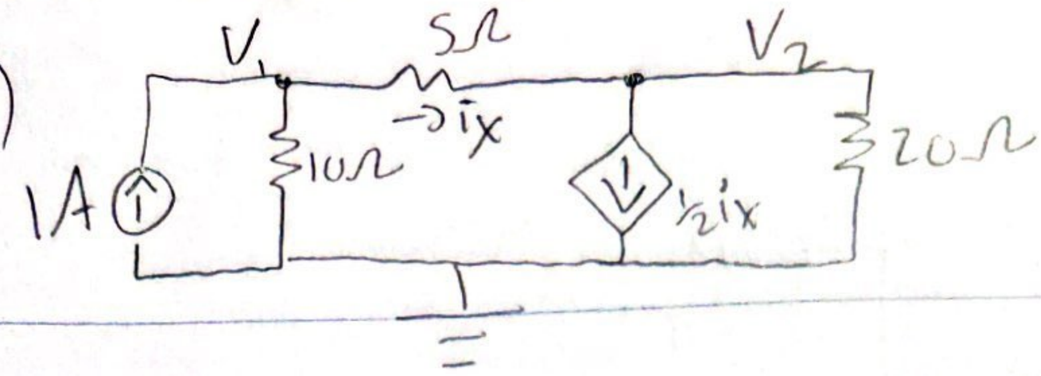
circuits test 2

3)




$V1: \; -1 + \frac{V_1}{10} + \frac{V_1 - V_2}{5} = 0 \qquad i_x = \frac{V_1 - V_2}{5}$

$V1\left(\frac{1}{10} + \frac{1}{5}\right) - V_2\left(\frac{1}{5}\right) = 1 \Rightarrow V1(.3) + V_2(-.2) = 1$

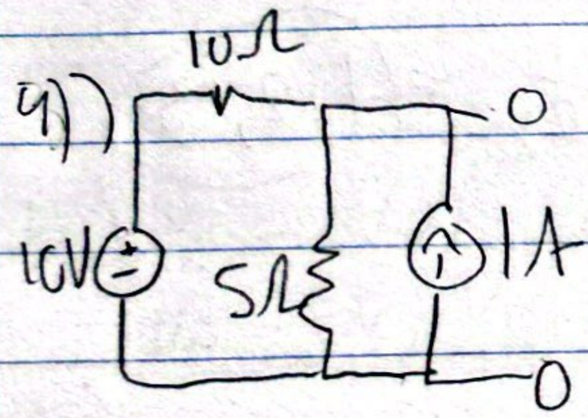
$V2: \; \frac{V_2 - V_1}{5} + \frac{1}{2} i_x + \frac{V_2}{20} = 0$

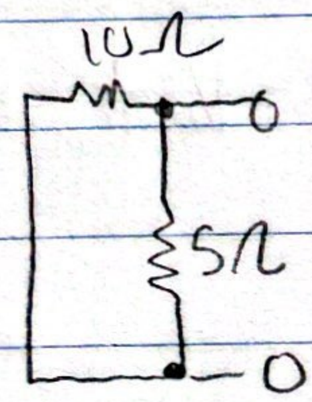
$\frac{V_2 - V_1}{5} + \frac{1}{2}\left(\frac{V_1 - V_2}{5}\right) + \frac{V_2}{20} = 0$

$V1(-0.1) + V2(0.15) = 0$

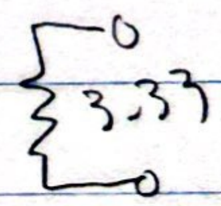
$$\begin{bmatrix} .3 & -.2 \\ .1 & .15 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

4)



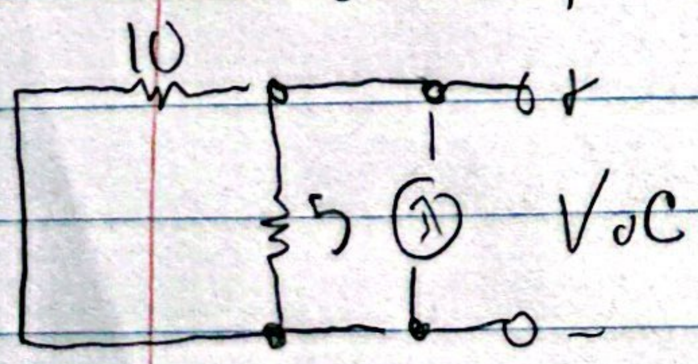




$\frac{1}{\frac{1}{10} + \frac{1}{5}} = 3.33\Omega$



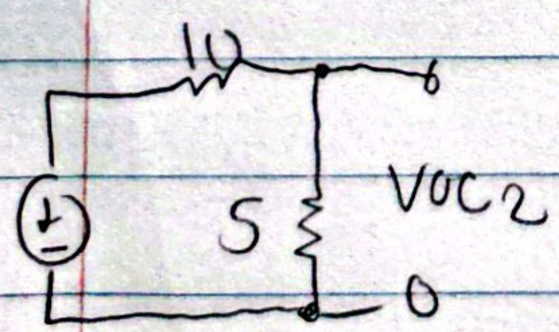

$R_{th} = 3.33\Omega$

$V_{oc}$: by superposition



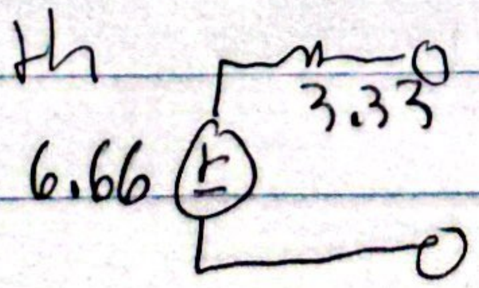

$V_{oc_1} = 3.33\Omega(1A) = 3.33V$

$V_{oc_2} = 10\frac{5}{10+5} = 3.33$




$V_{oc} = V_{oc_1} + V_{oc_2} = 3.33 + 3.33 = 6.66$

th

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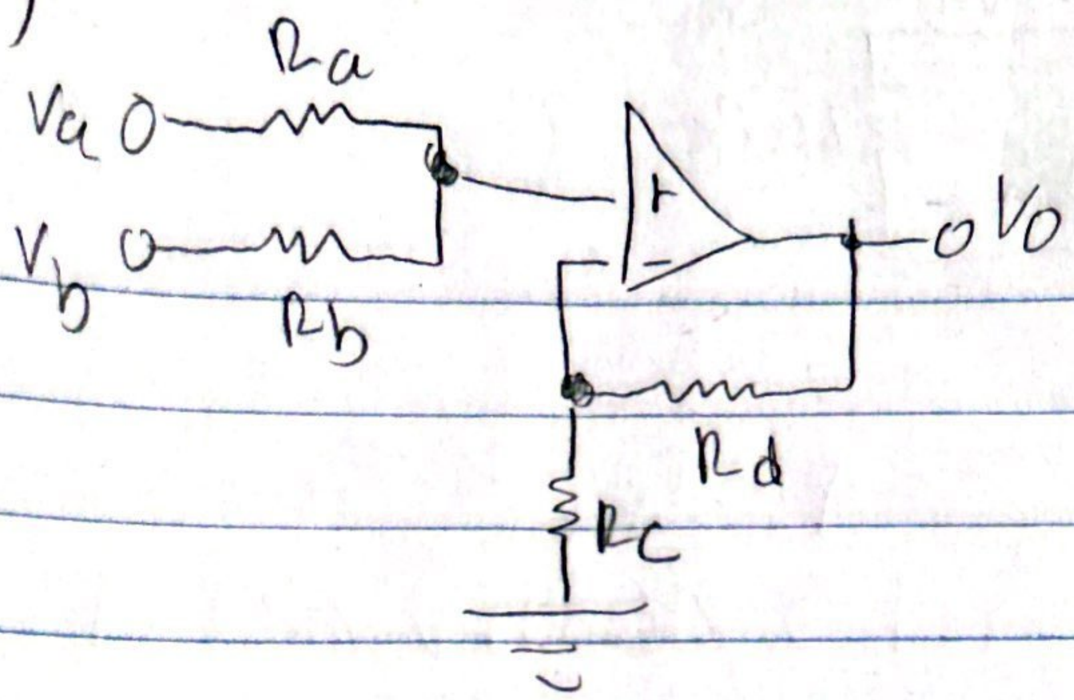
test 1

5)




$$V_2 = V_o \frac{R_c}{R_c + R_d} \quad -①$$

$$V_i = V_2 \quad -②$$

$$V_1 = \frac{V_1 - V_a}{R_a} + \frac{V_1 - V_b}{R_b} = 0$$

$$V_1 = \left(\frac{1}{R_a} + \frac{1}{R_b}\right) - V_a \frac{1}{R_a} - V_b \frac{1}{R_b} = 0 \quad ③$$

$$V_o \frac{R_c}{R_c + R_d}\left(\frac{1}{R_a} + \frac{1}{R_b}\right) = V_a \frac{1}{R_a} + V_b \frac{1}{R_b} = (1, 2, 3)$$

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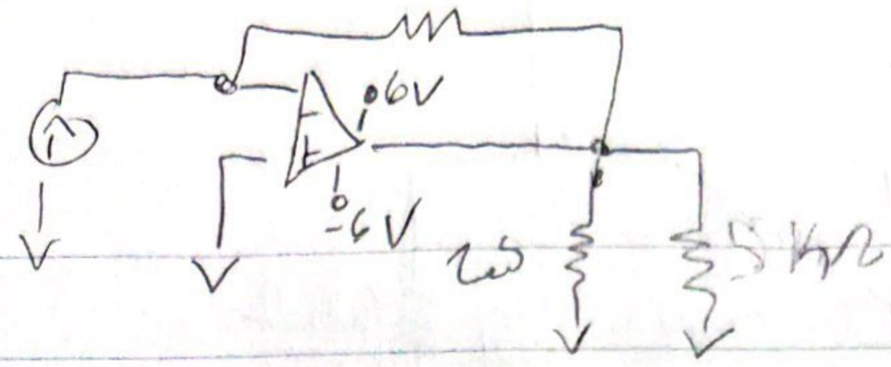
HW 3 circuits

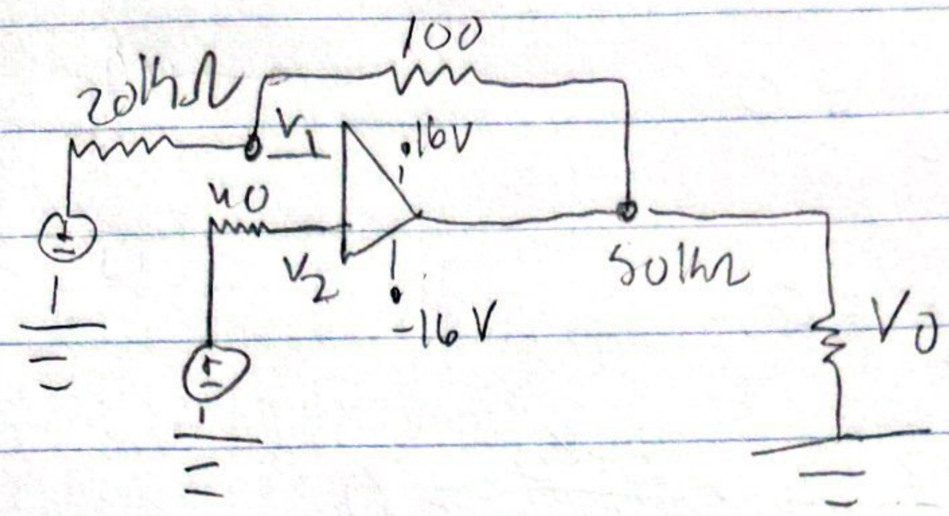
5.3




$V_o = (0.0005A)(10{,}000\Omega) = 5V$

so, $i_c = \frac{5V}{5000\Omega} = \boxed{1mA}$

5.4




$V_1 = V_2$

$V_1 = \left(\frac{V_a - V_1}{20} = \frac{V_1 - V_o}{100}\right)100$

$\Rightarrow 5V_a - 5V_1 = V_1 - V_o$

$V_o = 6V_1 - 5V_a$

$V_2 \left[\frac{V_b - V_2}{40} = 0\right] 40$

$\Rightarrow V_b - V_2 = 0 \quad V_b = V_2 = V_1$

$V_o = 6V_b - 5V_a$

a) $V_a = 4V, V_b = c$

$V_o = 6(0) - 5(4) = -16V$

$V_a = 2V \quad V_b = c$

b) $V_o = 6(0) - 5(2) = -10V$

$V_a = 2V, V_b = 1V$

c) $V_o = 6(1) - 5(2) = -4V$

d) $V_o = 6(2) - 5(1) = 7V$

e) $V_o \pm 16, V_b = 1.6V$

$-16 = (1.6)6 - 5(V_a) \Rightarrow V_a = 5.12$

$16 \quad (1.6)6 - 5(V_a) \Rightarrow V_a = -1.28$

$\boxed{-1.28 \le V_a \le 5.12}$

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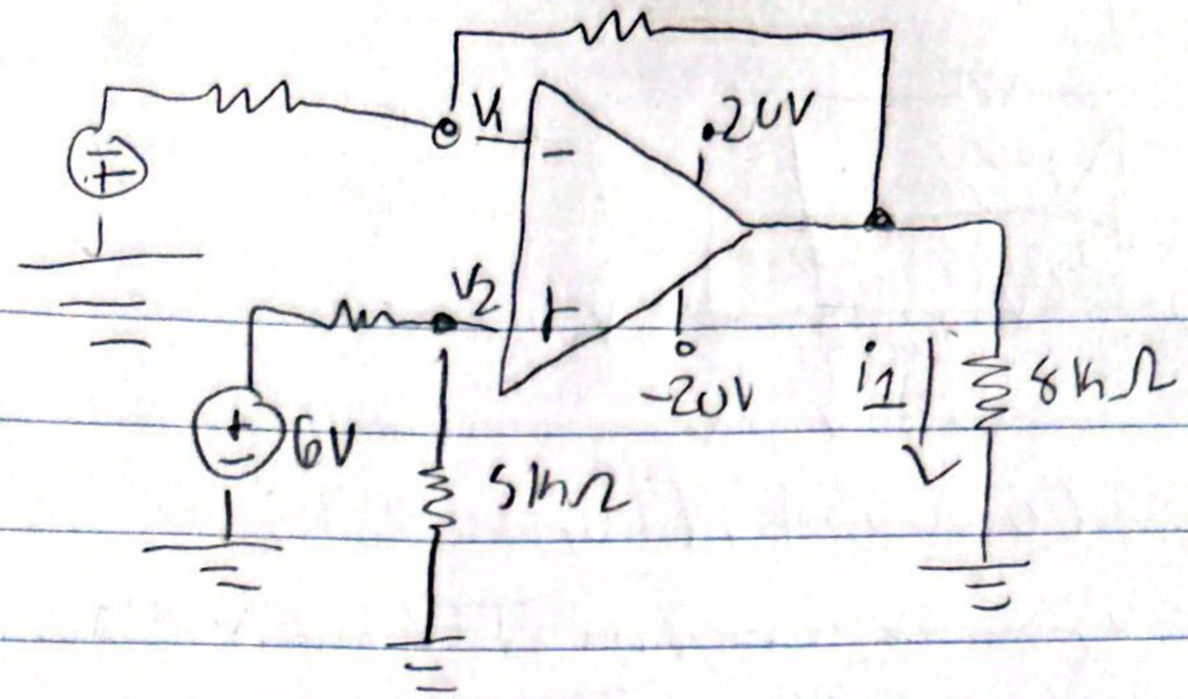
circuits
HW 3

5.6




$V_1: \frac{V-5}{3k\Omega} + \frac{V_1 - V_o}{6k\Omega} = 0$

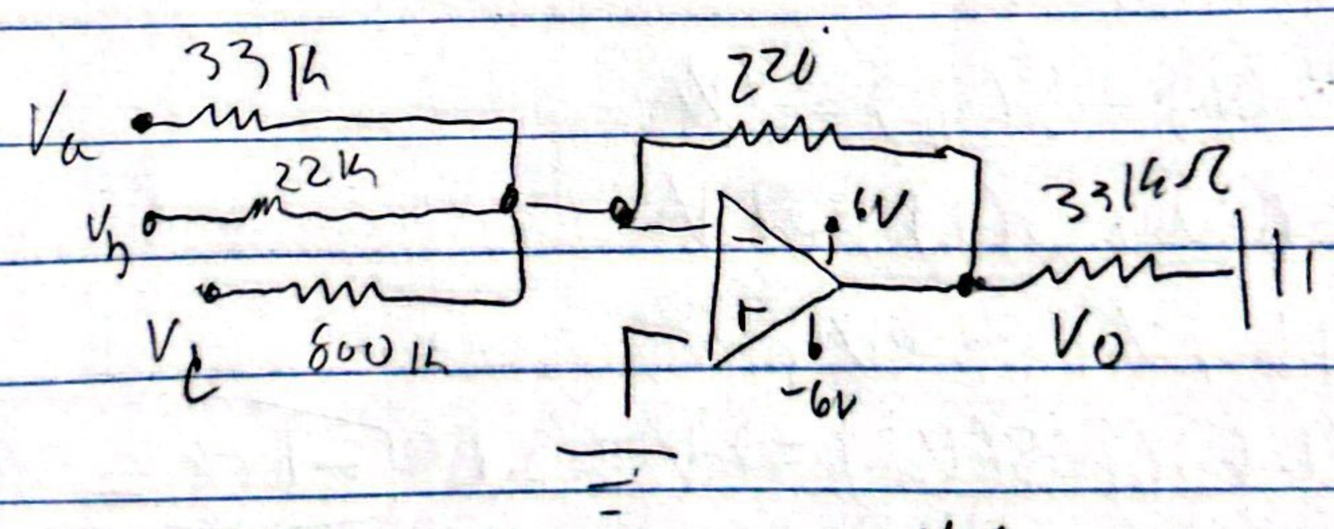
$V_2: \frac{V_2 - 6}{10k\Omega} + \frac{V_2}{3k\Omega} = 0$

$\Rightarrow V_2 = 2V \rightarrow \frac{2-5}{3k\Omega} + \frac{2-V_o}{6k\Omega} = 0$

$\frac{V_o}{6000} = -0.00060 > V_o = -4V$

$$\boxed{\begin{aligned} V_o &= 20 \cdot 4 = 16V \\ i_1 &= \frac{16}{8000} = 2mA \end{aligned}}$$

5.12




b) $V_a = 1.2V$ $V_b = -1.5V$, $V_c = 4V$

$V_o = \frac{220k\Omega}{33}(1.2) + \frac{220k\Omega}{2.2k\Omega}(1.5) - \frac{220k\Omega}{80k\Omega}(4) = -4V$

c) Let $V_b$ be unknown

$V_o = -8 + 10V_b - 11 \pm 6$

then, $\boxed{1.3 \le V_b \le 2.5}$

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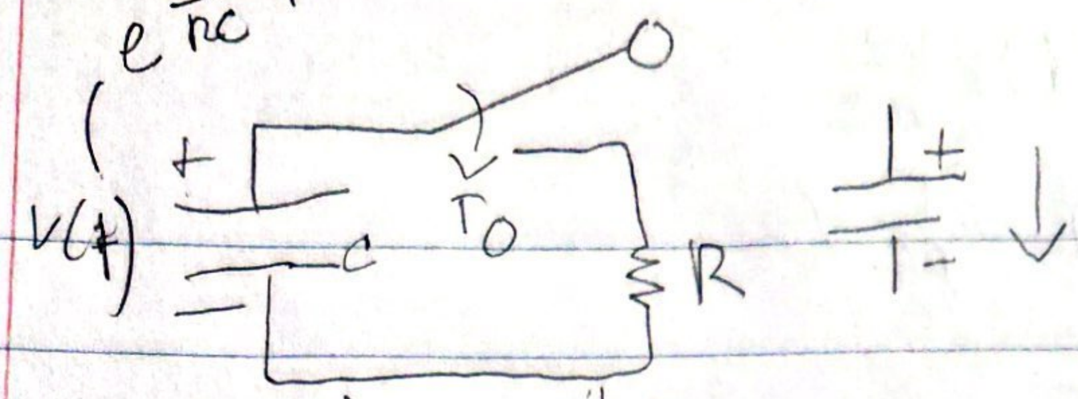
circuits lecture 10/21/2025

$e^{-\frac{1}{RC}t}$



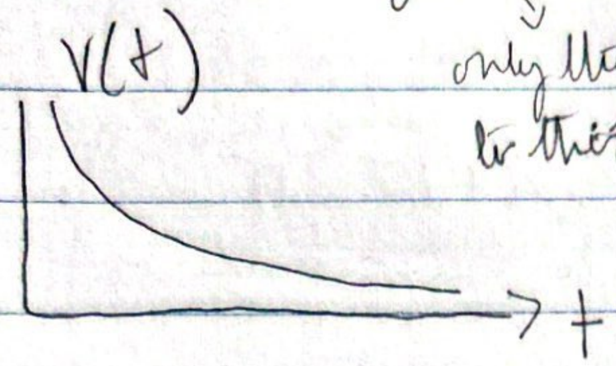

$i = C\frac{\partial v}{\partial t}$

$C\frac{\partial v}{\partial t} + \frac{V(t)}{R} = 0$

$\frac{\partial v}{\partial t} = \frac{-1}{RC}V(t)$

$V(t) = V_0 e^{-\frac{1}{RC}t}$

only the solution to this one circuit




$V(t) = e^{t}$

$\frac{d}{dt}V(t) = Se^{st} = SV(t)$ $\quad \frac{\partial}{\partial t}V(t) = Se^{st} = SV(t)$

$V(t) = e^{-\frac{1}{RC}t}$

$V(t) = \pi e^{-\frac{1}{RC}t}$

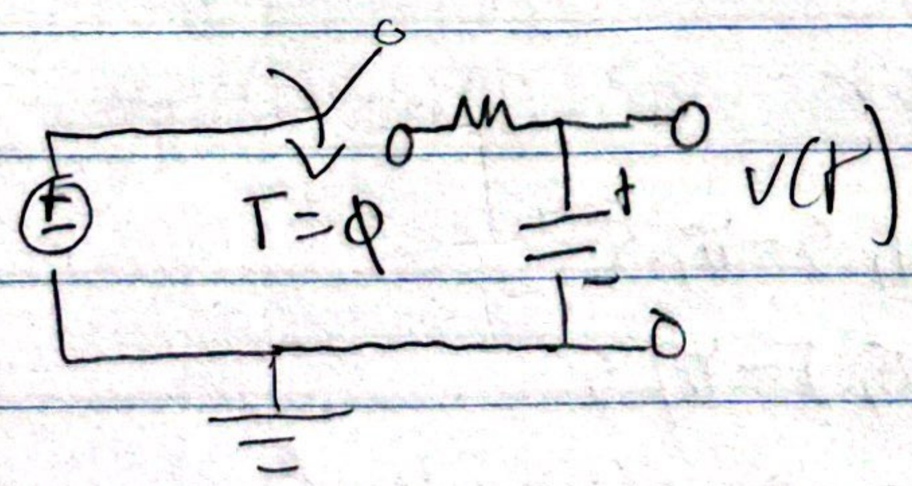
$\frac{\partial}{\partial t}V(t) = \pi\frac{-1}{RC}e^{-\frac{1}{RC}t} = \frac{-1}{RC}\underbrace{\pi e^{-\frac{1}{RC}t}}_{V(t)} = -\frac{1}{RC}V(t)$

$RC = \tau$

Time constant

$\tau = \tau$ when $e^{t/\tau} = 1$ $\quad V_0 e^{-\frac{1}{RC}t} = V_0 - \frac{t}{\tau}$ $\quad V(\tau) = V_0 e^{-\frac{\tau}{\tau}}$

$V(\tau) = 0.386$




$\frac{V(t) - V_s}{R} + C\frac{\partial V}{\partial t} = 0$

$\frac{V(t)}{R} - \frac{V_s}{R} + C\frac{\partial V}{\partial t} = 0$

$\frac{\partial V}{\partial t} = \frac{V_s}{RC} - \frac{V(t)}{RC} = \frac{-1}{RC}V(t) + V_s/RC$

$\frac{\partial}{\partial t}V(t) = -SV(t) + S\pi \Rightarrow V(t) = \pi e^{st}$

$\frac{d}{dt}(\pi e^{st}) = Se^{st} = SV(t) - S\pi$

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circuits lecture
10/22/2025

$$\frac{\partial V}{\partial t} = \frac{V_s}{RC} - \frac{V(t)}{RC} = -\frac{1}{RC}V(t) + \frac{V_s}{RC}$$

$$\frac{\partial}{\partial t}V(t) = -\frac{1}{RC}V(t) - \frac{-1}{RC}V_s$$

$$S = -1/RC$$

$$\pi = V_s$$

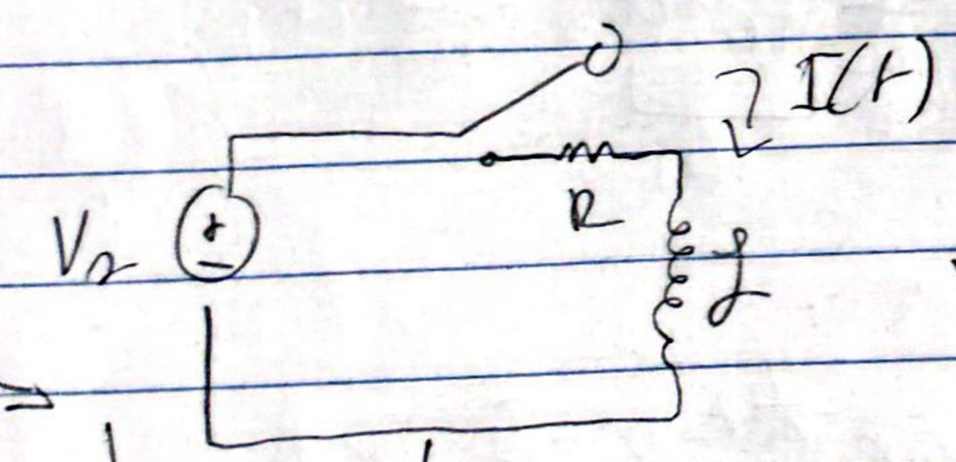
$$\frac{\partial}{\partial t}(\pi + \pi_2 e^{st}) = \pi_2 S e^{st} = \pi_2 S V(t) - S\pi$$

$$= S e^{st} + S\pi - S\pi$$

$$= S(e^{st} + \pi) - S\pi = SV(t) - S\pi$$

$$\frac{\partial}{\partial t}V(t) = \frac{\partial}{\partial t}\left(V_s + \pi e^{-\frac{1}{RC}t}\right)$$

$$= \pi \frac{-1}{RC} e^{-\frac{1}{RC}t} = \pi \frac{-1}{RC} V(t)$$

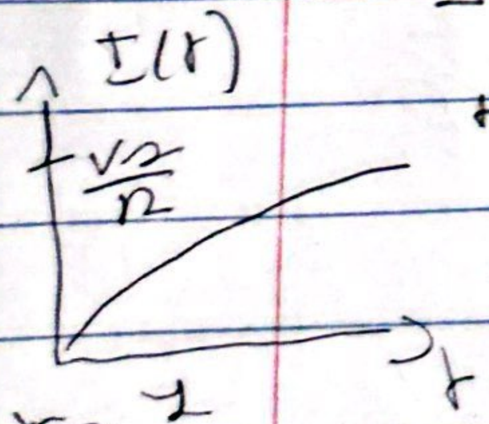



$$V(t) = L\frac{\partial i(t)}{\partial t}$$

$$RI(t) + L\frac{\partial I(t)}{\partial t} - V_s = \phi$$

$$\frac{\partial I(t)}{\partial t} = \frac{V_s}{L} - \frac{RI(t)}{L}$$

$$-\frac{1}{RC} \to \frac{R}{L}$$




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

$$i(t) = \pi_1 + \pi_2 e^{st}$$

$$\frac{\partial I(t)}{\partial t} = \phi + \pi_2 S e^{st}$$

$$= \pi_2 S e^{st} + \pi_1 S - \pi_1 S$$

$$= S(\pi_2 e^{st} + \pi_1) - \pi_1 S$$

$$= S i(t) - S\pi_1 = -\frac{R}{L} i(t) + V_s \frac{R}{L}$$

$$S = -R/L \to S\pi_1 = V_s/L$$

$$= -\frac{R}{L} i(t) + S\pi_1 = \frac{-R}{L}(I(t)) + \frac{V_s}{L}$$

$$-\frac{R}{L}\pi_1 = \frac{V_s}{L} \quad -\frac{R}{L}\frac{V_s}{R}$$

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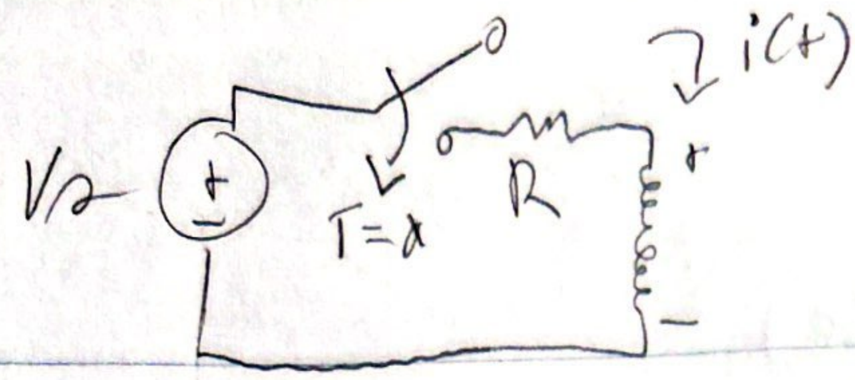
Circuits
Lecture
10/23/25




$$Ri(t) + L\frac{\partial i(t)}{\partial t} - V_s = 0$$

$$\frac{\partial i(t)}{\partial t} = \frac{V_s}{L} - \frac{Ri(t)}{L}$$

$$i(t) = \pi_1 + \pi_2 e^{st}$$

$$\frac{\partial i(t)}{\partial t} = 0 + s\pi_2 e^{st}$$
$$= \pi_2 s e^{st} + s\pi_1 - s\pi_1$$
$$= s(\pi_2 e^{st} + \pi_1) - s\pi_1$$
$$= s\,i(t) - s\pi_1$$

$$\frac{\partial i(t)}{\partial t} = \frac{V_s}{L} + s\,i(t)$$

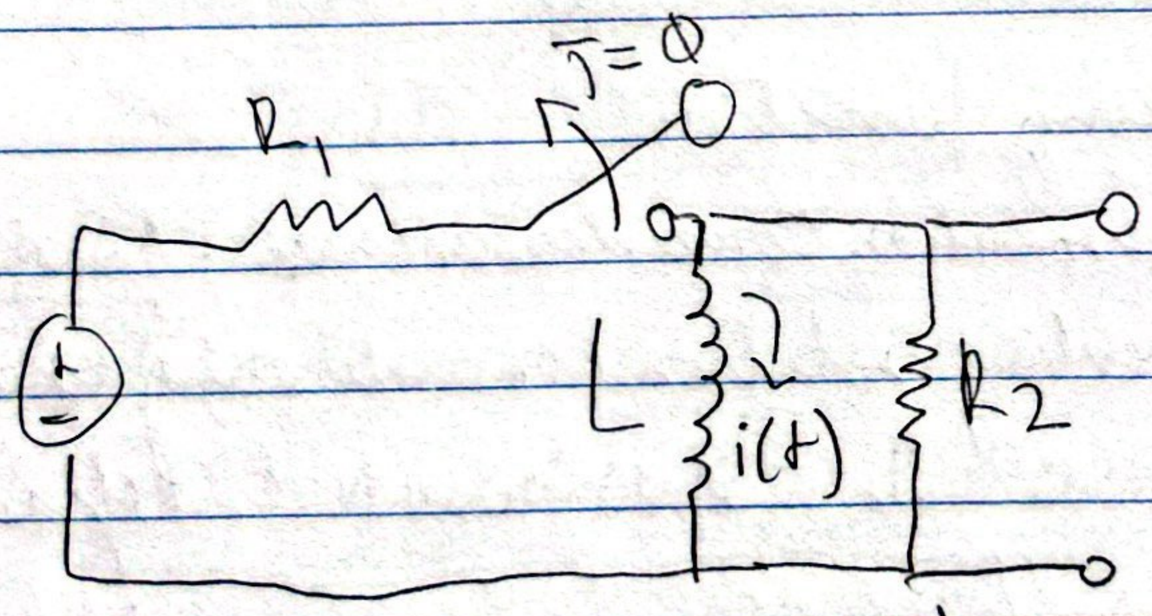
$$s = -R/L$$

$$\frac{V_s}{L} = -s\pi_1 = \frac{-R}{L}\pi_1 = \frac{V_s}{L}$$

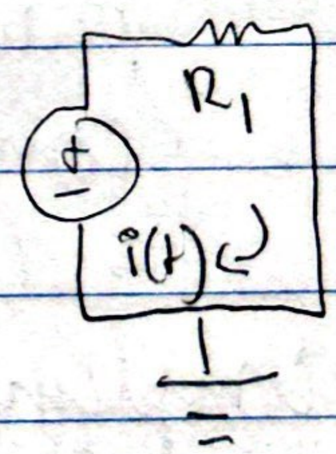
$$\Rightarrow \pi_1 = \frac{-V_s}{L}\cdot\frac{L}{R} = \frac{-V_s}{R}$$

$$i(t) = \frac{V_s}{R} + \pi_2 e^{-\frac{R}{L}T}$$

ex 1:




$T \leq 0$



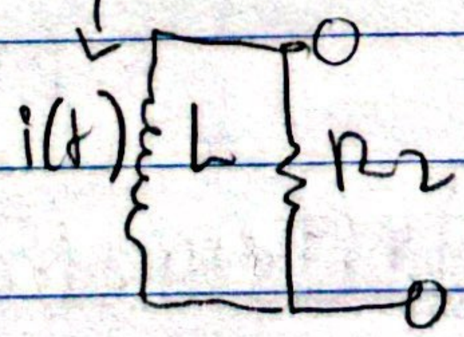

$$i(t) = \frac{V_s}{R_1}$$

$$V(t) = 0$$

$T \geq 0$

have from the math

$$i(t) = \pi_1 + \pi_2 e^{st}$$
$$\frac{\partial}{\partial t} i(t) = s\,i(t) - s\pi_1$$




$$v(t) = -R_2 i(t) = \frac{-R_2}{R_1} V_s e^{\frac{R_2}{L}T}$$

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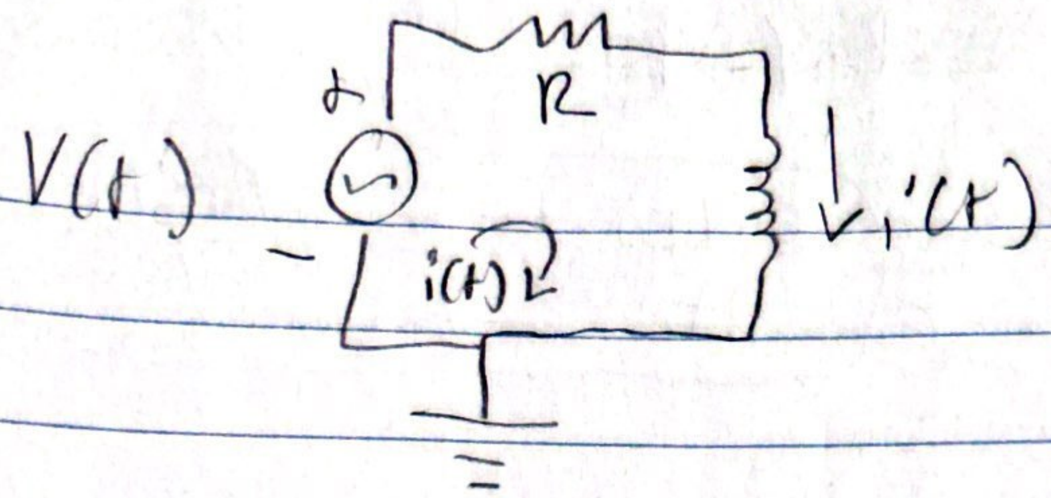



$$-V(t) + i(t)\cdot R + L\frac{di(t)}{dt} = 0$$

$$\frac{L}{R}\frac{di(t)}{dt} + i(t) = \frac{V(t)}{R}$$ ← forcing function

$$\tau\frac{d}{dt}i(t) + i(t) = \frac{V(t)}{R}$$

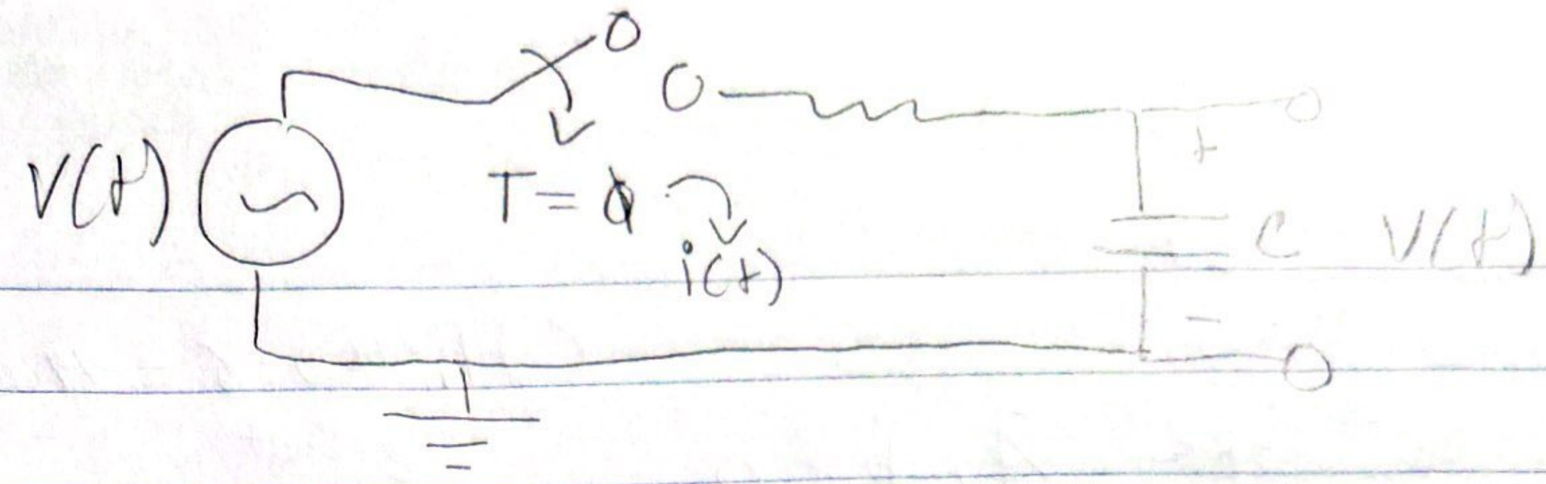
$\frac{V(t)}{R}$ – forcing function

$\frac{V(t)}{R}$ forcing function

particular solution considers source

complementary solution considers only energy stored before starter

complementary




assume $V(t) = 2\sin(wt)$

want $i(t) = i_p(t) + i_{c_1}(t)$

step 1: solve KCL or KVL

$$-V(t) + i(t)R + \frac{1}{C}\int i(t)\,dt + V_C(0) = 0$$

$$i(t)R + \frac{1}{C}\int i(t)\,dt + V_C(0) = V(t)$$ plugin $V(t) = 2\sin(wt)$

$$R\frac{di(t)}{dt} + \frac{1}{C}i(t) = \frac{dV(t)}{dt}$$ $\frac{d}{dx} = 2w\cos(vt)$

$$R\frac{di(t)}{dt} + \frac{1}{C}i(t) = 2w\cos(vt)$$

$$RC\frac{di(t)}{dt} + i(t) = 2w\cos(wt)$$

step 2: guess

$$i_p(t) = A\cos(wt) + B\sin(wt)$$

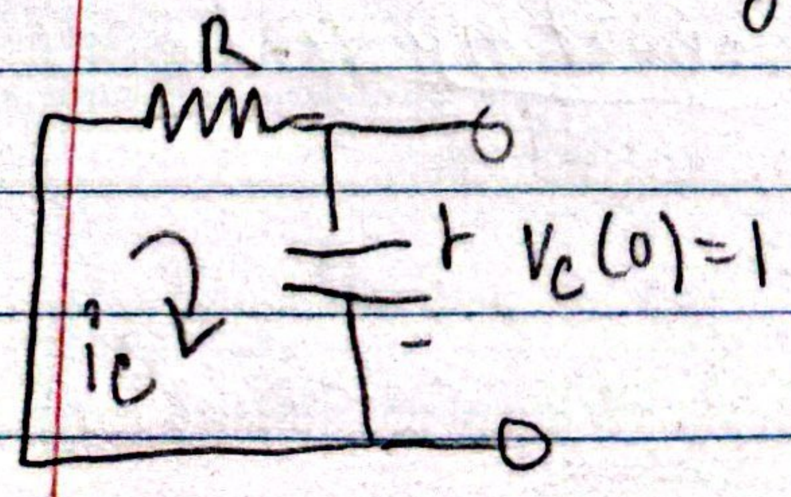
$$\frac{di_p(t)}{dt} = Aw\sin(wt) + Bw\cos(wt)$$

$$A = \frac{2wc}{R^2c^2v^2+1}\ ;\ B = \frac{2R^2c^2w^2}{R^2c^2w^2+1}$$

$$i_p(t) = -\left(\frac{2wc}{R^2c^2w^2+1}\right)\cos(wt) + \left(\frac{2R^2c^2w^2}{R^2c^2w^2+1}\right)\sin(wt)$$

step 3:

$$i_c(t) = r_1 e^{-t/RC} = RC\frac{di_c(t)}{dt} + i(t) = 0$$




$$i(t) = \frac{2wc}{R^2c^2v^2+1} = r_1 = \frac{-1}{R}$$

$$r_1 = \frac{-1}{R} - (A)$$

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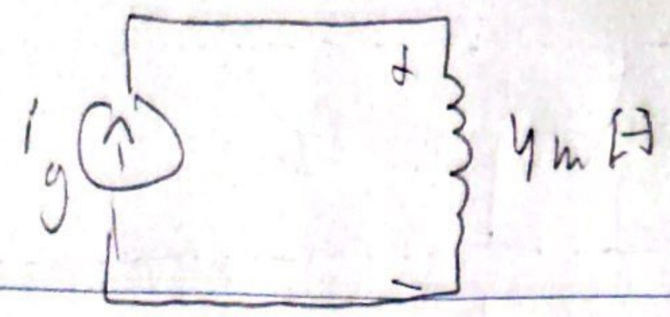
circuits HW3

6.1




$i_g(t) = 0 \quad t < 0$

$i_g(t) = 8e^{-300t} - 8e^{-1200t}$ A, $t \geq 0$

$L = 34\,mH = 0.034\,mH$

a) $v(t) = L\frac{di}{dt}$

$i(t) = 8e^{-300t} - 4e^{-1200t}$

$\frac{di}{dt} = -8 \times 300e^{-300t} + 8 \times 1200e^{-1200t}$

at $t = 0$ both exp $e^0 = 1$

$\frac{di}{dt}|t=0 = -2400 + 9600 = 7200$

$V(0) = 0.034 \times 7200 = 244.8V$

b) $v(t) = 0$: $-8 \times 300e^{-300t} + 8 \times 1200e^{-1200t} = 0$

$-300e^{-300t} = -1200e^{-1200t}$

$e^{-300t} = 4e^{-1200t}$

$t = \frac{\ln 4}{900} \approx \frac{1.386}{900} \approx 0.00154\,s = 1.54\,ms$

c) $p(t) = v(t) \cdot i(t)$

$-v(t) = L\frac{di}{dt}$, $i(t)$ $\frac{di}{dt} = -8 \times 300e^{-300t} + 8 \times 1200e^{-1200t}$

$p(t) = 0.034[-2400e^{-300t} + 9600e^{-1200t}] \cdot [8e^{-300t} - 8e^{-1200t}]$

$p(t) = 0.034[-192\,00e^{-600t} + 96000e^{-1500t} - 76800e^{-2400t}]$

$p(t) = -652.8e^{-600t} + 3264e^{-1500t} - 2611.2e^{-2400t}$

$\boxed{= -76.8e^{-600t} + 384e^{-1500t} - 307.2e^{-2400t}\,W}$

d) $p(t) = dp/dt$

e)

f) $w(t) = \frac{1}{2}L[i(t)]^2 \quad t = 1.54\,ms = \boxed{28.57\,mJ}$

c) $1.\ 2400 \cdot 8 = -19200;\ e^{-300t} \cdot e^{-300t}$

$e^{-600t}$

$2.\ -2400 \cdot -8 = 19200;\ e^{-300t} \cdot e^{-1200t}$

$e^{-1500t}$

$3.\ 9600 \cdot 8 = 76800;\ e^{-1200t} \cdot e^{-1200t}$

$e^{-1500t}$

$e^{-2400t}$

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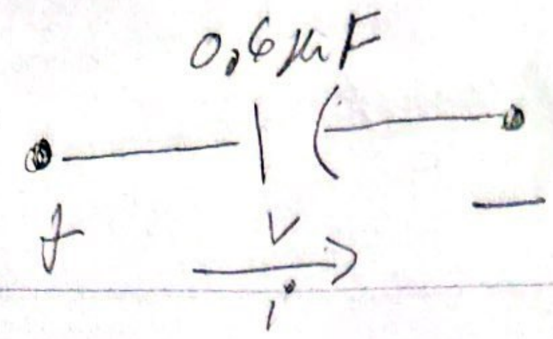
circuits HW3

6.2




$C = 0.6\mu F = 0.6e^{-6}F$

$(v(t))\ t \geq 0$:

$v(t) = 40e^{-15{,}000t}\sin(30{,}000t)$

for $t < 0$, $v(t) = 0$

a) $i(0)$

$i(t) = C\frac{dv(t)}{dt}$ $\frac{dv}{dt}$

$v(t) = 40e^{-15{,}000t}\sin(30{,}000t)$

$\frac{dv(t)}{dv} = 40\frac{d}{dt}[e^{-15000t}]\sin(30{,}000t) + 40e^{-15000t}\frac{d}{dt}[\sin 30{,}000t]$

$= 40\cdot(-15{,}000)e^{-15{,}000t}\sin(30{,}000t) + 40e^{-15000t}\cdot 30{,}000\cos(30{,}000t)$

$= -600{,}000e^{-15000t}\sin(30{,}000t) + 1{,}200{,}000e^{-15000t}\cos(30{,}000t)$

$t = 0$

$e^0 = 1$ $\sin(0) = 0$, $\cos(0) = 1$

$\frac{dv}{dt}\Big|_{t=0} = -600{,}000(1)(0) + 1{,}200{,}000(1)(1) = 1{,}200{,}000$

$i(0) = C\frac{dv}{dt}\Big|_{t=0} = 0.6e^{-6}\times 1{,}200{,}000 = 0.6\times 1.2 = \boxed{0.72A}$

b) $t = \pi/80$ ms

$v(t)$ $i(t)$ at $t_0 = \pi/80\ e^{-3}$

$t_0 = \frac{\pi}{80\cdot 10^3} = \frac{\pi}{80{,}000} \simeq 3.927e^{-5}$

$V_0 = v(t_0) = 40e^{-15000t_0}\sin(30{,}000t_0)$

$i_0 = i(t_0) = C\frac{dv}{dt}\Big|_{t=t_0}$

$30{,}000t_0 = 30{,}000\cdot 3.927e^{-5} = 1.1781\,rad = 67.5°$

$15{,}000t_0 = 15000\cdot 3.927e^{-5} = 0.5890s$

$e^{-0.5890s} \simeq 0.554$ $\sin(1.1781) = 0.924$ $\cos(1.1781) = 0.383$

$V_0 = 40\times 0.554\times 0.924 \simeq 20.47$

$i(t_0) = C[-600{,}000e^{-15{,}000t_0}\sin(30{,}000t_0) + 1{,}200{,}000e^{-15000t_0}\cos(30{,}000t_0)]$

$i_0 = 0.6e^{-6}\times(-52{,}359) = -0.0314A$

c) $t = \pi/40$ ms $w(t) = \frac{1}{2}Cv^2(t)$

$= \frac{1}{2}(0.6e^{-6})\times(20.47)^2 \simeq 0.3e^{-6}\times 419.1 \simeq 0.1257e^{-3}J$

$\boxed{= 126\mu J}$

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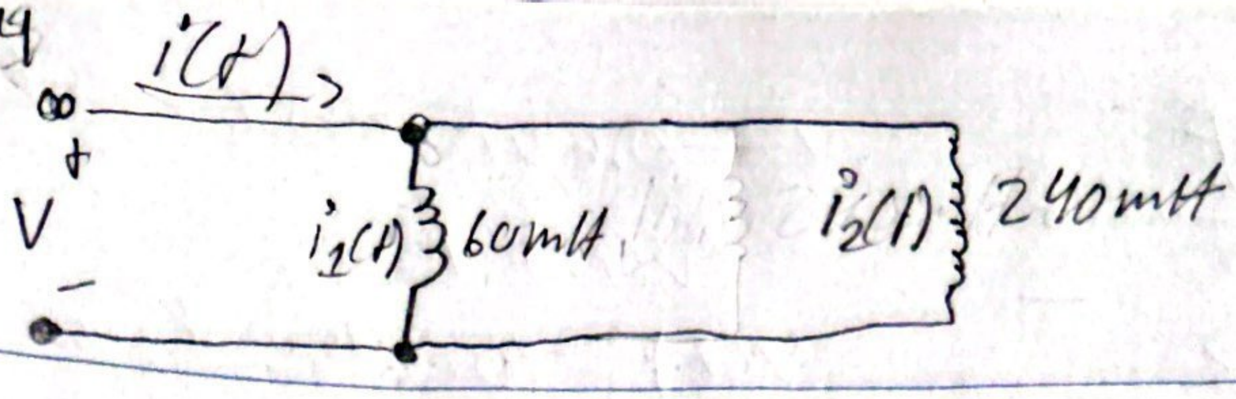
Circuits
HW4

6.4




$L_1$: 60mH = 0.060H

$L_2$: 240mH = 0.240H

$v(t) = -30e^{-5t}\,mV = -0.030e^{-5t}\,V$ for $t \geq 0$

Initial currents $i_1(0) = +3A$ $i_2(0) = -5A$

a) $\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} = \frac{1}{L_{eq}} = \frac{1}{0.060} + \frac{1}{0.240} = \frac{1}{0.060} + \frac{1}{0.240}$

$\frac{1}{L_{eq}} = 16.6667 + 4.1667 = 20.8333$

$L_{eq} = \frac{1}{20.833} = 0.048H = \boxed{48mH}$

b) $L_{eq}$: $i(0) = i_1(0) + i_2(0) = 3 + (-5) = \boxed{-2A}$

c) $V(t) = L_{eq}\frac{di}{dt}$ $\frac{di}{dt} = \frac{v(t)}{L_{eq}} = \frac{-0.030e^{-5t}}{0.048}$

$\frac{di}{dt} = -0.625e^{-5t}$ $di = -0.625e^{-5t}dt$

$i(t) - i(0) = \int_0^t -0.625e^{-5t}dt$

$\int -0.625e^{-5t}dt = -0.625 \cdot \frac{e^{-5t}}{-5} = 0.125e^{-5t}$

so, $i(t) - i(0) = 0.125[e^{-5t} - 1]$

$i(t) = i(0) + 0.125[e^{-5t} - 1]$

$i(0) = -2$ $i(t) = -2 + 0.125[e^{-5t} - 1] = \boxed{0.125e^{-5t} - 2.125}$

d) $v(t) = L_1\frac{di_1}{dt} = -0.030e^{-5t} = 0.060\frac{di_1}{dt} = \frac{di_1}{dt} = \frac{-0.030e^{-5t}}{0.060}$

$di_1 = -0.5e^{-5t}dt = i_1(t) - i_1(0) = \int_0^t -0.5e^{-5t}dt = -0.5 \cdot \frac{e^{-5t}}{-5}$

$i_1(t) = i_1(0) + 0.1[e^{-5t} - 1] = 3 + 0.1[e^{-5t} - 1] = 0.1e^{-5t} + 2.9$

$\frac{di_2}{dt} = -0.030e^{-5t}/0.240 = -0.125e^{-5t}$

$i_2(t) - i_2(0) = \int_0^t -0.125e^{-5t}dt = 0.025e^{-5t}$

$\boxed{i_1(t) = 0.1e^{-5t} + 2.9 \quad i_2(t) = 0.025e^{-5t} - 5.025}$

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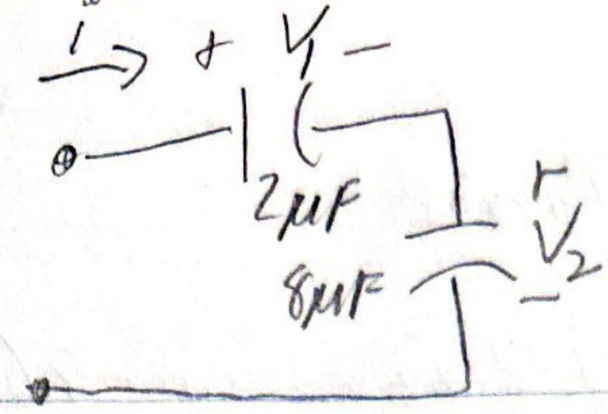
Problem 4

6.5




$i(t) = 240e^{-10t}\ \mu A$ for $t \geq 0$

$C_1 = 2\mu F$ $C_2 = 8\mu F$

$V_1(0) = 10V$, $V_2(0) = -5V$

$t \to \infty$ $E_{total} = E_1 + E_2$

$E = \frac{1}{2}C[V(\infty)^2 - V(0)^2]$

$Q(t) = \int_0^\infty i(t)dt$ $Q = \int_0^\infty 240e^{-10t}\mu A\,dt = 240\int_0^\infty e^{-10t}dt\,\mu A$

$240\mu A = 240e^{-6}A$ $\int e^{-at}dt = \frac{-1}{a}e^{at}$

$\int_0^\infty e^{-10t}dt = \left[\frac{-1}{10}e^{-10t}\right]_0^\infty = \frac{1}{10}$

$Q = 240e^{-6} \times \frac{1}{10} = 24e^{-6}C$

$V_1(\infty) = V_1(0) + Q/C_1$, $V_2(\infty) = V_2(0) = Q/C_2$

$10 + \frac{24e^{-6}}{2e^{-6}} = 10 + 12 = \boxed{22V}$ $-5 + \frac{24e^{-6}}{8e^{-6}} = -5 + 3 = \boxed{-2V}$

$E_1 = \frac{1}{2} \cdot 2 \times e^{-6}[22^2 - 10^2] = 1e^{-6}[484 - 100] = 0$

$E_2 = \frac{1}{2} \cdot 8e^{-6}[(-2)^2 - (-5)^2] = 4e^{-6}[4 - 25] = \boxed{-84e^{-6}}$

$E_{total} = E_1 + E_2 = 384\mu J + (-84\mu J) = 300\mu J$

$E = \frac{1}{2}C(V(\infty)^2)$ $E_i = \frac{1}{2}C_1[V_1(0)^2] + \frac{1}{2}C_2[V_2(0)^2]$

$E_{trapped} = E_{final} - E_{initial}$

$E_{initial,1} = \frac{1}{2} \cdot 2e^{-6} \cdot (10^2) = 1e^{-6} \cdot 100 = 100e^{-6}$

$E_{initial,2} = \frac{1}{2} \cdot 8e^{-6} \cdot (5^2) = 4e^{-6} \cdot 25 = 100 \times 10^{-6}$

$E_{init,total} = 200\mu J$

$E_{final,1} = \frac{1}{2} \cdot 2e^{-6} \cdot (22^2) = 1e^{-6} \cdot 484 = 484e^{-6}$

$E_{final,2} = \frac{1}{2} \cdot 8e^{-6} \cdot (2^2) = 4e^{-6} \cdot 4 = 16e^{-6}$

$\Big\}\ 500e^{-6}$

$E_{trapped} = \frac{C_1 \cdot C_2}{C_1 + C_2}[V_1(0) - V_2(0)]^2 = \frac{2 \times 8}{2+8}\mu F \times (10 - (-5))^2 = \frac{16}{10}\mu F \cdot 15$

$= 1.6 \times 225 = \boxed{360\mu J}$

$E_{final} = \frac{1}{2}\frac{C_1 \cdot C_2}{C_1 + C_2}[V_1(0) - V_2(0)]^2 = \frac{1}{2} \cdot 1.6 \cdot 225 = \boxed{180\mu J}$

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circuits
qtw4

6.6 $L_1 \frac{di_1}{dt} + R_1 i_1 + M\frac{di_2}{dt} - R_m i_2$

1) $4\left(\frac{di_1}{dt}\right) + 25i_1 + 8\left(\frac{di_2}{dt}\right) - 20i_2 = -5i_g - 8\left(\frac{di_g}{dt}\right)$

2) $8\left(\frac{di_1}{dt}\right) - 20i_1 + 16\left(\frac{di_2}{dt}\right) + 800i_2 = -16\left(\frac{di_g}{dt}\right)$

$i_g(t) = 1.96 - 1.96e^{-4t}$ A

$i_1(t) = -0.4 - 11.6e^{-4t} + 12e^{-5t}$ A

$i_2(t) = -0.01 - 0.99e^{-4t} + e^{-5t}$ A

$\frac{di_1}{dt}$ $(-11.6)(-4)e^{-4t} + 12(-5)e^{-5t} = 46.4e^{-4t} - 60e^{-5t}$

$\frac{di_2}{dt}$ $(-0.99)(-4)e^{-4t} + 1(-5)e^{-5t} = 3.96e^{-4t} - 5e^{-5t}$

$\frac{di_g}{dt} = 1.96(-4)e^{-4t} = 7.84e^{-4t}$

1) $185.6e^{-4t} - 290e^{-4t} + 31.68e^{-4t} + 19.8e^{-4t}$

$= (-53.9e^{-5t})$

$-240e^{-5t} + 300e^{-5t} - 40e^{-5t} - 20e^{-5t} = (300 - 240 - 20)e$

$= 0e^{-5t}$

Constants $-10 + 0.2 = -9.8$ left side $(-53.92)e^{-4t} - 9.8$

Right side: $-5i_g - 8\frac{di_g}{dt}$ $-5i_g = -5(1.96 - 1.96e^{-4t}) = -9.8 + 9.8e$

$-8\frac{di_g}{dt} = -8 \times 7.84e^{-4t} = \boxed{62.72e^{-4t}}$

total: $-9.8 + 9.8e^{-4t} - 62.72e^{-4t} = \boxed{-9.8 - 52.92e^{-4t}}$

2) $371.2 + 2324 + 63.36 - 792 = (371.2 + 2324 + 63.36 - 792)$

$= -125.44e^{-5t}$

$-480 - 240 - 80 + 800 = 0e^{-5t}$ $8 - 8 = 0$

left side $\boxed{-125.44e^{-4t}}$

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6.1 the current in a 50μH inductor is known to be

$i_L = 18te^{-10t}$ A for $t \geq 0$

$L = 50\mu H = 50e^{-6} H$

$i_L = 18te^{-10t}$ A, $t \geq 0$

A) $V_L(t) = L\frac{di_L}{dt}$ $\quad \frac{di_L}{dt} = \frac{d}{dt}[18t \cdot e^{-10t}] = 18e^{-10t} + 18t \cdot (-10)e$

$= 18e^{-10t} - 18te^{-10t}$

$V_L(t) = 50e^{-6}[18e^{-10t} - 180te^{-10t}]$

$= (0.0009)e^{-10t} - (0.009)te^{-10t}$ [V]

$V_L(t) = 0.9e^{-10t} - 9te^{-10t}$ mV $= 0.9e^{-10t}(1-10t)$ mV

B) $t = 200ms = 0.2s \rightarrow p(t) = V_L(t) \cdot i_L(t)$

$e^{-10t} = e^{-2} = 0.1353$

$i_L(0.2) = 18 \cdot 0.2 \cdot 0.1353 = 0.4869A$

$V_L(0.2) = 0.9 \cdot 0.1353 \cdot (1-2) = 0.9 \cdot 0.1353(-1) = \boxed{0.1218}$

$p(0.2) = (-0.0001218) \cdot (0.4869) = \boxed{-59.34\mu W}$

d) $t = 0.2s$ $\quad W_L = \frac{1}{2}Li_L^2$

$W_L = \frac{1}{2} \cdot 50e^{-6} \cdot (0.4869)^2 = 0.2371$

$= 25e^{-6} \cdot 0.2371 \approx 5.93e^{-6} = \boxed{5.93\mu J}$

e) $\frac{di_L}{dt} = 0$ $\quad \frac{di_L}{dt} = 18e^{-10t} - 180te^{-10t} = e^{-10t}(18 - 180t)$

$18 - 180t = 0 \Rightarrow t = 0.1s = 100ms$

$i_L(0.1) = 18 \times 0.1 \times e^{-1} = 0.6622A$

$W_L = \frac{1}{2} \times 50e^{-6} \times (0.6622)^2 = \boxed{10.96\mu J}$

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Circuits HW

6.13 The voltage across a 5μF capacitor is known to be

$V_c = 500te^{-2500t}$ V for $t \geq 0$

$C = 5\mu F = 5e^{-6}$ F

$V_c(t) = 500te^{-2500t}$ V, $t \geq 0$

a) $i_c(t) = C\frac{dV_c}{dt}$

$\frac{dV_c}{dt} = \frac{d}{dt}(500te^{-2500t}) = 500e^{-2500t} + 500t \cdot (-2500)e^{-2500t}$

$= \boxed{500e^{-2500t} - 1{,}250{,}000te^{-2500t}}$

$i_c(t) = 5e^{-6}[500e^{-2500t} - 1{,}250{,}000te^{-2500t}]$

$= (2.5e^{-3})e^{-2500t} - (6.25e^{-3})te^{-2500t}$ A

$= \boxed{2.5e^{-3}e^{-2500t}(1 - 2500t)\text{ A}}$

b) $p(t) = V_c(t) \cdot i_c(t)$

$t = 100e^{-6} = 0.0001$ s $\quad e^{-2500t} = e^{-0.25} = 0.7788$

$V_c(0.0001) = 500 \times 0.0001 \times 0.7788 = 0.03894$ V

$i_c(0.0001) = 2.5e^{-3} \times 0.7788 \times (1 - 2500 \times 0.0001) = 0.25$

$1 - 0.25 = 0.75$

$i_c(0.0001) = 2.5e^{-3} \cdot 0.7788 \cdot 0.75 = 0.00146$ A

$p(0.0001) = 0.03894 \cdot 0.00146 = 0.0000569$ W $= \boxed{56.9\mu W}$

d) $W_c = \frac{1}{2}C V_c^2(t)$ $\quad W_c = 0.5 \times 5e^{-6}(0.03894)^2 = \boxed{3.79\text{ nJ}}$

e) $\frac{dV_c}{dt} = 500e^{-2500t} - 1{,}250{,}000te^{-2500t} = e^{-2500t}(500 - 1{,}250{,}000t)$

$500 - 1{,}250{,}000t = 0 \Rightarrow t = \frac{500}{1{,}250{,}000} = 0.0004$ s $= 400\mu s$

$V_c(0.0004) = 500 \times 0.0004 \times e^{-2500 \times 0.0004} =$

$500 \times 0.0004 \times e^{-1} = 0.2 \times 0.3679 = 0.07358$

$W_{c,max} = 0.5 \times 5 \times 10^{-6} \times (0.07358)^2$

$= 13.53 \times 10^{-9}$ J $= \boxed{13.53\text{ nJ}}$

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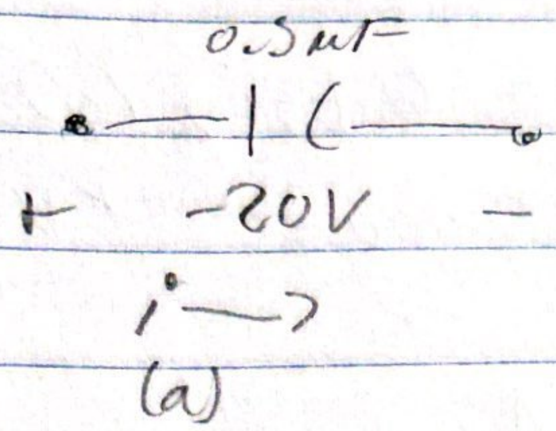
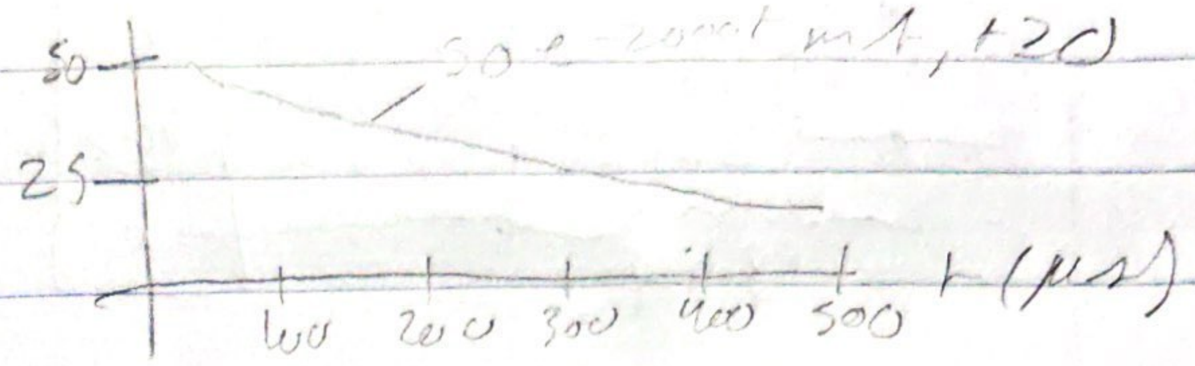
The initial voltage on the 0.5μF capacitor is −20V the capacitor current has the waveform shown in the figure




$C = 0.5\mu F = 0.5e^{-6} F$

$V(0) = -20V$

$i(t) = 50e^{-2000t}$ mA

time for a: $t_1 = 500\mu s = 500e^{-6} = 0.0005s$

$$i_c(t) = C\frac{dv_c}{dt} \Rightarrow \frac{dv_c}{dt} = \frac{i_c(t)}{C}$$

$$V_c(t) = V_c(0) + \frac{1}{C}\int_0^t i_c(\tau)\,d\tau$$

$$i_c(t) = 50e^{-2000t}\text{ mA} = 0.05e^{-2000t}\text{ A}$$

$$V_c(t) = -20 + \frac{1}{0.5e^{-6}}\int_0^t 0.05e^{-2000\tau}\,d\tau$$

$$\int_0^t e^{-2000\tau}\,d\tau = \left[\frac{-1}{2000}e^{-2000\tau}\right]_0^t = \frac{-1}{2000}(e^{-2000t} - 1)$$

$$\int_0^t 0.05e^{-2000\tau}\,d\tau = 0.05 \times \frac{1}{2000}(e^{-2000t} - 1) = -0.000025(e^{-2000t}$$

$$\frac{1}{0.5e^{-6}} \times -0.000025 = \frac{-0.000025}{0.5e^{-6}} = 50(e^{-2000t} - 1)$$

$$V_c(t) = -20 - 50e^{-2000t} + 50 = 30 - 50e^{-2000t}$$

a) $V_c(0.0005) = 30 \times e^{-1} = 11.605V$

$$W_c = \frac{1}{2}C[V_c(t)]^2$$

$$W_c = 0.5 \times 0.5e^{-6} \times (11.605)^2 = 0.25e^{-6} \times 134.71 = \boxed{33.7\mu J}$$

b) $t \to \infty$, $e^{-2000t} \to 0$

$$V_c(\infty) = 30 - 0 = 30V$$

$$W_c = 0.5 \times 0.5 \times 10^{-6} \times (30)^2 = \boxed{225\mu J}$$

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circuits
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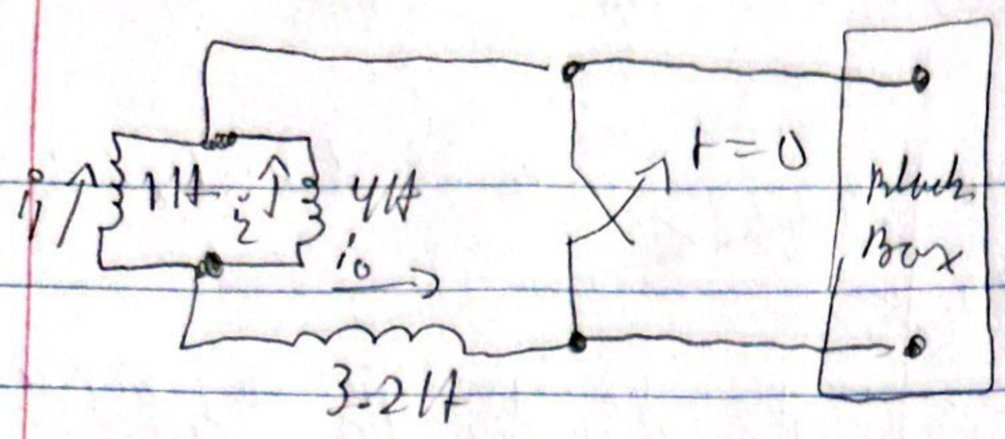


$L_1 = 1H$

$L_2 = 4H$

$L_3 = 3.2H$

$i_1(0) = -6A, \; i_2(0) = 1A$

$V_o(t) = 2000e^{-100t}V$ for $t \geq 0$

a) $i_o(0) = i_1(0) + i_2(0) = -6+1 = -5A$

b) $i_o(t), t \geq 0$

$\frac{1}{L_{eq}} = \frac{1}{1} + \frac{1}{4} + \frac{1}{3.2} = 1 + 0.25 + 0.3125 = 1.5625$

$L_{eq} = \frac{1}{1.5625} = 0.64H$

$V_o(t) = 2000e^{-100t}V$ $L_{eq}$

$\frac{di_o}{dt} = \frac{V_o(t)}{L_{eq}} = \frac{2000e^{-100t}}{0.64} = 3125e^{-100t}$

$di_o = 3125e^{-100t}dt \quad i_o(t) = i_o(0) + \int_0^t 3125e^{-100t}dt$

$\int_0^t e^{-100t}dt = \left[\frac{-1}{100}e^{-100t}\right]_0^t = \frac{-1}{100}(e^{-100t} - 1)$

$i_o(t) = -5 + 3125 \cdot \frac{-1}{100}(e^{-100t} - 1)$

$i_o(t) = -5 + 3125 \cdot \frac{-1}{100}(e^{-100t} - 1)$

$= \boxed{26.25 - 31.25e^{-100t} \text{ for } t \geq 0}$

c) $V_o(t) = L_1\frac{di_1}{dt} = \frac{2000e^{-100t}}{1} = 2000e^{-100t}$

$i_1(t) = i_1(0) + \int_0^t 2000e^{-100t}dt$

$= -6 + 2000 \cdot \frac{-1}{100}(e^{-100t} - 1) = \boxed{14 - 20e^{-100t}}$

d)

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