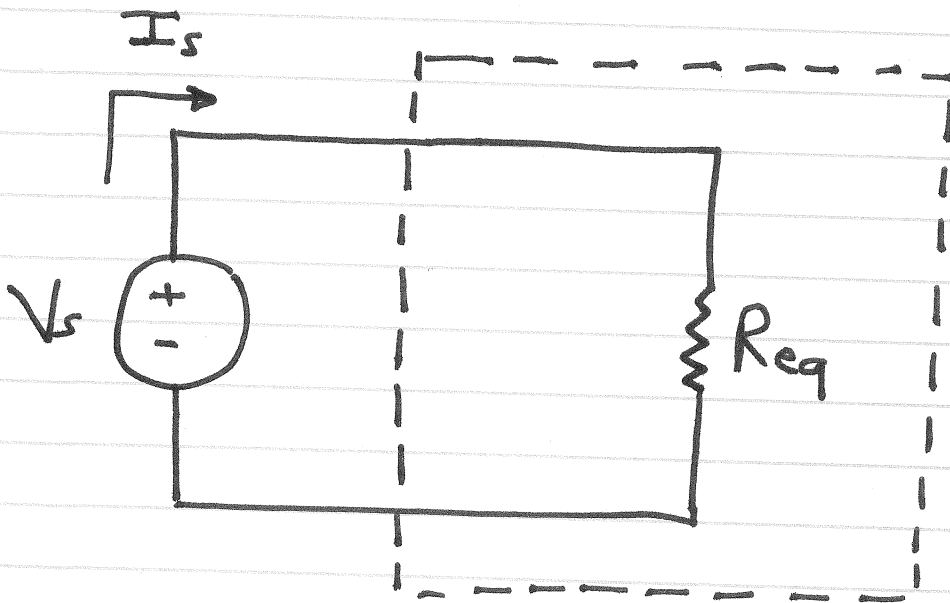
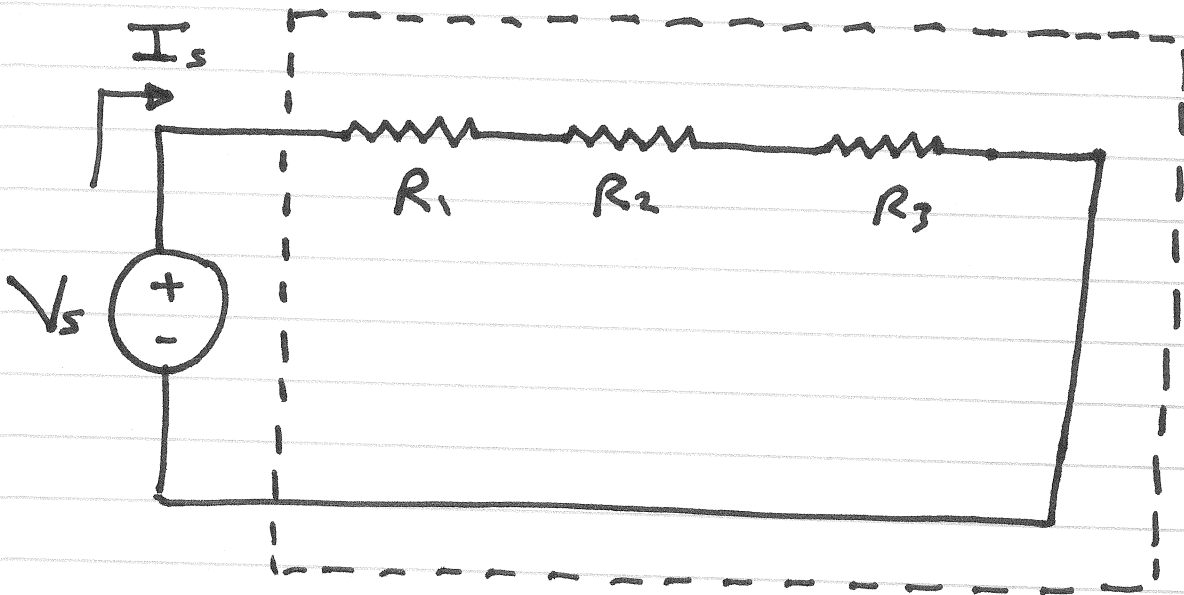
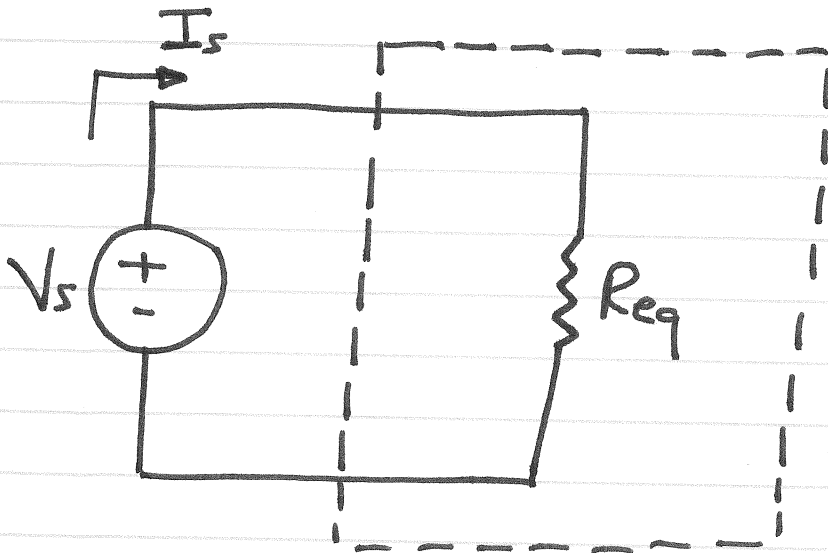
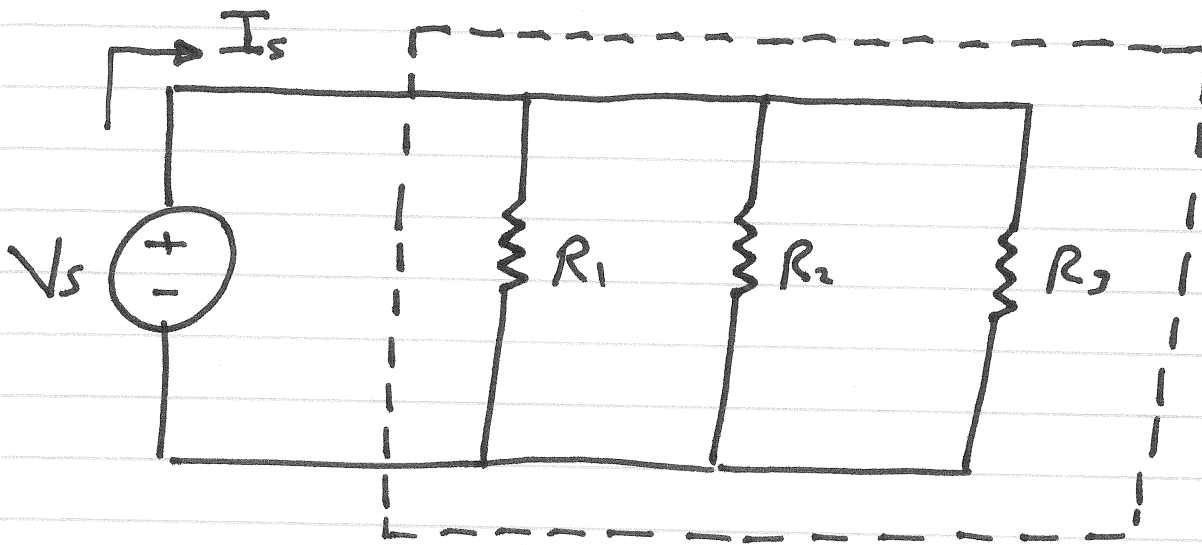


## Resistors in Series



$$R_{eq} = R_1 + R_2 + R_3$$

# Resistors in Parallel



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

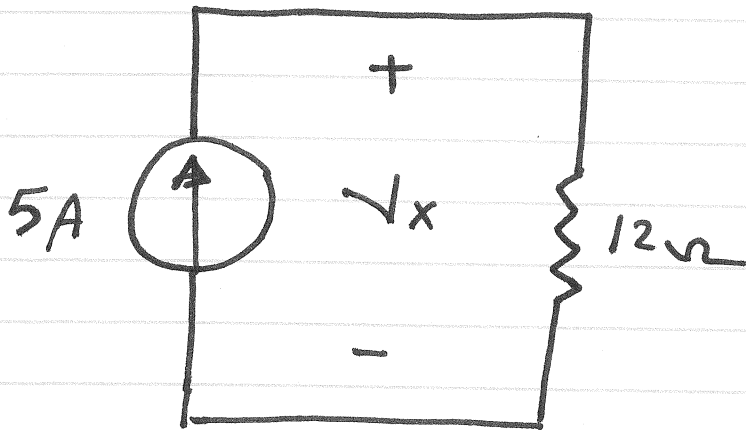
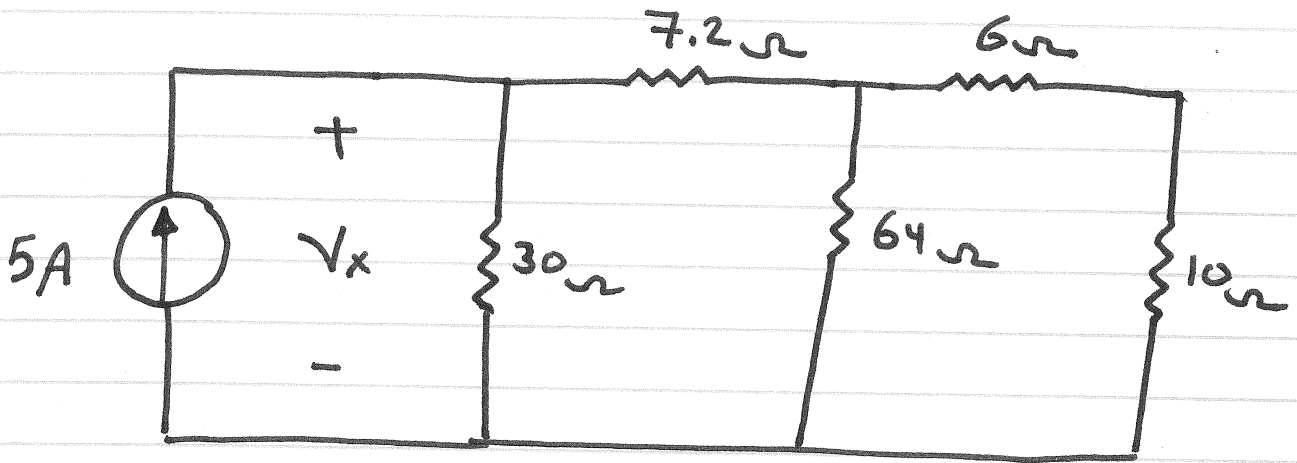
## Two Resistors in Parallel

$$R_{eq} = R_1 \parallel R_2$$

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

$$0.5 \min(R_1, R_2) < R_1 \parallel R_2 < \min(R_1, R_2)$$

Find  $V_x$



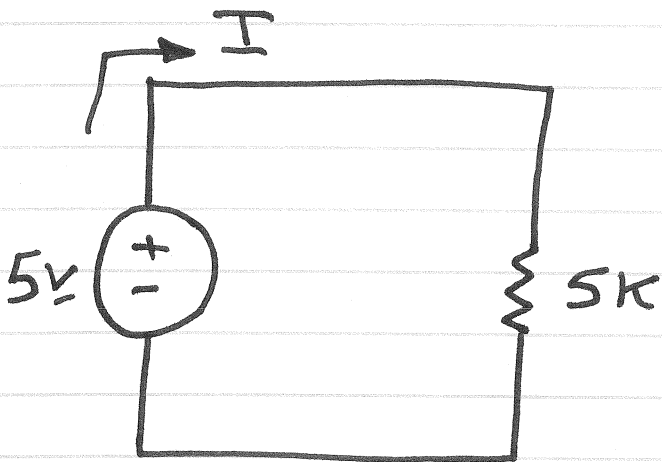
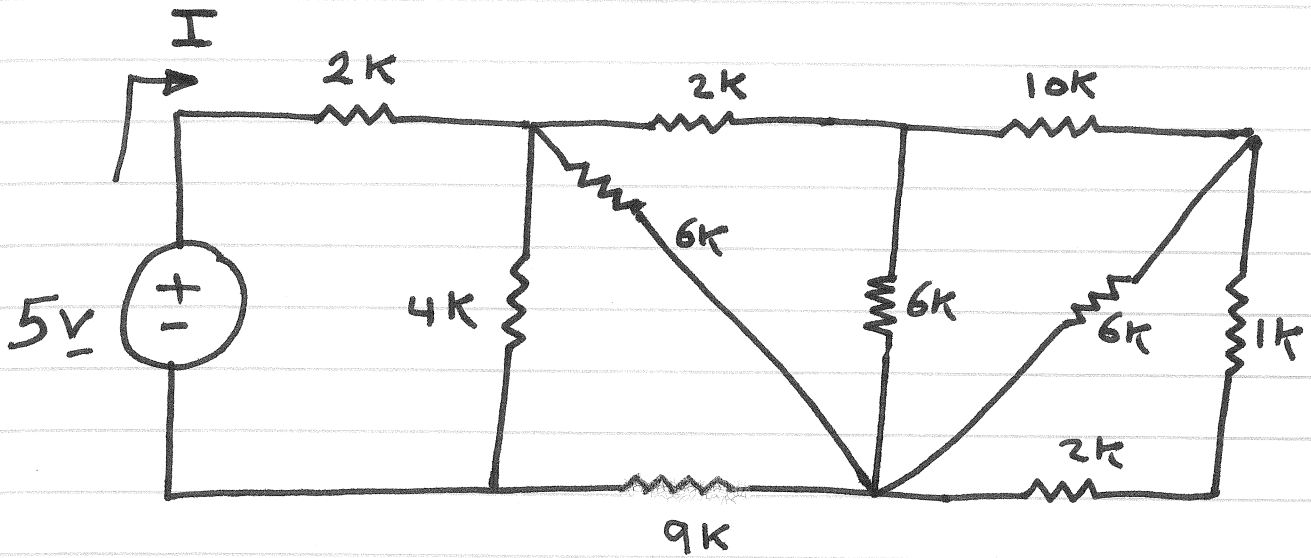
$$V_x = (5)(12) = 60\text{V}$$

$$16\ \Omega \parallel 64 = 12.8\ \Omega$$

$$20\ \Omega \parallel 30\ \Omega = 12\ \Omega$$

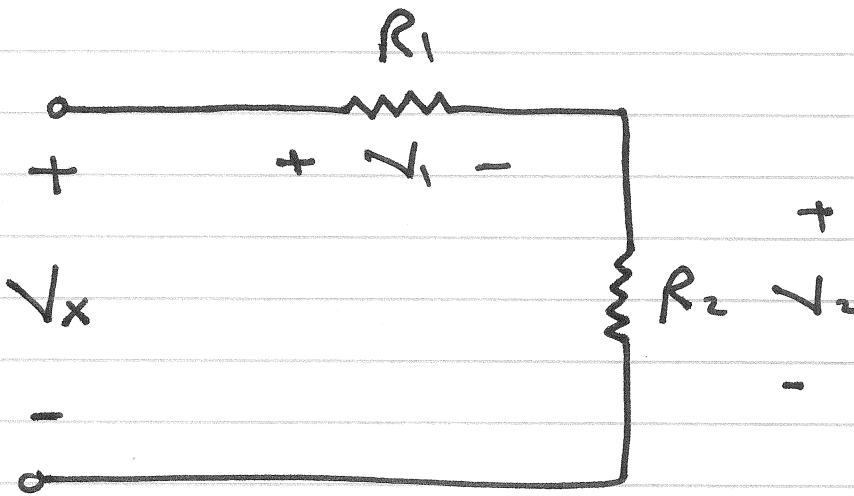
-37-

Find I



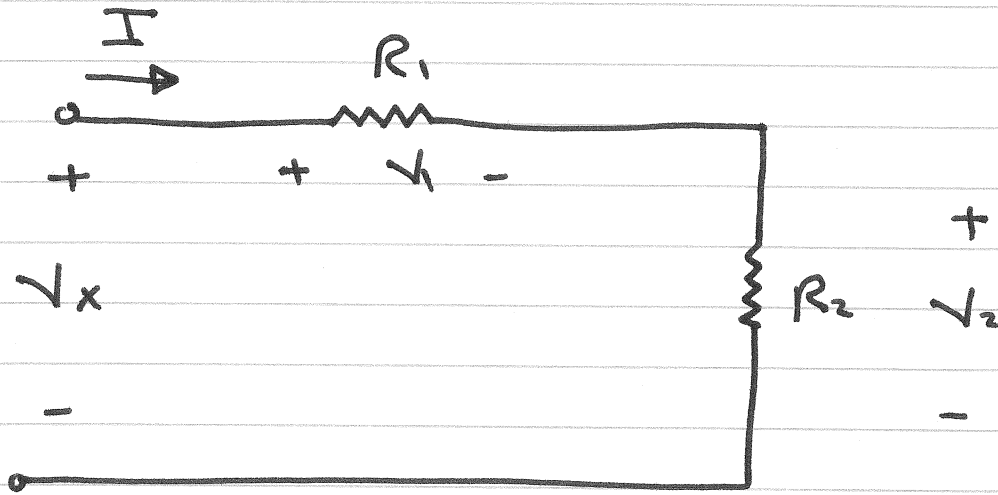
$$I = \frac{5v}{5k} = 1mA$$

# Voltage Divider Rule



$$V_1 = \frac{R_1}{R_1 + R_2} V_x$$

$$V_2 = \frac{R_2}{R_1 + R_2} V_x$$



KVL :

$$V_x = V_1 + V_2$$

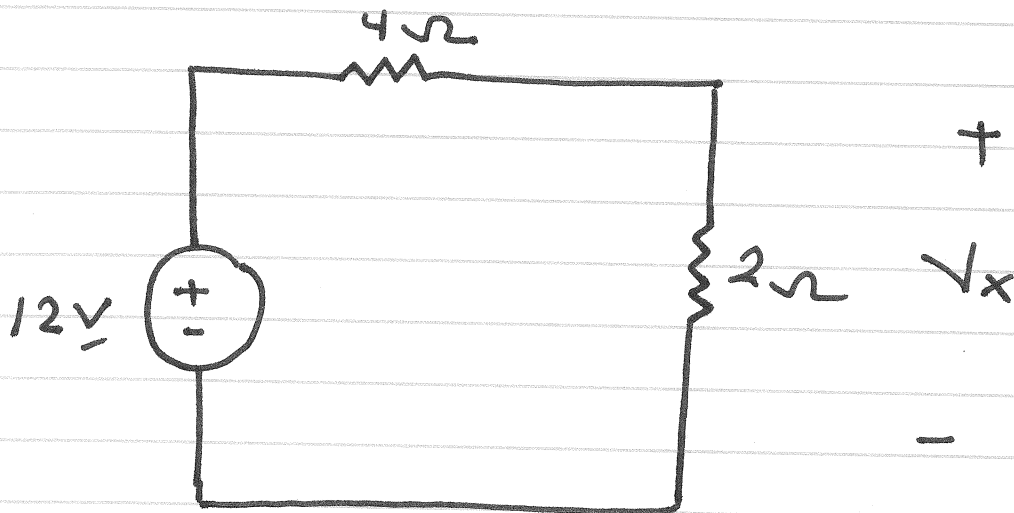
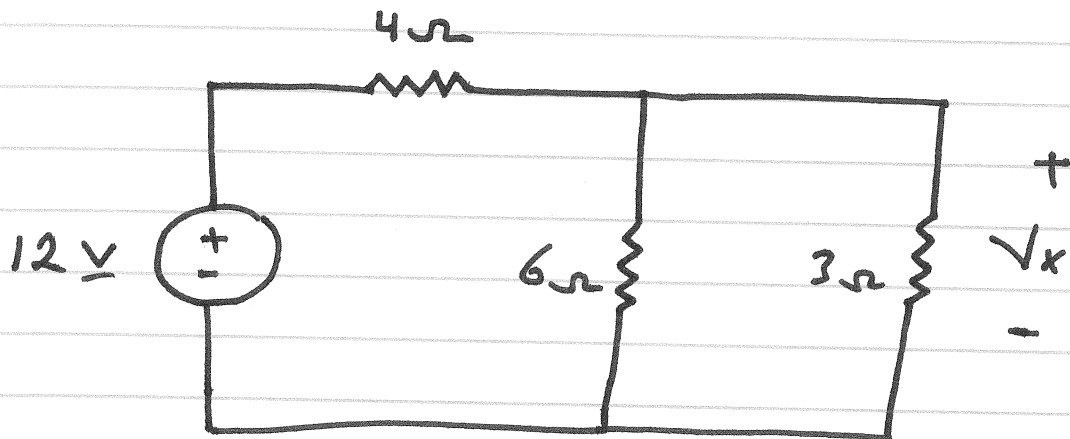
$$V_x = R_1 I + R_2 I$$

$$\therefore I = \frac{V_x}{R_1 + R_2}$$

$$V_1 = R_1 I = \frac{R_1}{R_1 + R_2} V_x$$

$$V_2 = R_2 I = \frac{R_2}{R_1 + R_2} V_x$$

Find  $V_x$

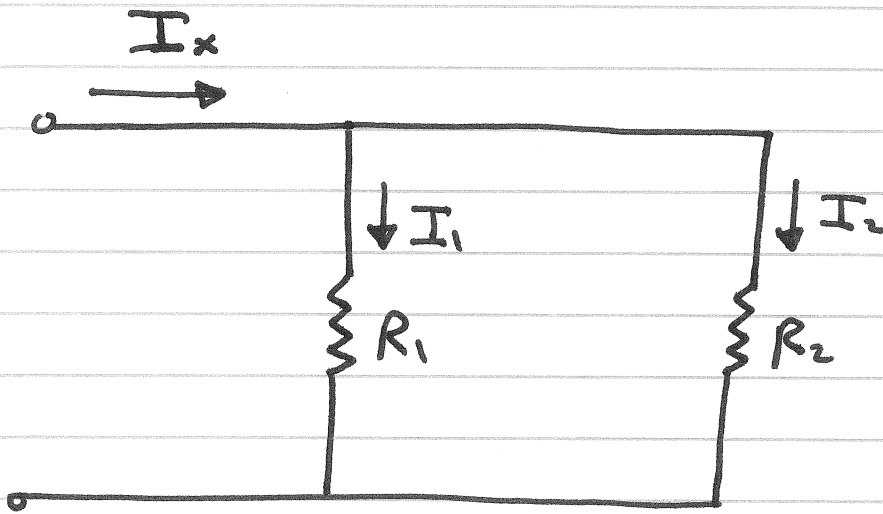


$$V_x = \frac{2}{4+2} \cdot 12$$

$$V_x = 4 \text{ V}$$

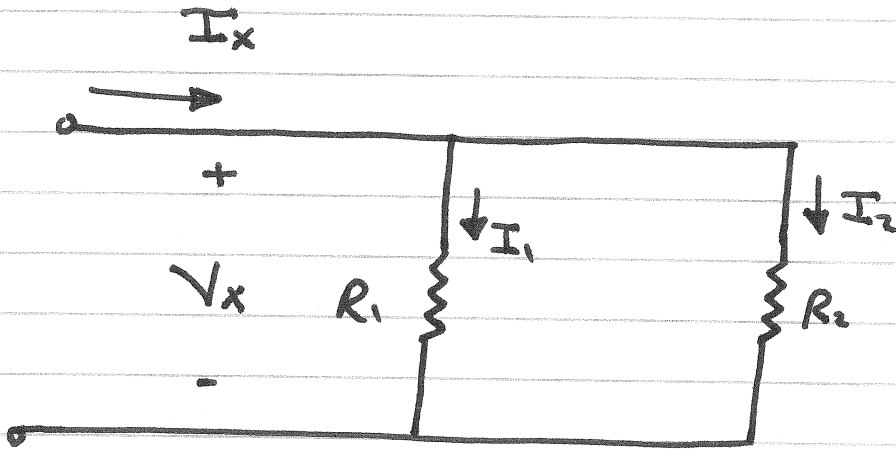


# Current Divider Rule



$$I_1 = \frac{R_2}{R_1 + R_2} I_x$$

$$I_2 = \frac{R_1}{R_1 + R_2} I_x$$



KCL :

$$I_x = I_1 + I_2$$

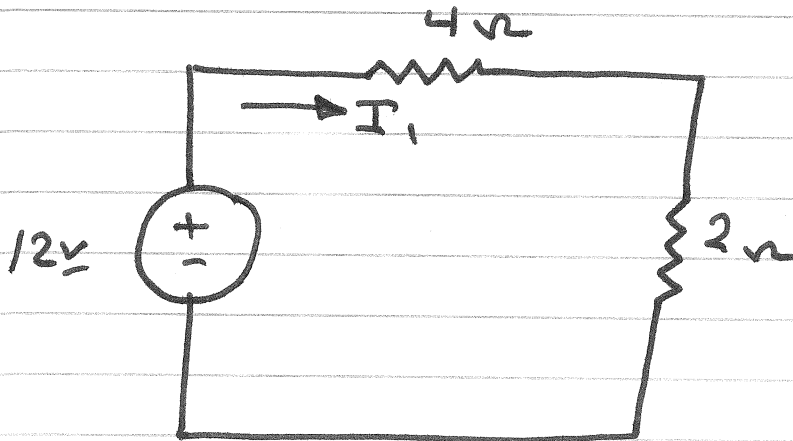
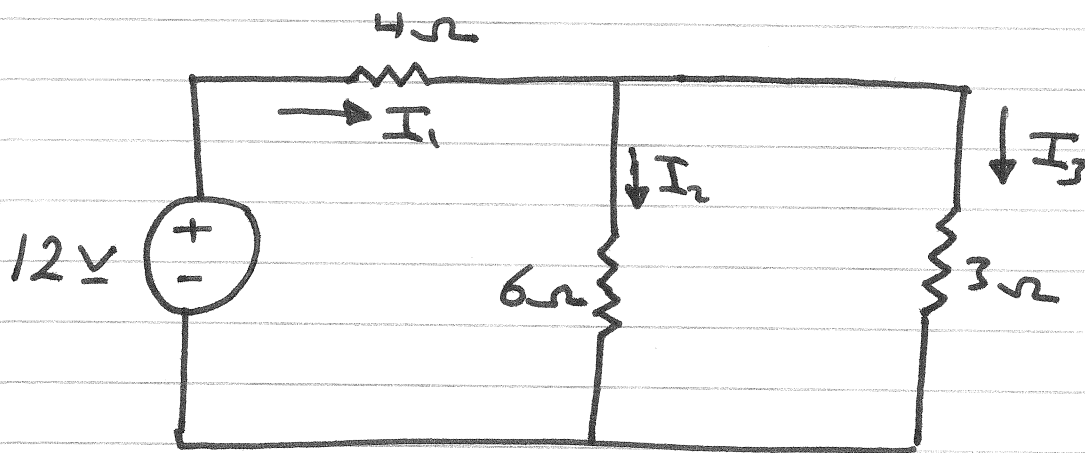
$$I_x = \frac{V_x}{R_1} + \frac{V_x}{R_2}$$

$$\therefore V_x = \frac{R_1 R_2}{R_1 + R_2} I_x$$

$$I_1 = \frac{V_x}{R_1} = \frac{R_2}{R_1 + R_2} I_x$$

$$I_2 = \frac{V_x}{R_2} = \frac{R_1}{R_1 + R_2} I_x$$

Find  $I_3$

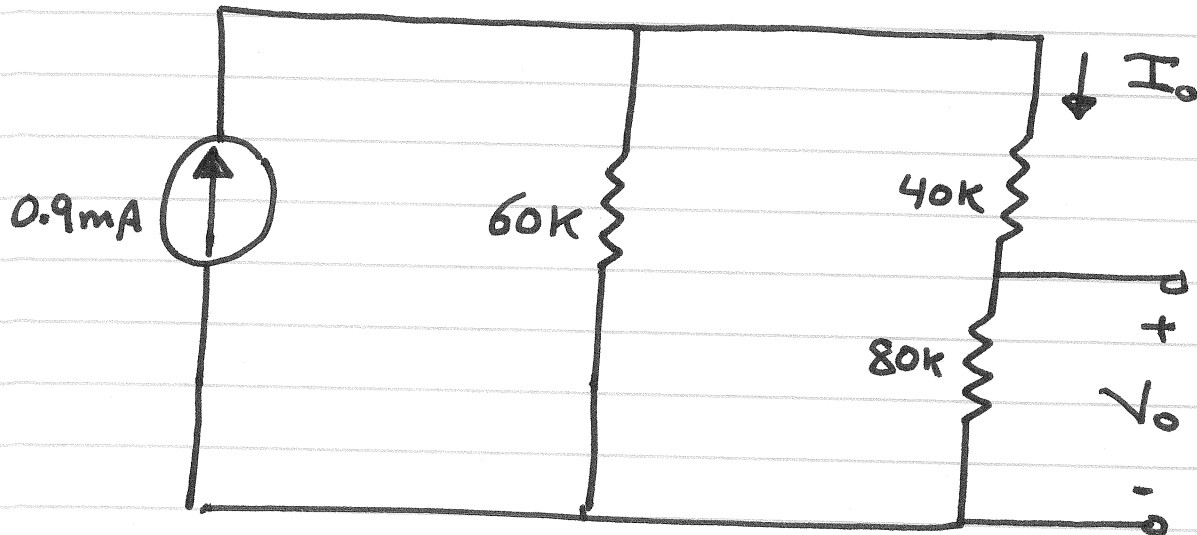


$$I_1 = \frac{12}{4+2} = 2A$$

$$I_3 = \frac{6}{6+3} I_1$$

$$I_3 = \frac{6}{9} \cdot 2 = 1.33A$$

Find  $V_o$



$$I_o = \frac{60 \text{ k}}{60 \text{ k} + (40 \text{ k} + 80 \text{ k})} \cdot 0.9 \text{ mA}$$

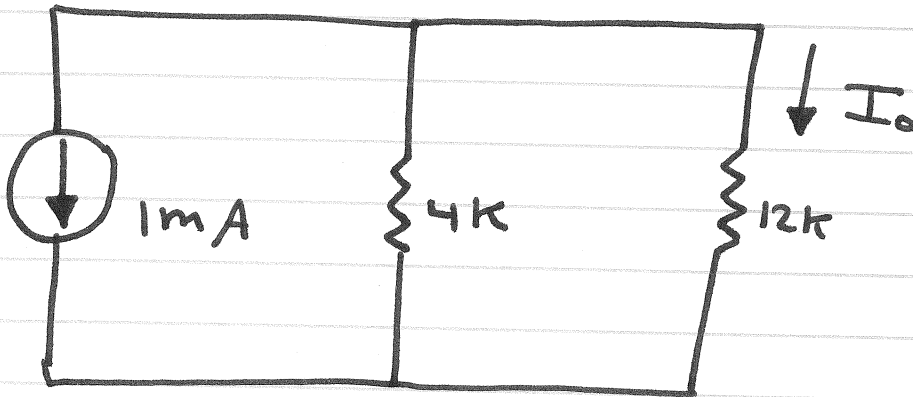
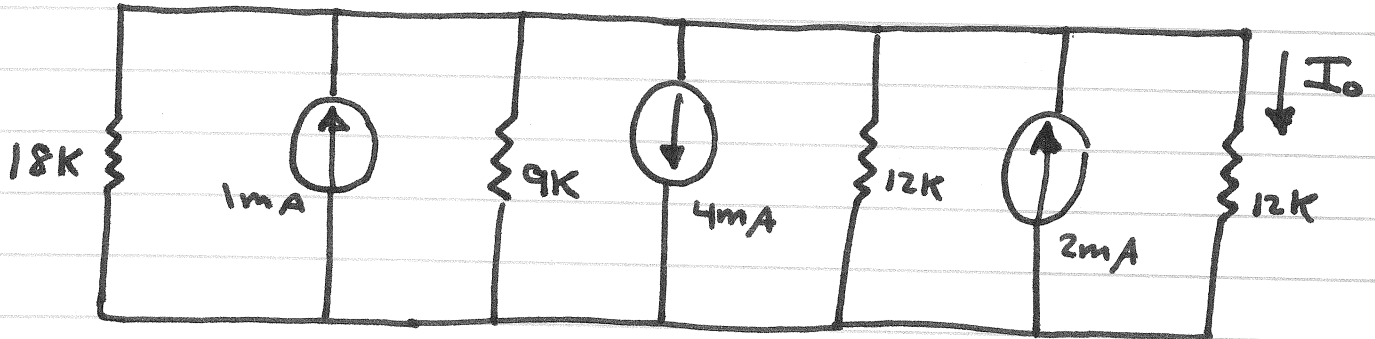
$$I_o = 0.3 \text{ mA}$$

$$V_o = 80 \text{ k} I_o$$

$$V_o = 24 \text{ V}$$

-45-

Find  $I_o$



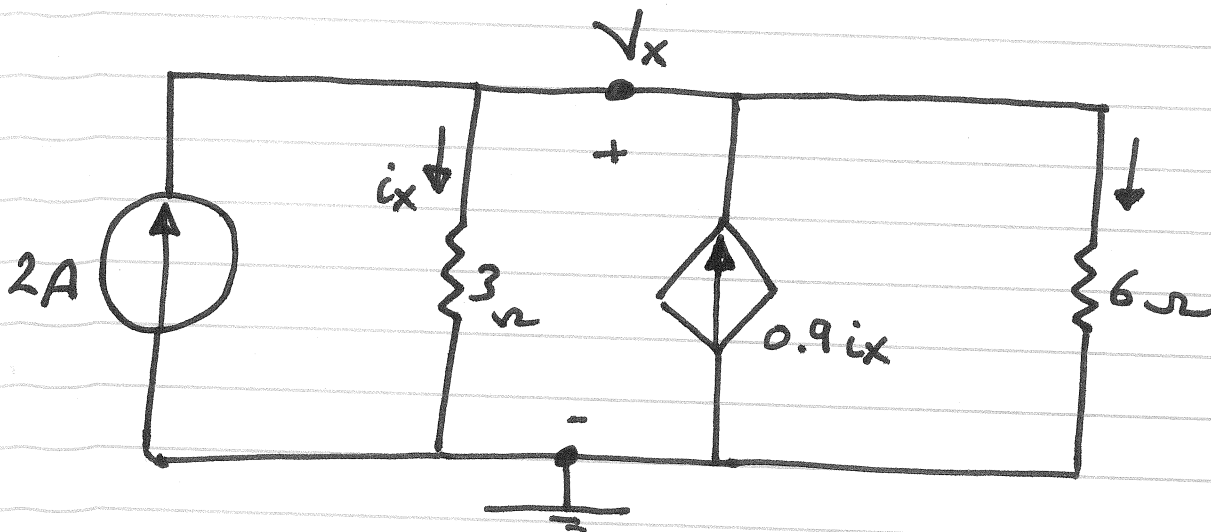
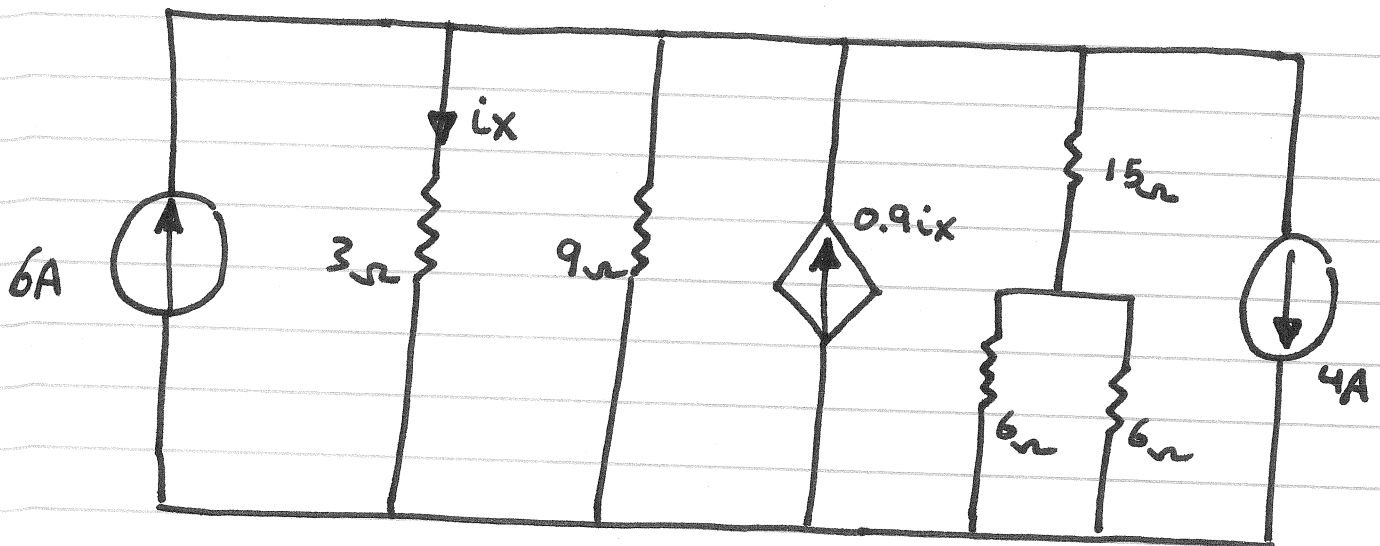
$$18k \parallel 9k \parallel 12k = 4k$$

$$I_o = - \frac{4k}{4k + 12k} 1mA$$

$$I_o = - 0.25mA$$

-46-

Find the power supplied by the  $0.9i_x$  source



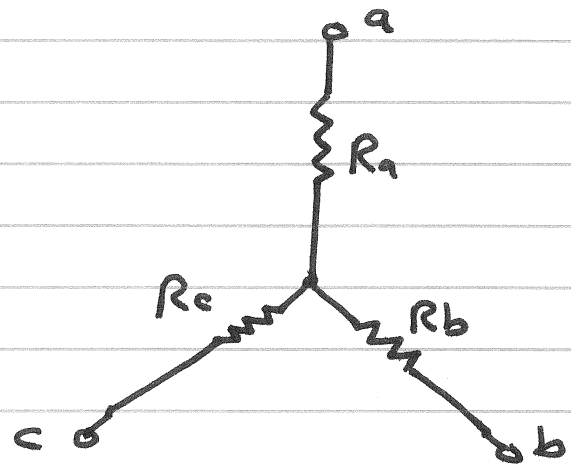
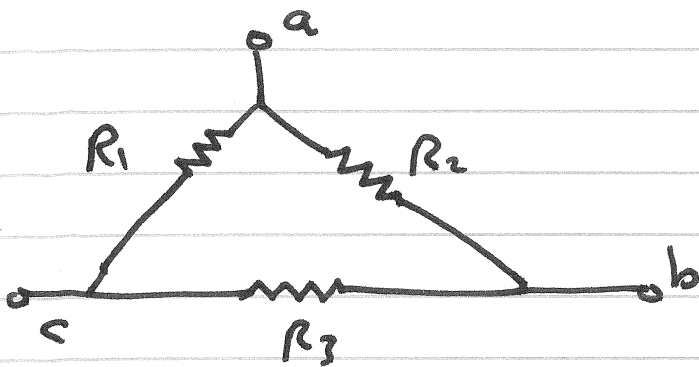
$$2 + 0.9i_x = i_x + \frac{v_x}{6}$$

$$i_x = \frac{v_x}{3}$$

$$\therefore v_x = 10\text{V} ; i_x = \frac{10}{3}\text{A}$$

$$P_{0.9i_x} = -(0.9i_x)v_x = -30\text{W} \text{ Supplying}$$

## Delta $\rightleftharpoons$ Wye Transformation



$$R_{ab} = R_a + R_b = \frac{R_2 (R_1 + R_3)}{R_1 + R_2 + R_3}$$

$$R_{bc} = R_b + R_c = \frac{R_3 (R_1 + R_2)}{R_1 + R_2 + R_3}$$

$$R_{ca} = R_c + R_a = \frac{R_1 (R_2 + R_3)}{R_1 + R_2 + R_3}$$

Solving this set of equations

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

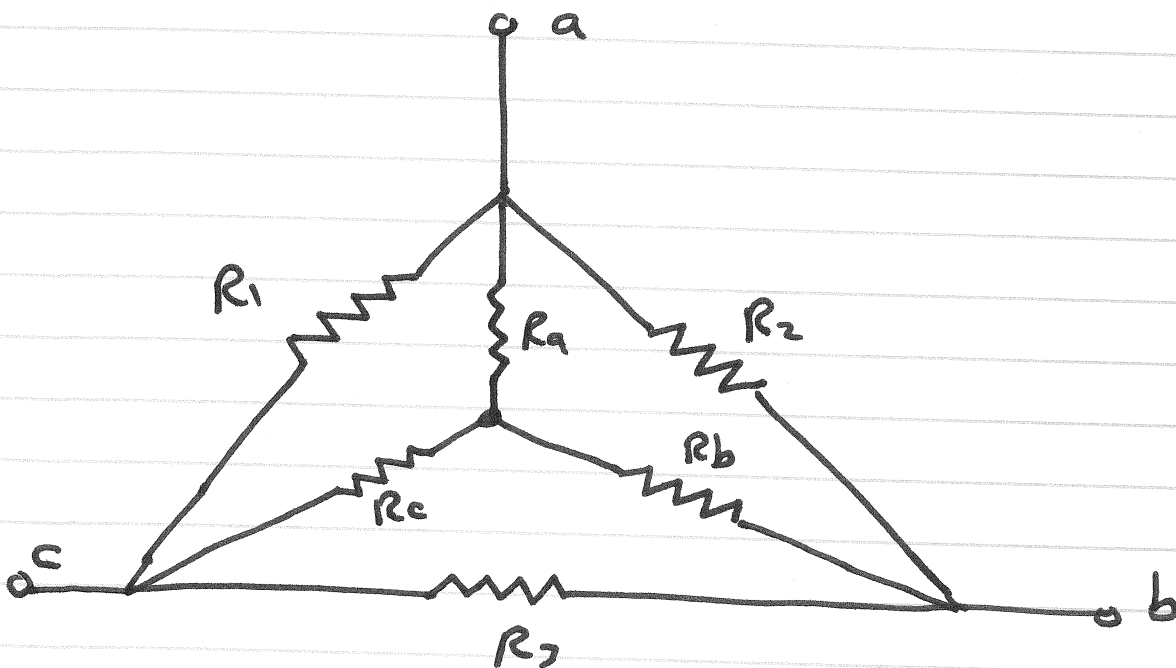
$$R_b = \frac{R_2 R_3}{R_1 + R_2 + R_3}$$

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

$$R_1 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_b}$$

$$R_2 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_c}$$

$$R_3 = \frac{R_a R_b + R_b R_c + R_c R_a}{R_a}$$





For the balanced case where

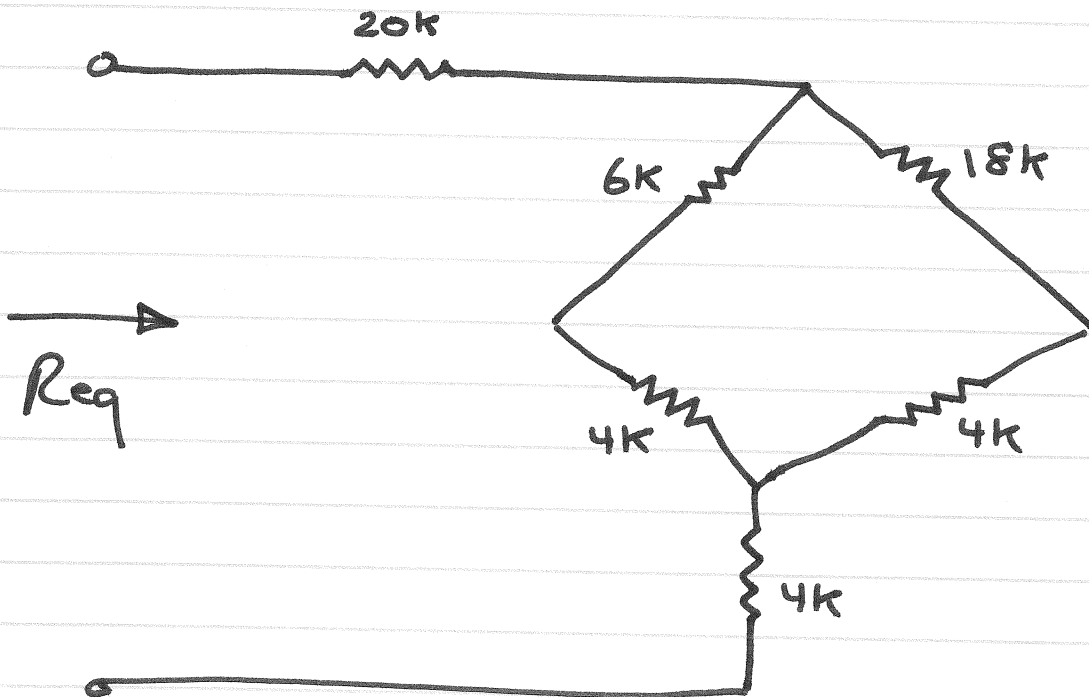
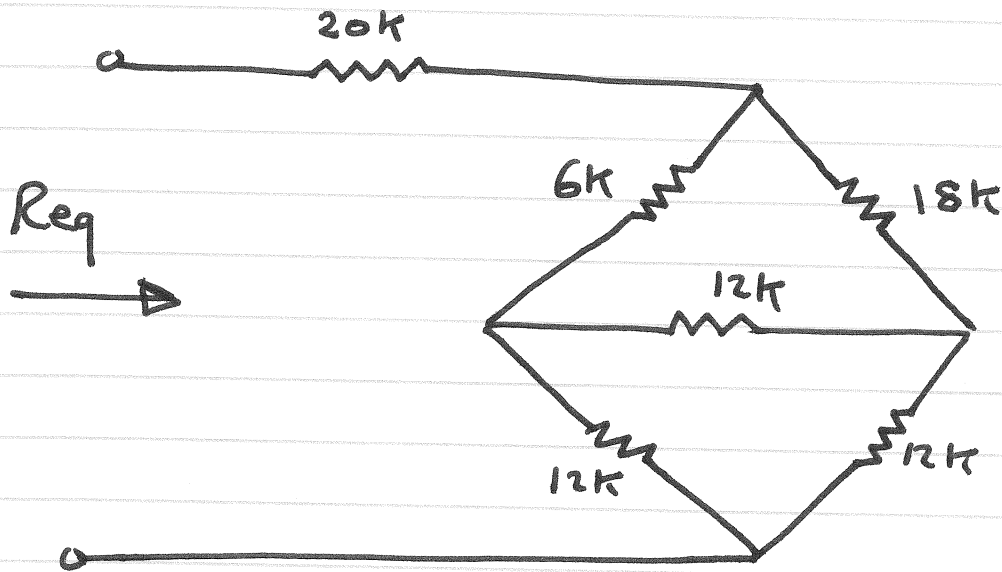
$$R_a = R_b = R_c = R_y$$

$$R_1 = R_2 = R_3 = R_\Delta$$

$$R_\Delta = 3 R_y$$

$$R_y = \frac{1}{3} R_\Delta$$

Find Req

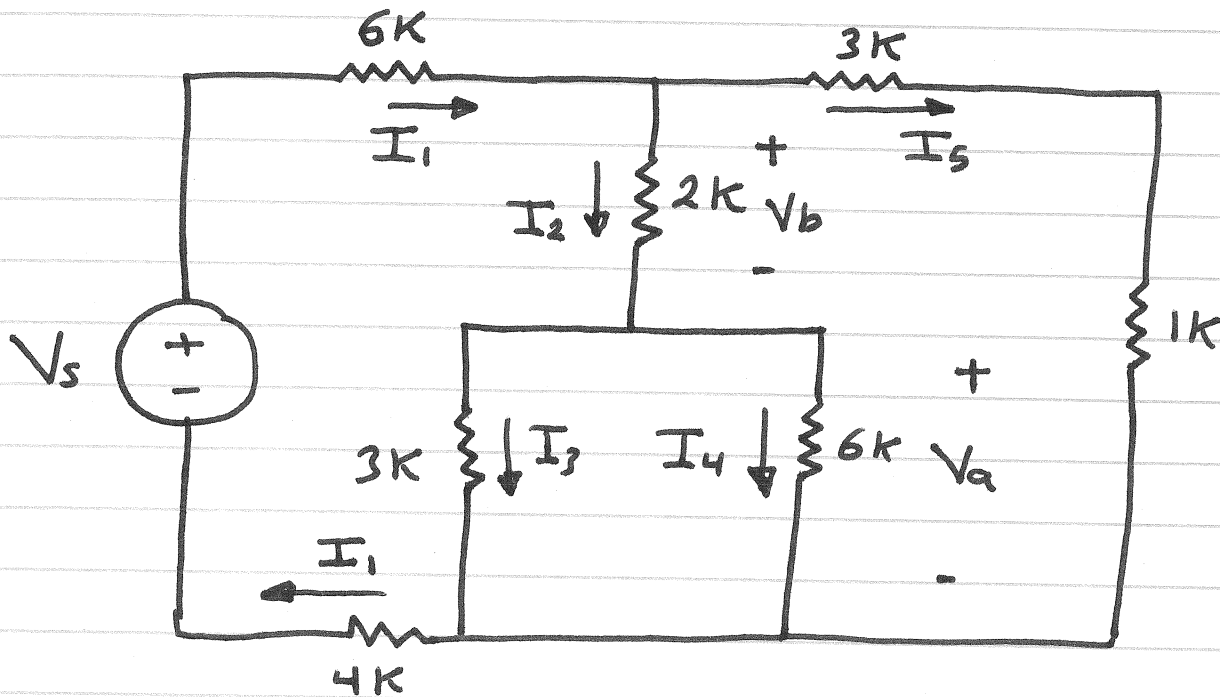


$$R_{eq} = 20k + 4k + (6k + 4k) \parallel (18k + 4k)$$

$$R_{eq} = 30.88k$$

Design :

Given  $I_4 = 0.5 \text{ mA}$ , Find  $V_s$



$$V_a = (6k\Omega)(0.5 \text{ mA}) = 3 \text{ V}$$

$$I_3 = \frac{V_a}{3k} = 1 \text{ mA}$$

$$I_2 = I_3 + I_4 = 1.5 \text{ mA}$$

$$V_b = (2k\Omega)(1.5 \text{ mA}) = 3 \text{ V}$$

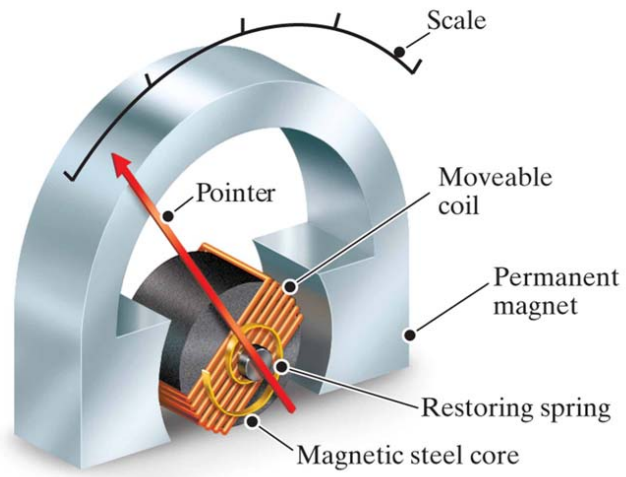
$$I_5 = \frac{V_a + V_b}{4k} = 1.5 \text{ mA}$$

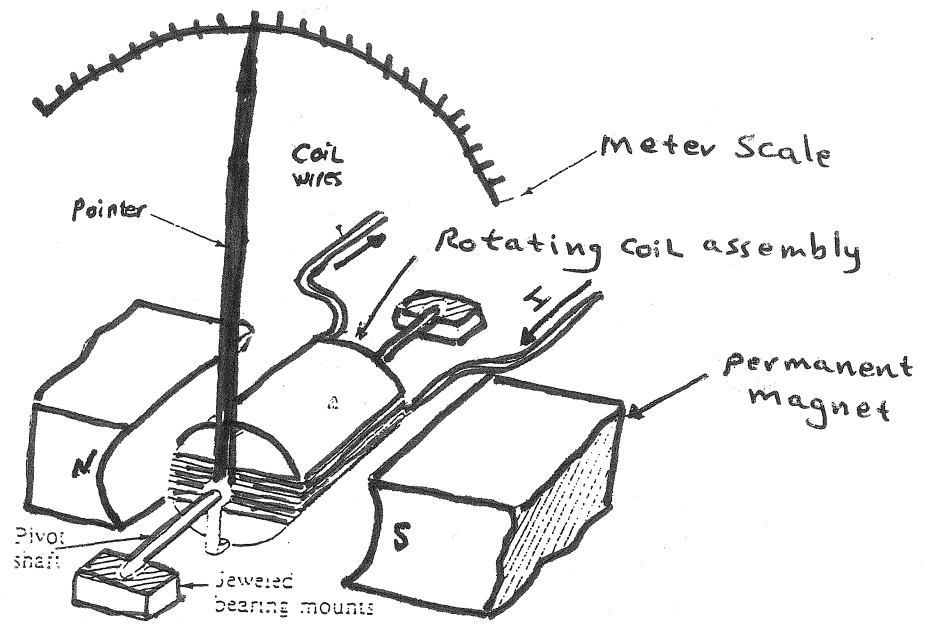
$$I_1 = I_2 + I_5 = 3 \text{ mA}$$

$$V_s = (10k\Omega) I_1 + V_b + V_a = 36 \text{ V}$$

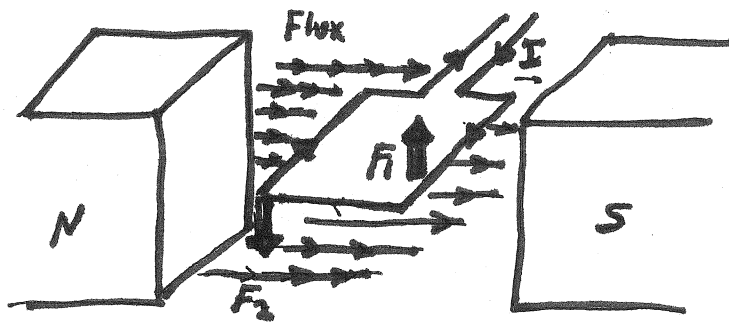
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Figure 3.23 A schematic diagram of a d'Arsonval meter movement.





Basic components of a D'Arsonval movement



$$F_1 = F_2 = I l B$$

$$\tau = I l B d$$

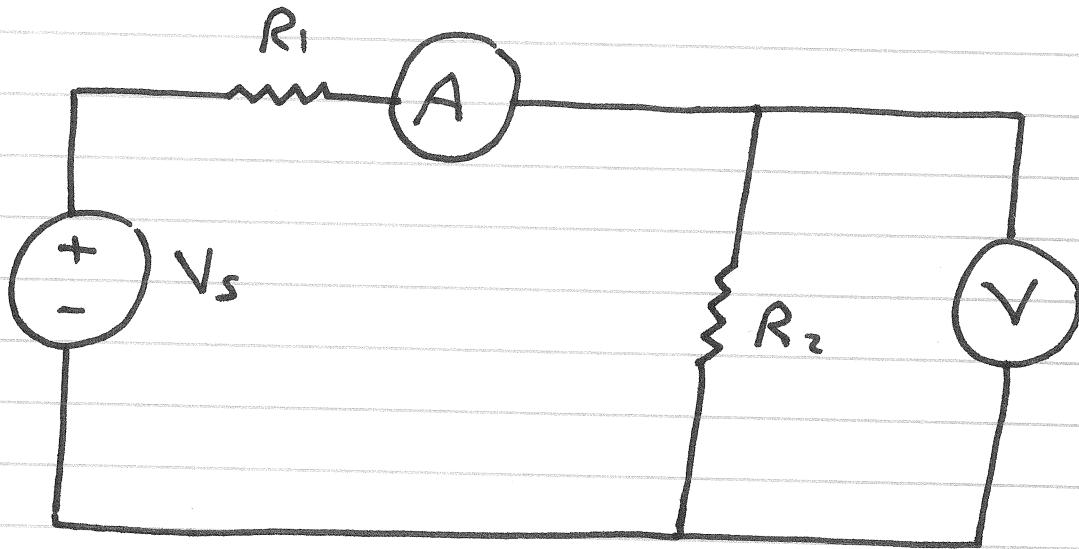
If the coil has  $N$  turns

$$\tau = I l B N d$$

## The D'Arsonval meter movement

- If a current is passed through the movable coil, the resulting magnetic field reacts with the magnetic field of the permanent magnet producing a torque which is counterbalanced by a restoring spring.
- The deflection of the pointer attached to the coil is proportional to the current produced by the quantity being measured.

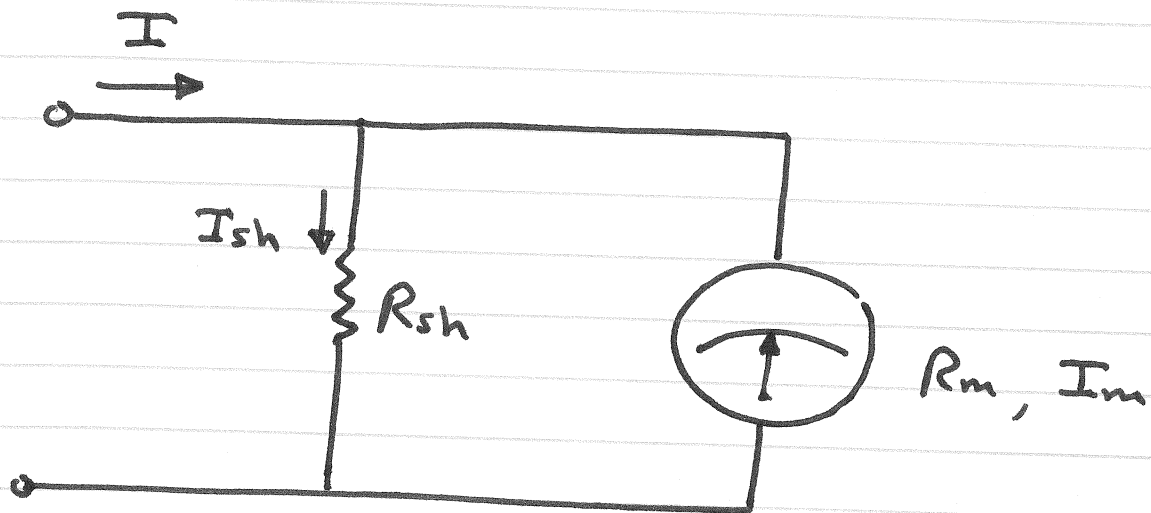
# Measuring Voltage and Current



Ammeter : designed to measure current

Voltmeter : designed to measure voltage

# Dc Ammeter



$$R_{sh} I_{sh} = R_m I_m$$

$$R_{sh} = \frac{R_m I_m}{I_{sh}} = \frac{R_m I_m}{I - I_m}$$



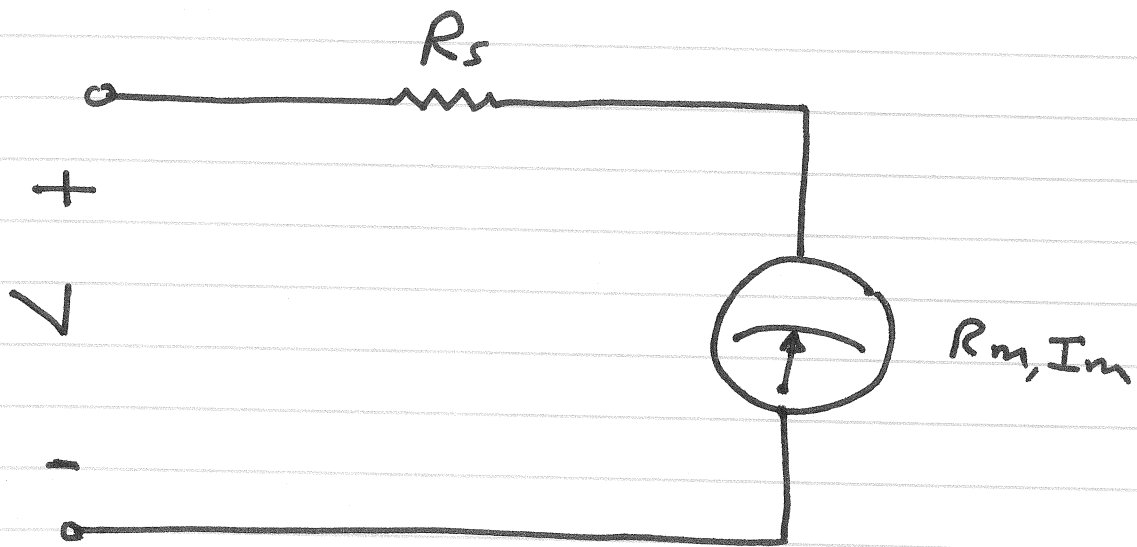
A 0-1mA meter movement with an internal resistance of  $100\ \Omega$  is to be converted to a 0-100mA Ammeter.

$$I_m = 1\text{mA}$$
$$R_m = 100\ \Omega$$

$$I = 100\text{mA}$$
$$I_{sh} = 99\text{mA}$$

$$R_{sh} = \frac{I_m R_m}{I - I_m} = 1.01\ \Omega$$

Dc Voltmeter



$$V = R_s I_m + R_m I_m$$

$$R_s = \frac{V - R_m I_m}{I_m}$$

A basic D'Arsonval movement with

$$I_m = 1 \text{ mA} \quad \text{and} \quad R_m = 100 \, \Omega$$

is to be converted into a dc voltmeter

with the range  $0 - 10 \text{ V}$

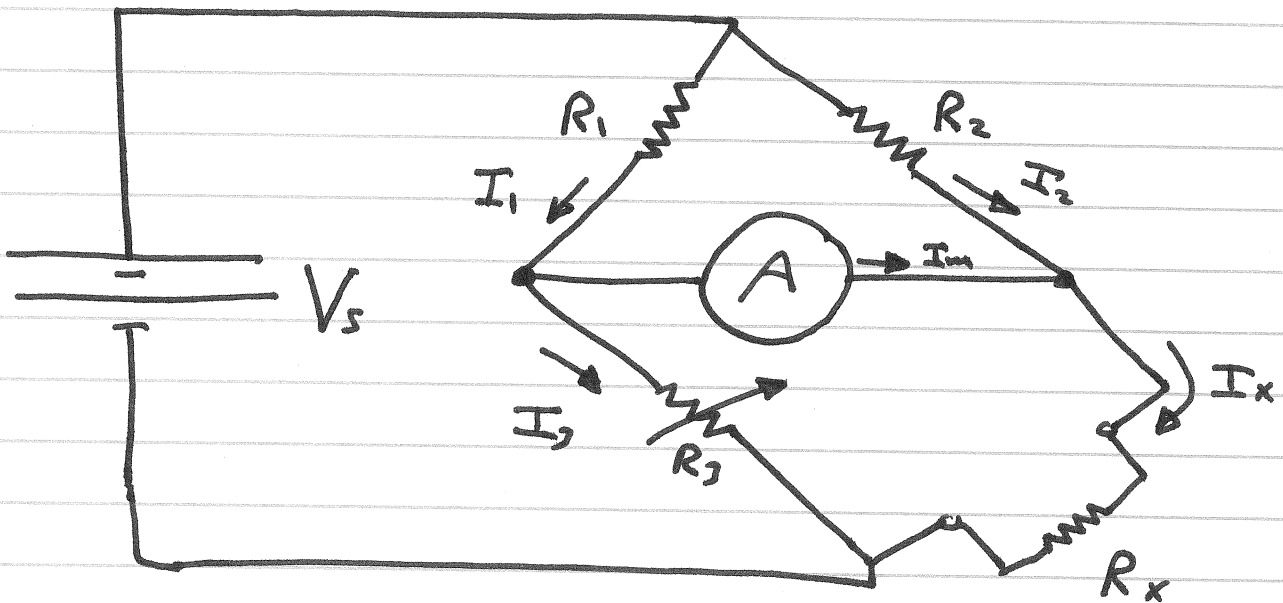
$$R_s = \frac{V - R_m I_m}{I_m}$$

$$= \frac{10 - (100)(1 \times 10^{-3})}{1 \times 10^{-3}}$$

$$R_s = 9900 \, \Omega$$

# Measuring Resistance

## Wheatstone Bridge



$R_3$  is adjusted until  $I_m = 0$

Bridge is balanced :  $I_1 = I_2$   
 $I_3 = I_x$   
 $V_m = 0$

$$R_1 I_1 = R_2 I_2$$

$$R_3 I_3 = R_x I_x$$

$$\frac{R_1 I_1}{R_3 I_3} = \frac{R_2 I_2}{R_x I_x}$$

$$\frac{R_1}{R_3} = \frac{R_2}{R_x} \longrightarrow R_x = \frac{R_2 R_3}{R_1}$$