BOLETÍN 6

[CIRCUITOS ELÉCTRICOS]

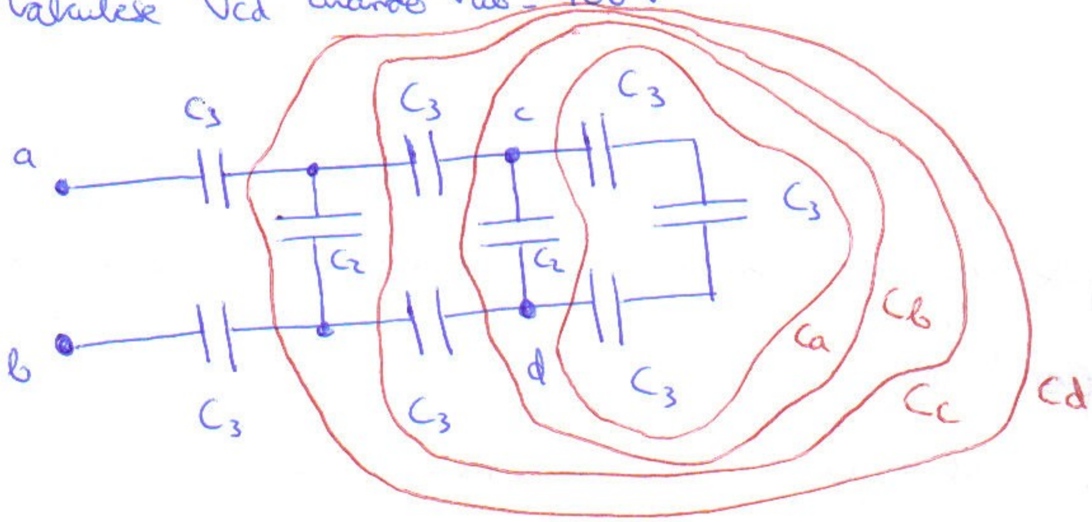
(1) En la figura cada condensador vale: $C_3 = 3\mu F$ y $C_2 = 2\mu F$.

Se pide:

a) Calcúlese la capacidad equivalente de la red comprendida entre los puntos a y b.

b) Hállese la carga de cada uno de los condensadores próximos a los puntos a y b, cuando $V_{ab} = 900V$

c) Calcúlese V_{cd} cuando $V_{ab} = 900V$



$$C_a = \frac{1}{\frac{1}{C_3}+\frac{1}{C_3}+\frac{1}{C_3}} = \frac{C_3}{3} = \frac{3}{3} = 1\mu F$$ (En serie)

(En paralelo)

$$C_b = C_a + C_2 = 3\mu F$$

$$C_c = \frac{1}{\frac{1}{C_3}+\frac{1}{C_b}+\frac{1}{C_3}} = \frac{3}{3} = 1\mu F$$ (En serie)

(En paralelo)

$$C_d = C_c + C_2 = 3\mu F$$ (En serie)

$$C_{eq} = \frac{1}{\frac{1}{C_3}+\frac{1}{C_d}+\frac{1}{C_3}} = \frac{3}{3} = 1\mu F$$

b) $V_{ab} = \dfrac{Q}{C_{eq}}$ $\qquad$ $Q = V_{ab} \cdot C_{eq} = 900 \cdot 1 \cdot 10^{-6} = 900\ \mu C$

c) $Q = 900\ \mu C$

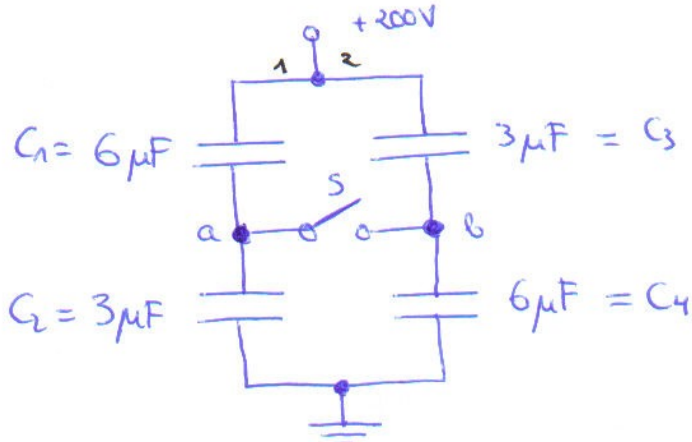
$$V_{cd} = \frac{Q}{C_{eq,cd}}$$

(2) Los condensadores de la figura están inicialmente descargados y se hallan conectados como indica el esquema, con el interruptor S abierto.

a) ¿Cuál es la diferencia de potencial V_{ab}?

b) ¿Y el potencial del punto b después de cerrado S?

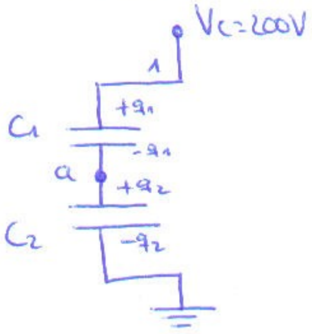
c) ¿Qué cantidad de carga fluye a través de S cuando se cierra?



Serie	Paralelo
$Q = Q_1 = Q_2$	$Q = Q_1 + Q_2$
$V = V_1 + V_2$	$V = V_1 = V_2$
$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$	$C_{eq} = C_1 + C_2$

a) V_{ab}? $\quad V_{ab} = V_a - V_b$

• Rama 1:



C_1 serie C_2:

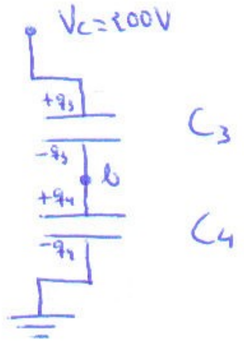
$$C_{1,2} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} = 2\mu F$$

$$q_{1,2} = C_{1,2} \cdot V_c = 2\mu F \cdot 200\,V = 400\mu C$$

En serie: $q_{1,2} = q_1 = q_2$

$$V_a = V_{C_2} = \frac{q_2}{C_2} = \frac{q_{1,2}}{C_2} = \frac{400\mu C}{3\mu F} = \frac{400}{3}\ V$$

• Rama 2:



C_3 serie C_4:

$$C_{3,4} = \frac{1}{\frac{1}{C_3} + \frac{1}{C_4}} = 2\mu F$$

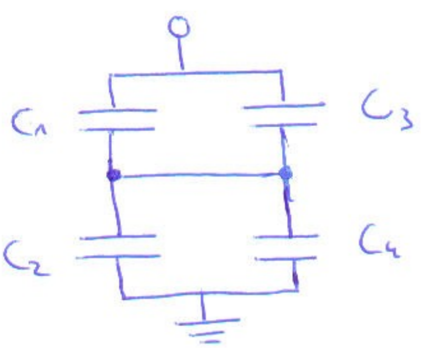
$$q_{3,4} = C_{3,4} \cdot V_c = 2\mu F \cdot 200V = 400\mu C$$

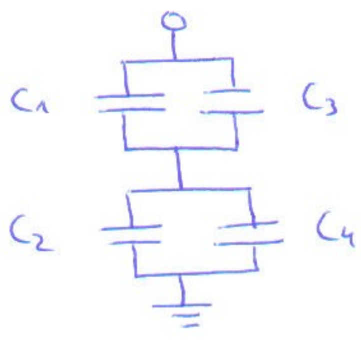
En serie: $q_{3,4} = q_3 = q_4$

$$V_b = V_{C_4} = \frac{q_4}{C_4} = \frac{q_{3,4}}{C_4} = \frac{400\mu C}{6\mu F} = \frac{200}{3}\ V$$

$$V_{ab} = \frac{400}{6}\ V$$

b) $V_{ab} = 0 \iff S$ cerrado

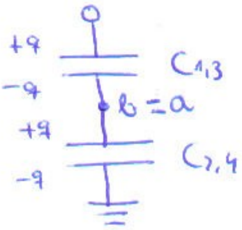




$((C_1 \| C_3)$ serie $((C_2 \| C_4)$:

$$C = \frac{1}{\frac{1}{C_{1,3}} + \frac{1}{C_{2,4}}} = \frac{1}{\frac{1}{C_1+C_3} + \frac{1}{C_2+C_4}} = \frac{1}{\frac{1}{9} + \frac{1}{9}} = \frac{9}{2}\,\mu F = 4{,}5\,\mu F$$

$$Q = C \cdot V_c = 4{,}5 \cdot 200 = 900\,\mu C$$



$$V_b = \frac{Q_{2,4}}{C_{2,4}} = \frac{Q}{C_{2,4}} = \frac{900\,\mu C}{9\,\mu F} = 100\ V$$

$$\left(V_b = \frac{V_c}{2} \right)$$

c) $$\Delta q = \left[-q_1 - (-q_1')\right] + \left[q_2 - q_2'\right] = q_2 - q_2' - q_1 + q_1' =$$

$$= (q_2 - q_1) - (q_2' - q_1')$$

$q_{2,4} = 900\,\mu C$

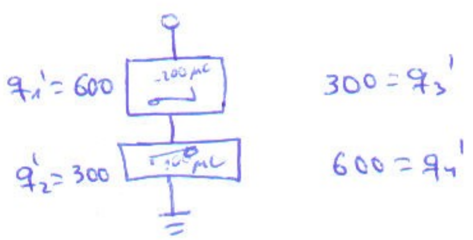
$q_{1,3} = 900\,\mu C$

$V_b = 100\,V = V_{2,4} \implies V_{1,3} = V_c - V_{2,4} = 100\ V$

$q_1' = C_1 \cdot V_1 = C_1 \cdot V_{1,3} = 6\,\mu F \cdot 100\,V = 600\,\mu C$

$q_2' = C_2 \cdot V_2 = C_2 \cdot V_{2,4} = 3\,\mu F \cdot 100\,V = 300\,\mu C$

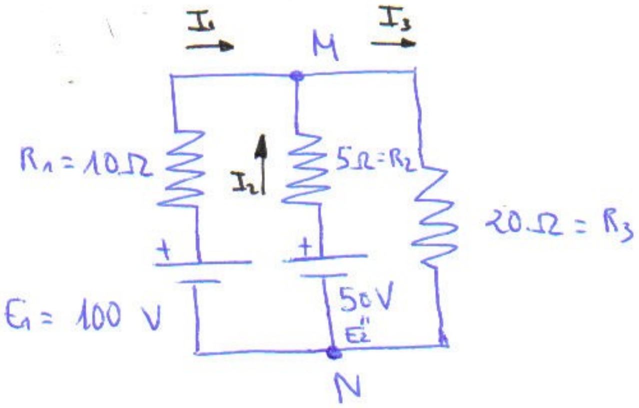
$$\Delta q = \left[-400 - (-600)\right] + \left[400 - 300\right] = 300\ \mu C$$



③ En el circuito de la figura se pide determinar:

a) Corrientes I_1, I_2 e I_3

b) Diferencia de potencial entre los puntos M y N:



a) Por la ley de los nudos:

(En M)

$$I_1 + I_2 = I_3$$

$$-E_1 + I_1 \cdot R_1 - R_2 \cdot I_2 + E_2 = 0$$

$$-E_2 + I_2 \cdot R_2 + I_3 \cdot R_3 = 0$$

[2 nudos, 3 ramas } (3-2)+1 = 2 ecuaciones]

$$-100 + 10 I_1 - 5 I_2 + 50 = 0$$

$$-50 + 5 \cdot I_2 + 20 \cdot I_3 = 0$$

$$I_1 + I_2 = I_3$$

$$\begin{cases} -50 + 5I_3 - 5I_1 + 20 I_3 = 0 \\ -100 + 10 I_1 - 5 I_3 + 5 I_1 = 0 \end{cases}$$

$$\begin{cases} -50 + 25 I_3 - 5 I_1 = 0 \\ -100 + 15 I_1 - 5 I_3 = 0 \end{cases}$$

$$I_3 = \frac{50 + 5 I_1}{25} = \frac{10 + I_1}{5}$$

$$-100 + 15 I_1 - \cancel{5} \cdot \frac{10 + I_1}{\cancel{5}} = 0$$

$$-100 + 15 I_1 - 10 - I_1 = 0$$

$$-110 = -14 I_1$$

$$I_1 = \frac{110}{14} \text{ A}$$

$$I_3 = \frac{10 + \frac{110}{14}}{5} = \frac{250}{70} = \frac{25}{7} \text{ A}$$

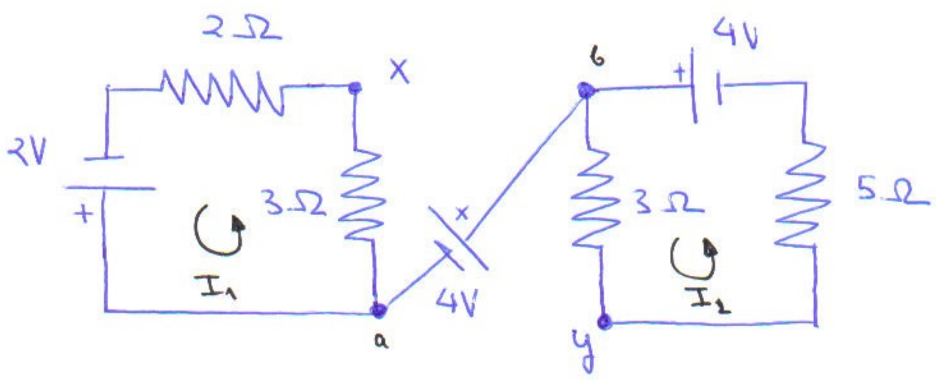
$$I_2 = I_3 - I_1 = \frac{50}{14} - \frac{110}{14} = -\frac{60}{14} \text{ A}$$

b) V_{MN}?

$$V_{MN} = -I_2 \cdot R \quad +50 = 7+50 = 57\,V$$

(Se podría hacer por cualquier rama, el potencial en paralelo es el mismo)

④ Determinar la tensión V_{xy} en el circuito de la figura:



$$-2 + 3 \cdot I_1 + 2 \cdot I_1 = 0 \quad \Rightarrow I_1 = \frac{2}{5}\,A$$

$$-4 + 3 \cdot I_2 + 5 \cdot I_2 = 0 \quad \Rightarrow I_2 = \frac{1}{2}\,A$$

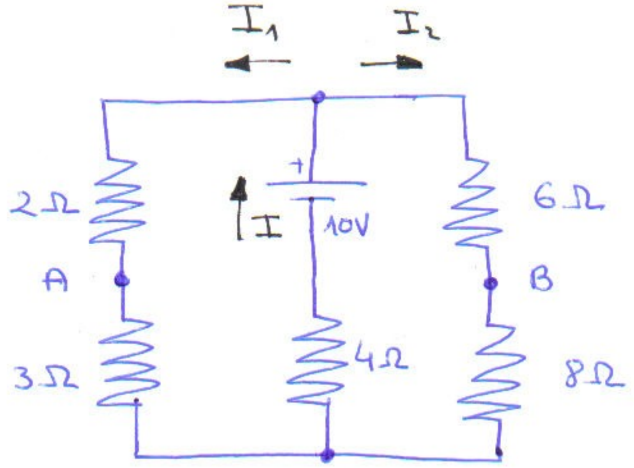
$$V_{xy} = V_{xa} + V_{ab} + V_{by} = 3(-I_1) + (-4) + 3 \cdot I_2 = -3 \cdot \frac{2}{5} - 4 + 3 \cdot \frac{1}{2} =$$

$$= -3{,}7\,V$$

5) En el circuito de la figura se pide determinar:

a) Corrientes I, I_1 e I_2.

b) Tensión V_{ab}



$$\begin{cases} I_1 \cdot 2 + I_1 \cdot 3 + 4 \cdot I - 10 = 0 \\ I_2 \cdot 6 + I_2 \cdot 8 + 4 \cdot I - 10 = 0 \end{cases}$$

$\left.\begin{matrix} 2 \text{ nudos} \\ 3 \text{ ramas} \end{matrix}\right\} 2 \text{ ec.}$

$$I = I_1 + I_2$$

$$\begin{cases} 5 I_1 + 4(I_1 + I_2) - 10 = 0 \\ 14 I_2 + 4(I_1 + I_2) - 10 = 0 \end{cases} \qquad \begin{cases} 9 I_1 + 4 I_2 - 10 = 0 \\ 18 I_2 + 4 I_1 - 10 = 0 \end{cases}$$

$$I_2 = \frac{10 - 4 I_1}{18} = \frac{5 - 2 I_1}{9}$$

$$9 I_1 + 4 \cdot \frac{5 - 2 I_1}{9} - 10 = 0$$

$$81 I_1 + 4(5 - 2 I_1) - 90 = 0$$

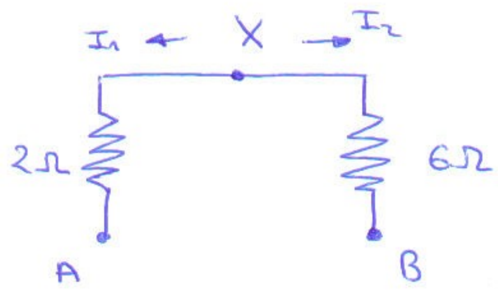
$$81 I_1 + 20 - 8 I_1 - 90 = 0$$

$$73 I_1 = 70 \implies I_1 = \frac{70}{73} = 0{,}96 \text{ A}$$

$$I_2 = \frac{5 - 2 \cdot \frac{70}{73}}{9} = \frac{365 - 140}{657} = \frac{225}{657} = \frac{25}{73} = 0{,}34 \text{ A}$$

$$I = I_1 + I_2 = 0{,}96 + 0{,}34 = 1{,}3 \text{ A}$$

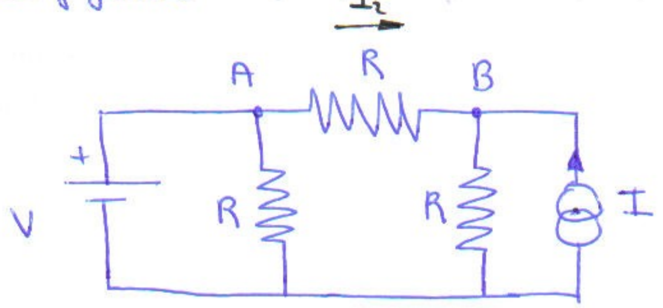
b)



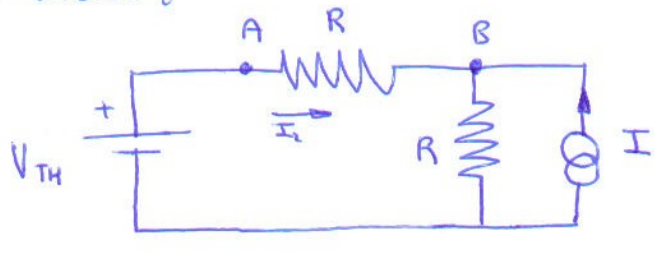
$$V_{ab} = V_{ax} + V_{xb}$$

$$V_{ab} = -2 \cdot I_1 + 6 \cdot I_2 = -2 \cdot 0{,}96 + 0{,}34 \cdot 6 = 0{,}12\ V$$

6) Usando el teorema de Thévenin, calcular la corriente I_2 en la red de la figura:



Sabemos que se puede quitar una resistencia en paralelo con un generador ideal de tensión:



Como consecuencia del Th de Thevenin, sabemos que podemos quitar una resistencia en paralelo con un generador de tensión, puesto que no afecta a los demás valores de las magnitudes eléctricas del circuito (aunque sí a la corriente del propio generador). También se puede hacer el equivalente Thev. entre a y b.

$$-V_{TH} + I_2 \cdot R + (I_2 + I) \cdot R = 0$$

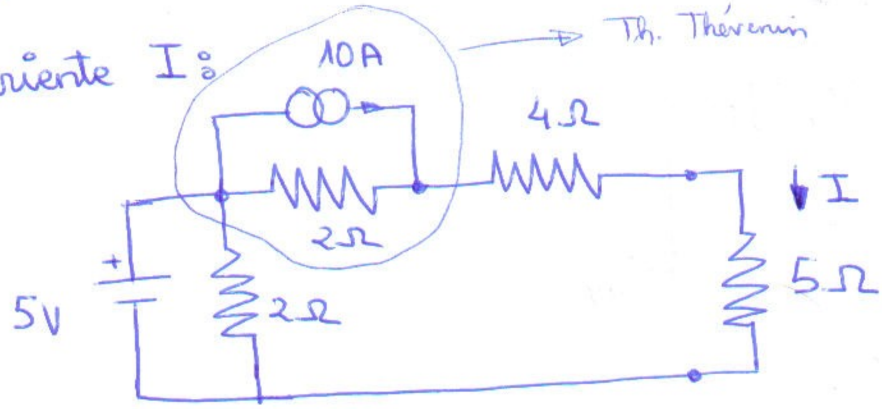
$$-V_{TH} + R \cdot I_2 + R I_2 + R \cdot I = 0$$

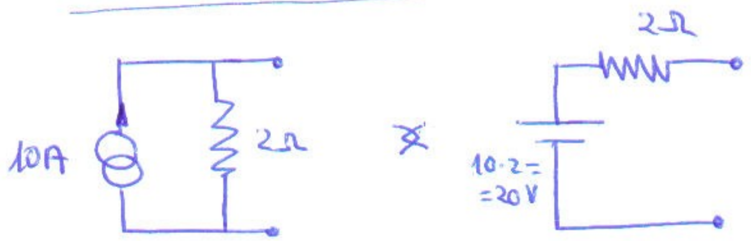
$$-V_{TH} + 2 \cdot R \cdot I_2 + R \cdot I = 0$$

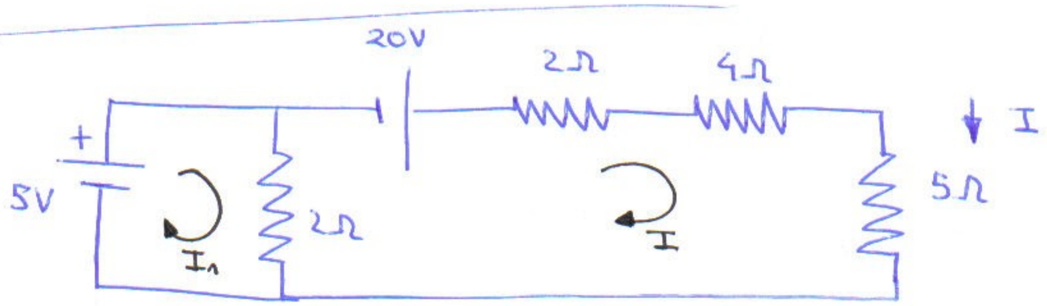
$$2R \cdot I_2 = V - R \cdot I$$

$$I_2 = \frac{V - RI}{2R}$$

7) En el circuito de la figura, calcular el valor de la corriente I:







$$\begin{cases} -5 + 2\cdot I_1 - 2\cdot I = 0 \\ -20 + 2\cdot I + 4\cdot I + 5\cdot I + 2\cdot I - 2\cdot I_1 = 0 \end{cases}$$

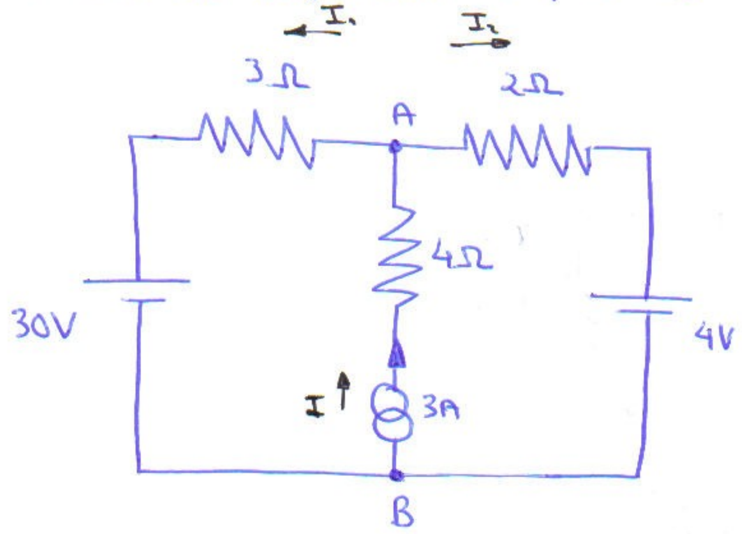
$$\begin{cases} -5 + 2I_1 - 2\cdot I = 0 \\ -20 + 13I - 2I_1 = 0 \end{cases}$$

$$I = \frac{25}{11} = 2{,}27\ A \qquad 2I_1 = 5 + 2\cdot I = 5 + 2\cdot 2{,}27 = 9{,}49$$

$$I_1 = 4{,}775\ A$$

QuéGrande.org

8) Calcular la diferencia de potencial V_{ab} en el circuito de la figura:



$$\begin{cases} 3 \cdot I_1 + 30 + 4 \cdot I = 0 \\ 2 \cdot I_2 + 4 + 4 \cdot I = 0 \end{cases} \qquad I = I_1 + I_2$$

$$\begin{cases} 3 \cdot I_1 + 30 + 4 I_1 + 4 I_2 = 0 \\ 2 \cdot I_2 + 4 + 4 I_1 + 4 I_2 = 0 \end{cases} \qquad \begin{cases} 7 I_1 + 4 I_2 + 30 = 0 \\ 6 I_2 + 4 I_1 + 4 = 0 \end{cases}$$

$$6 I_2 = -4 - 4 I_1 \qquad I_2 = \frac{-2-2I_1}{3}$$

$$7 \cdot I_1 + 4 \cdot \frac{(-2-2I_1)}{3} + 30 = 0$$

$$21 I_1 - 8 - 8 I_1 + 30 = 0$$

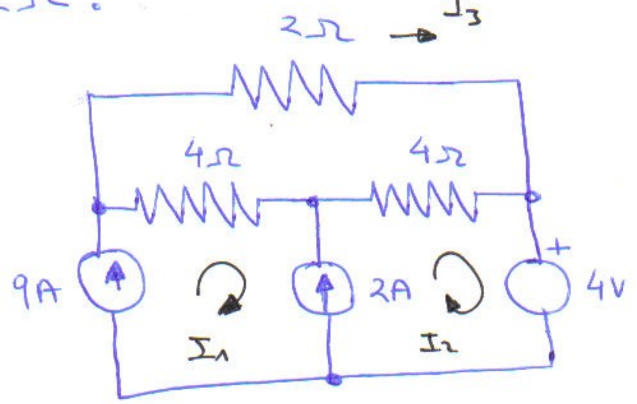
$$13 I_1 = -22 \qquad I_1 = \frac{-22}{13} \text{ A} \qquad I_2 = \frac{-2-2 \cdot \frac{(-22)}{13}}{3} =$$

$$= \frac{-26+44}{39} = \frac{18}{39} \text{ A}$$

$$I = \frac{-22}{13} + \frac{18}{39} = \frac{-66+18}{39} = \frac{-48}{39} \text{ A}$$

Creo que mal xD

⑨ En el circuito de la figura, hallar la potencia disipada en la resistencia de 2Ω:

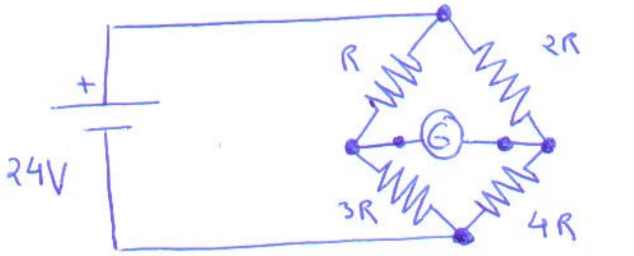


$P = I^2 \cdot R \ (W)$

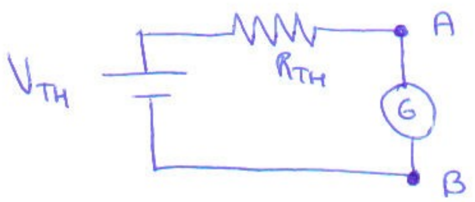
$$\boxed{P = I_3^2 \cdot 2}$$

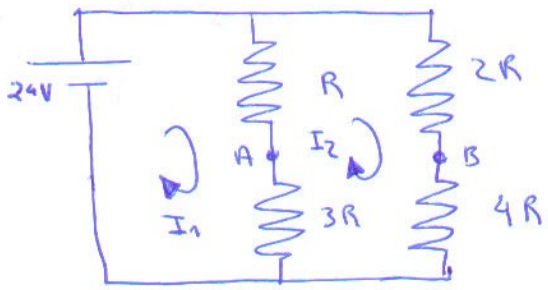
WTF? xD

(10) Determinar el valor de R que produce una desviación a fondo de escala del galvanómetro de la figura de resistencia interna $R_G = 1000\Omega$ y sensibilidad $S = 500\ \mu A$:



• Aplicando Thévenin:

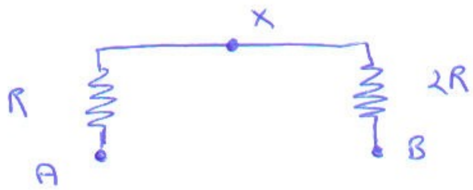




$V_{TH} = V_{AB}$

$R \cdot I_1 = 10$

$R \cdot I_2 = 4$

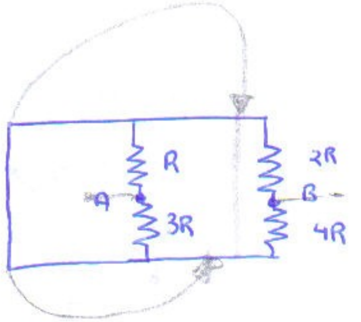


$V_{ab} = V_{ax} + V_{xb}$

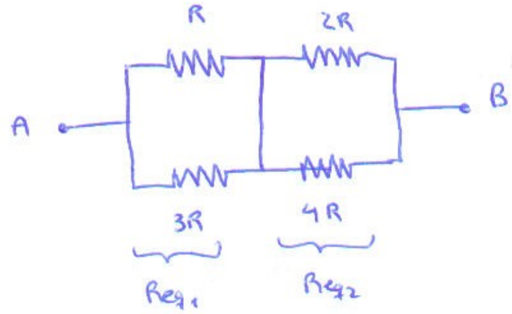
$24 = -I_1 (R + 3R) \Rightarrow I_1 = -6/R$

$24 = I_2 (2R + 4R) \Rightarrow I_2 = 4/R$

$V_{ab} = I \cdot R = V_{TH} = I_1 \cdot R + 2 \cdot I_2 \cdot R = -\frac{6R}{R} + 2 \cdot \frac{4R}{R} = -6 + 8 = 2V$



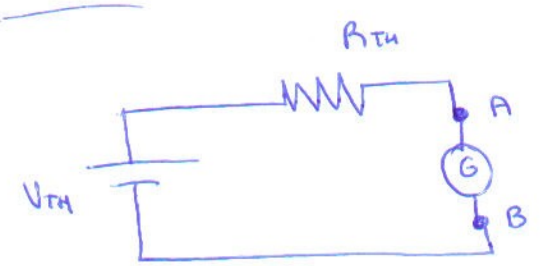
$\Longrightarrow$



$$R_{eq_1} = \frac{1}{\frac{1}{3R}+\frac{1}{R}} = \frac{1}{\frac{4}{3R}} = \frac{3R}{4}$$

$$R_T = \frac{3R}{4} + \frac{4R}{3} = \frac{25}{12}R$$

$$R_{eq_2} = \frac{1}{\frac{1}{4R}+\frac{1}{2R}} = \frac{1}{\frac{1}{4R}} = \frac{4R}{3}$$



$I_G = 500\ \mu A$

$R_G = 1000\ \Omega$

$V_{TH} = R_{TH} \cdot I_G + R_G \cdot I_G$

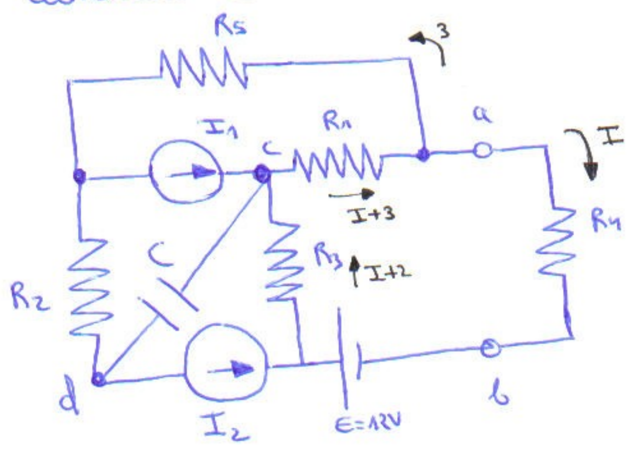
$$2 = \frac{25}{12} R \cdot 500 \cdot 10^{-6} + 1000 \cdot 500 \cdot 10^{-6}$$

$$R = 1440\ \Omega$$

(11) En el circuito de la figura determinar:

a) Potencia en la resistencia R_4.

b) Carga almacenada en el condensador C

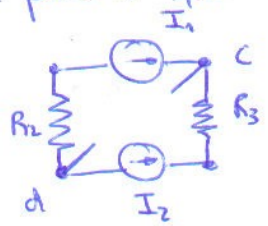


$R_i = i\ \Omega$

$I_i = i\ A$

$C = 1\ \mu F$

En continua, a efectos de análisis de circuito se pueden quitar los condensadores.



[DIRECTAMENTE (Kirchoff):]

$$I \cdot R_4 - 12 + (2+I) \cdot R_3 + (3+I) \cdot R_1 = 0$$

$$4 \cdot I - 12 + 2 \cdot 3 + 3I + 3 \cdot 1 + I = 0$$

$$8I = 3$$

$$I = \frac{3}{8} \text{ A} = 0{,}375 \text{ A}$$

$$Pot_{R_4} = I_{R_4}^2 \cdot R_4 = 0{,}375^2 \cdot 4 = 0{,}5625 \text{ W}$$

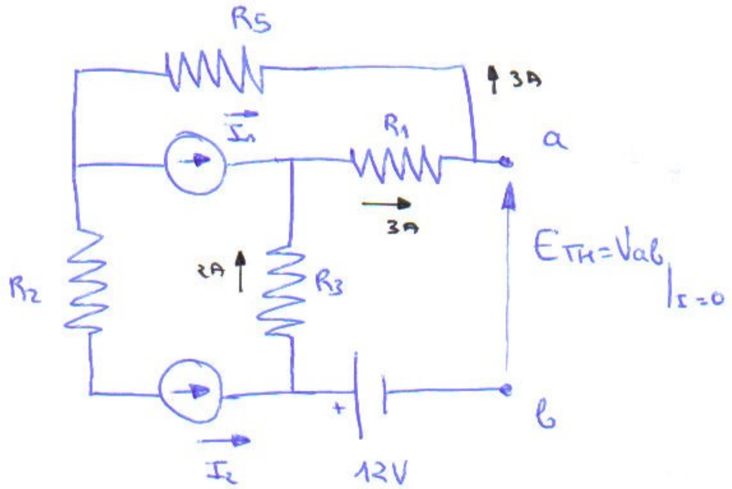
$$V_{cd} = (I+3) \cdot R_1 + 3 \cdot R_3 + R_2 \cdot I_2 = (3+0{,}375) \cdot 1 + 3 \cdot 5 + 2 \cdot 2 =$$

$$= 22{,}375 \text{ V}$$

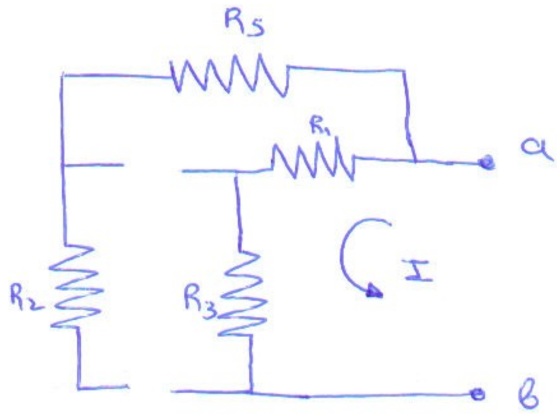
$$Q = C \cdot V \qquad Q = C \cdot V_{cd} = 1 \cdot 22{,}375 \cdot 10^{-6} = 22{,}375 \ \mu C$$

[POR THÉVENIN]

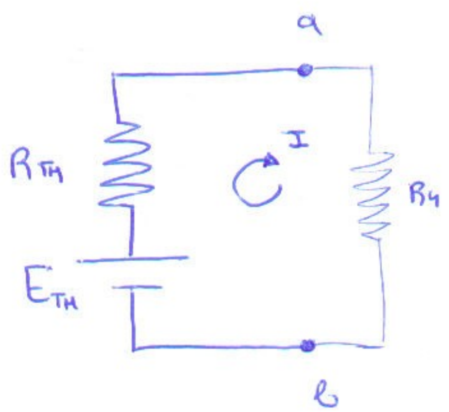
Terminales en circ. abierto:



$$E_{TH} = V_{ab} = -3 \cdot 1 - 2 \cdot 3 + 12 = 3V$$



$$R_{eq} = R_{TH} = R_1 + R_3 = 4\,\Omega$$

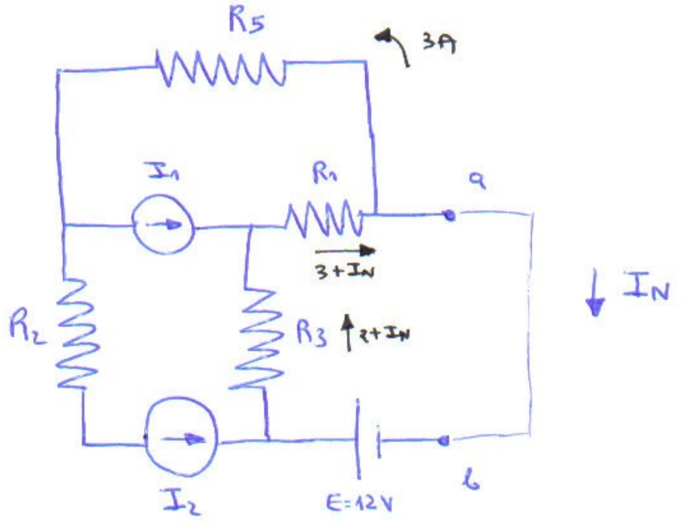


$$I = \frac{E_{TH}}{R_{TH}+R_4} = \frac{3}{4+4} = 0{,}375 \text{ A}$$

$$P = I^2 \cdot R = 0{,}5625 \text{ W}$$

(La carga sería como en el apartado anterior)

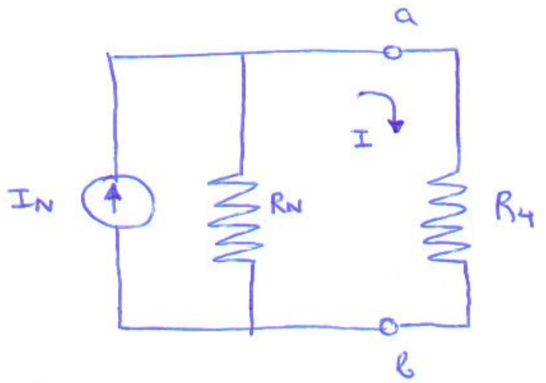
[POR NORTON]



$$-(3+I_N)\cdot 1 - (2+I_N)\cdot 3 + 12 = 0$$

$$I_N = \frac{3}{4} = 0{,}75 A$$

$R_N = R_{eq} = R_1 + R_3 = 4\Omega$ (Ver apartado anterior)



$$V_{ab} = I_N \cdot \frac{1}{\frac{1}{R_N} + \frac{1}{R_4}} = I \cdot R_4$$

$$I = I_N \cdot \frac{R_N}{R_N + R_4} =$$

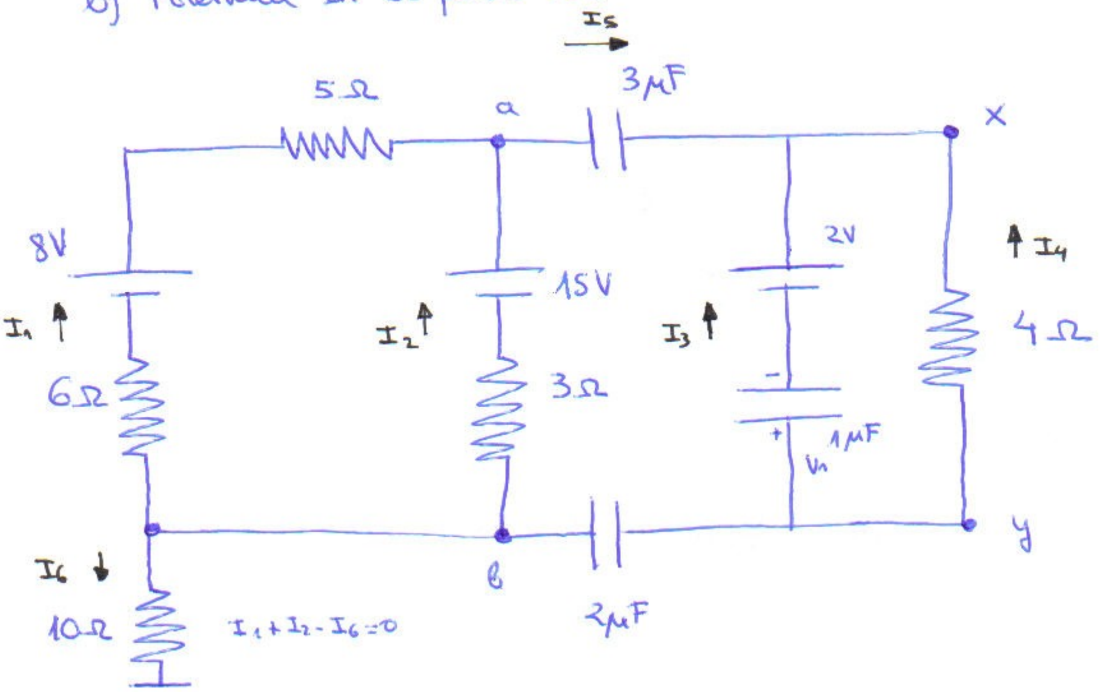
$$= 0{,}75 \cdot \frac{4}{4+4} = 0{,}75 \cdot \frac{1}{2} = 0{,}375 A$$

(Seguiría como apartados anteriores)

(12) En el circuito de la figura, determinar:

a) Carga almacenada por cada uno de los condensadores.

b) Potencial en el punto X.



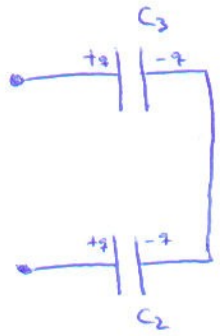
$C \xrightarrow{c.a} \quad I_3 = I_5 = 0$

$I_3 + I_5 = I_4 \Rightarrow I_4 = 0$

$V_1 - 2 = 0 \Rightarrow V_1 = 2V \qquad q_1 = C_1 \cdot V_1 = 1\mu F \cdot 2V = 2\mu C$

$$\begin{cases} 8 = 5 \cdot I_1 + 15 - 3 \cdot I_2 + 6 \cdot I_1 = 11 I_1 - 3 \cdot I_2 + 15 \\ I_1 + I_2 = I_5 = 0 \Rightarrow I_1 = -I_2 \end{cases}$$

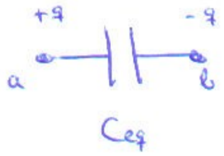
$I_1 = -0{,}5\ A \qquad I_2 = 0{,}5A$



$C_3 = 3\mu F$

$C_2 = 2\mu F$

$$C_{eq} = \frac{1}{\frac{1}{C_2}+\frac{1}{C_3}} = \frac{6}{5}\,\mu F$$



$$\underbrace{q}_{q_2=q_3=q} = V_{ab}\cdot C_{eq}$$

$$V_{ab} = 15 - 3\cdot I_2 = 13,5\,V$$

$$q = 13,5\cdot\frac{6}{5}\mu = 16,2\,\mu C = q_2 = q_3$$

b) V_x?

$$V_x = V_{xy} + V_{yb} + V_b$$

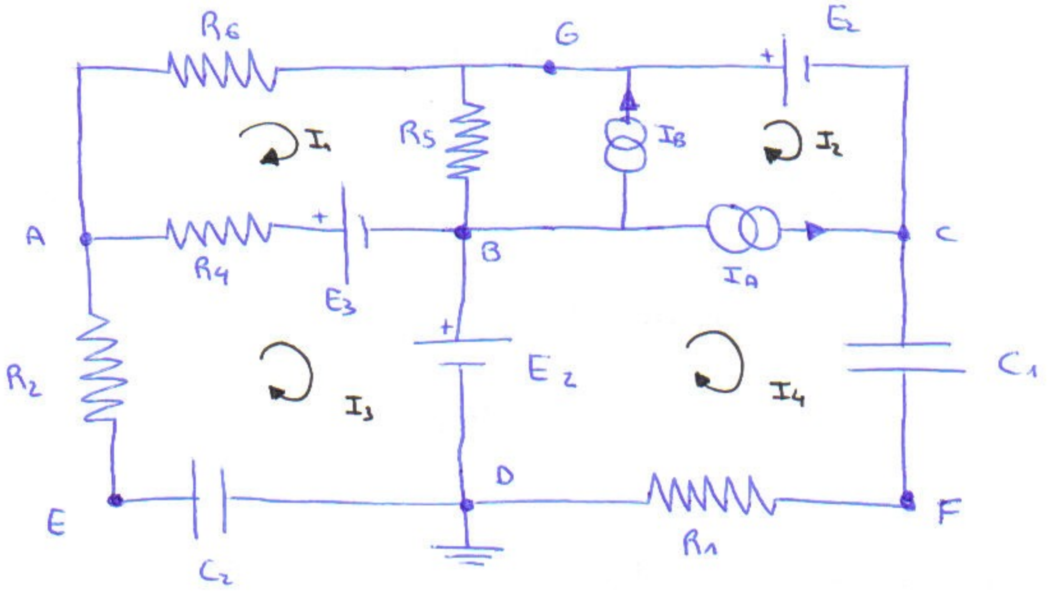
$$I_b = I_1 + I_2 = \frac{1}{2} + \left(-\frac{1}{2}\right) = 0\,A \Rightarrow V_b = 0$$

$$V_{yb} = \frac{q}{C} = \frac{16,2\,\mu C}{2\mu F} = 8,1\,V$$

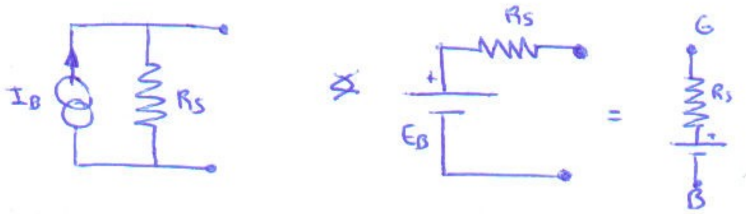
$$V_x = V_{yb} = 8,1\,V$$

• EJERCICIO EXAMEN:

Cargas.



$C_1 = 1\mu F$
$C_2 = 2\mu F$
$R_1 = 1\Omega$
$R_2 = 2\Omega$
$R_4 = 4\Omega$
$R_5 = 5\Omega$
$R_6 = 6\Omega$
$E_1 = 10V$
$E_2 = 10V$
$E_3 = 3V$
$I_A = 1A$
$I_B = 2A$



$V = R \cdot I = 2 \cdot 5 = 10V = E_B$

• En continua los condensadores actuan como circuito abierto. $(I_3 = I_4 = 0)$

$$\begin{cases} R_6 \cdot I_1 + R_5(I_1 - I_2) + E_B - E_3 + R_4(I_1 - I_3) = 0 \\ I_2 + I_A = I_4 \end{cases}$$

$I_4 = 0 \Rightarrow I_2 = -I_A = -1A$

$6 \cdot I_1 + 5(I_1 + 1) + 10 - 3 + 4(I_1 - 0) = 0$

$$I_1 = -\frac{12}{15} A$$

$$Q_1 = C_1 \cdot V_{CF}$$

$$Q_2 = C_2 \cdot V_{ED}$$

$$V_{CF} = V_{CB} + V_{BD} + \underbrace{V_{DF}}_{=0,\ I_4=0} = V_{CG} + V_{GB} + V_{BD} =$$

$$= -\cancel{10} + (I_1 - I_2) \cdot 5 + \cancel{10} + 10 = \left(-\frac{12}{15} + 1\right) \cdot 5 + 10 =$$

$$= \left(-\frac{4}{5} + 1\right) \cdot 5 + 10 = 1 + 10 = 11\ V$$

$$Q_1 = 1\mu F \cdot 11\ V = 11\ \mu C$$

$$V_{ED} = \underbrace{V_{EA}}_{=0} + V_{AB} + V_{BD} = 4(\underbrace{I_3}_{0} - I_1) + 3 + 10 =$$

$$= -4 \cdot I_1 + 3 + 10 = -4 \cdot \left(-\frac{4}{5}\right) + 13 = \frac{16}{5} + \frac{65}{5} = \frac{81}{5}\ V$$

$$Q_2 = 2\mu F \cdot \frac{81}{5} V = \frac{162}{5} \mu C = 32{,}4\ \mu C$$

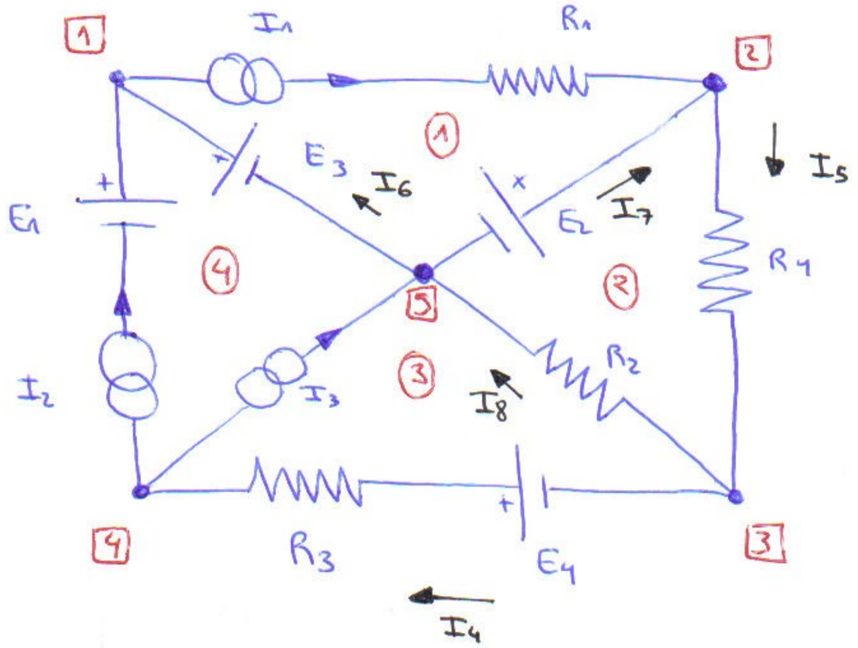
• EJERCICIO DE EXAMEN:

a) I en cada rama

b) Pot. entregada por los generadores y absorbida por las resistencias.

c) Calcular el equivalente Thévenin entre a y b

$R_i = i\ \Omega$



$I_1 = 1\,A$

$I_2 = 2\,A$

$I_3 = 3\,A$

$\boxed{1}$ $I_2 + I_6 = I_1$

$I_6 = -1\,A$

$\boxed{4}$ $I_4 = I_2 + I_3 = 5\,A$

$\boxed{3}$ $I_5 = I_8 + I_4 = I_8 + 5$

$\boxed{2}$ $I_1 + I_7 = I_5 = 1 + I_7$

$\boxed{5}$ $I_3 + I_8 = I_6 + I_7$

$3 + I_8 = -1 + I_7$

$I_5 = 2\,A \quad I_7 = 1\,A \quad I_8 = -3\,A$

b) Potencia disipada en las resistencias:

$P_{R_1} = I_1^2 \cdot R_1 = 1^2 \cdot 1 = 1\,W$

$P_{R_2} = I_8^2 \cdot R_2 = (-3)^2 \cdot 2 = 18\,W$

$P_{R_3} = I_4^2 \cdot R_3 = 5^2 \cdot 3 = 75\,W$

$P_{R_4} = I_5^2 \cdot R_4 = 2^2 \cdot 4 = 16\,W$

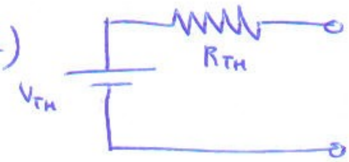
$P_{TOT} = 1 + 18 + 75 + 16 = 110\,W = P_{ent\,TOTAL}$

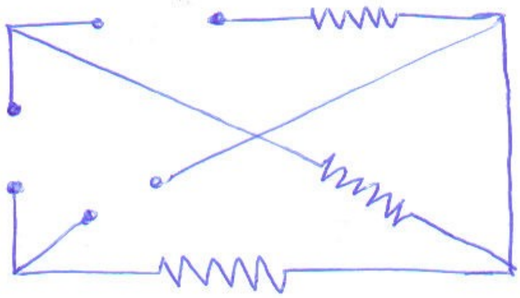
Pot. entregada por $I_1 = V_{I_1} \cdot I_1 = 0$ W

$$\left.\begin{array}{lll}
\text{'' por } I_2 = V_{I_2} \cdot I_2 & = -38\text{W} \\
\text{'' por } I_3 = V_{I_3} \cdot I_3 & = -51\text{W} \\
\text{'' por } E_1 = E_1 \cdot (-I_2) & = -2\text{W} \\
\text{'' por } E_2 = E_2 \cdot (-I_1) & = -2\text{W} \\
\text{'' por } E_3 = E_3 \cdot (-I_6) & = 3\text{W} \\
\text{'' por } E_4 = E_4 \cdot (-I_4) & = -20\text{W}
\end{array}\right\} -110\text{W}$$

$$V_{I_1} + I_1 \cdot 1 + \underbrace{E_2}_{2} - \underbrace{E_3}_{3} = 0 \Rightarrow V_{I_1} = 0$$

$$\left.\begin{array}{l}
V_{I_2} - 1 + 3 - V_{I_3} = 0 \\
V_{I_3} - I_8 \cdot 2 - 4 + I_4 \cdot 3 = 0
\end{array}\right\} \begin{array}{l} V_{I_2} = -19\text{V} \\ V_{I_3} = -17\text{V} \end{array}$$

c) 



$V_{ab} = I \cdot 4 = 2 \cdot 4 = 8$ V