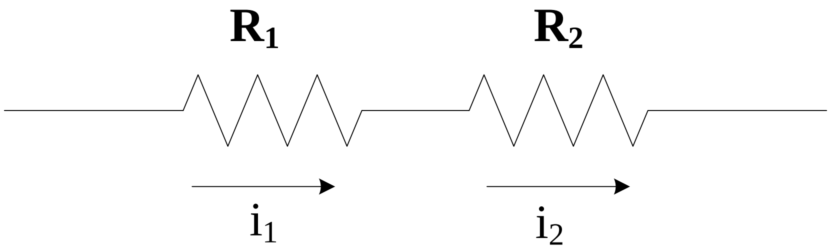
Week2

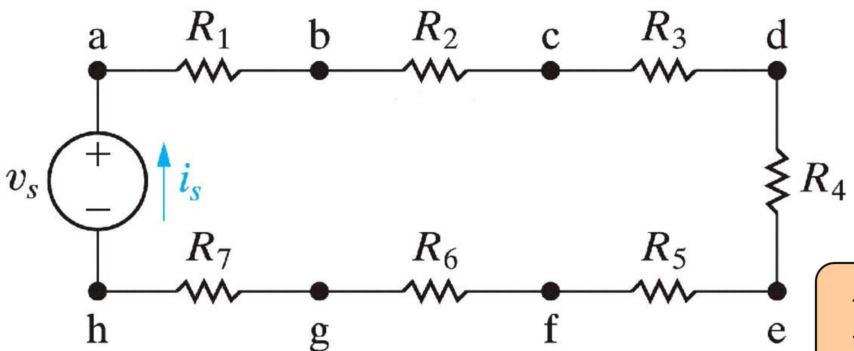
Resistive Circuits

Series Connection

Two Elements Connected at a Single Node



$$i_1 = i_2 \Big\}$$ **KCL**



$$v_s = i_s\left(R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7\right)$$

Resistors in series have the same current

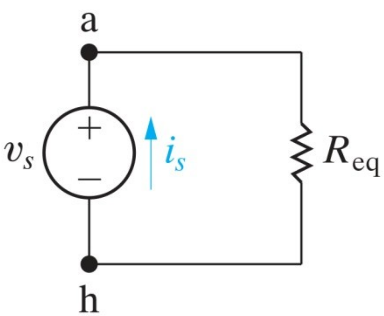


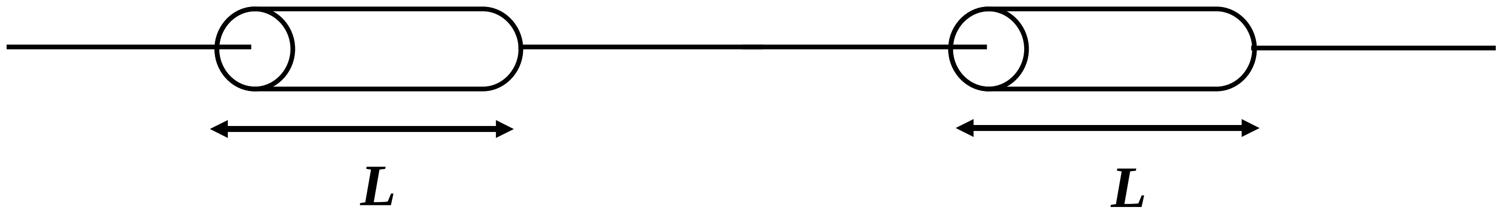
Figure: 03-03

$$v_s = i_s R_{eq}$$

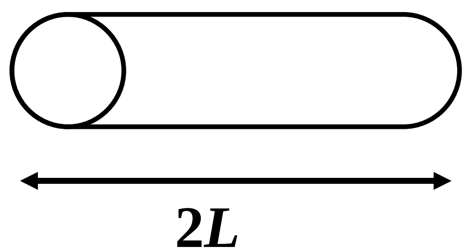
$$R_{eq} = R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7$$

Resistors in Series

Can be used to simplify circuits



Same as

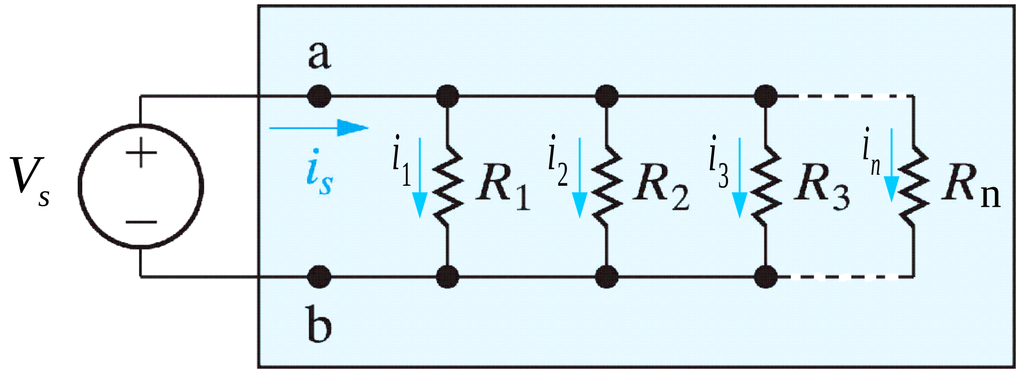


$$R = \rho \cdot \frac{L}{A}$$

Parallel Connections

Elements connected at a single node pair

2 nodes in this circuit



All Resistors In Parallel

All the resistors have the same voltage, v_s, across them

Currents are different

R_{eq}

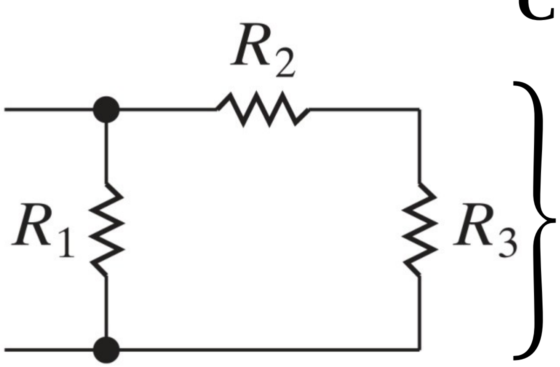


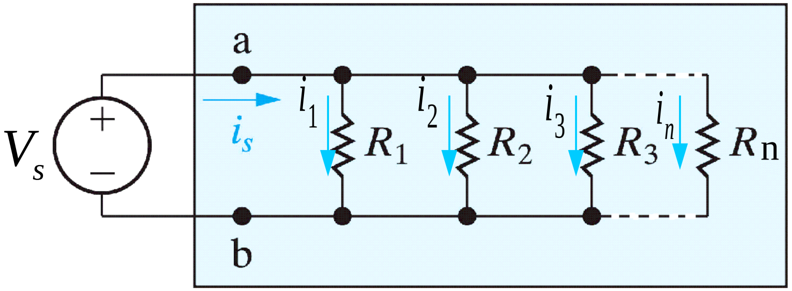
Figure: 03-06

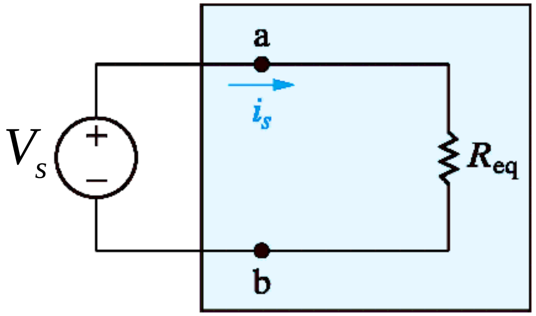
R_1 is not "||" R_3

$R_1 \parallel (R_2 + R_3) = R_{eq}$

R_2 and R_3 are in series

Equivalent Resistance of Resistors in Parallel





For n=4

$$i_s = i_1 + i_2 + i_3 + i_4 \quad \text{KCL} \qquad (1)$$

$$V_s = i_1 R_1 = i_2 R_2 = i_3 R_3 = i_4 R_4 \quad (2) \qquad \text{Ohm's Law}$$

$$i_s = \frac{V_s}{R_1} + \frac{V_s}{R_2} + \frac{V_s}{R_3} + \frac{V_s}{R_4}$$

Solve for *i*'s in (2) and then substitute into (1)

$$\boxed{\frac{i_s}{V_s} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{R_{eq}}}$$

Solve for i_s / V_s

Special Case: 2 Resistors in Parallel

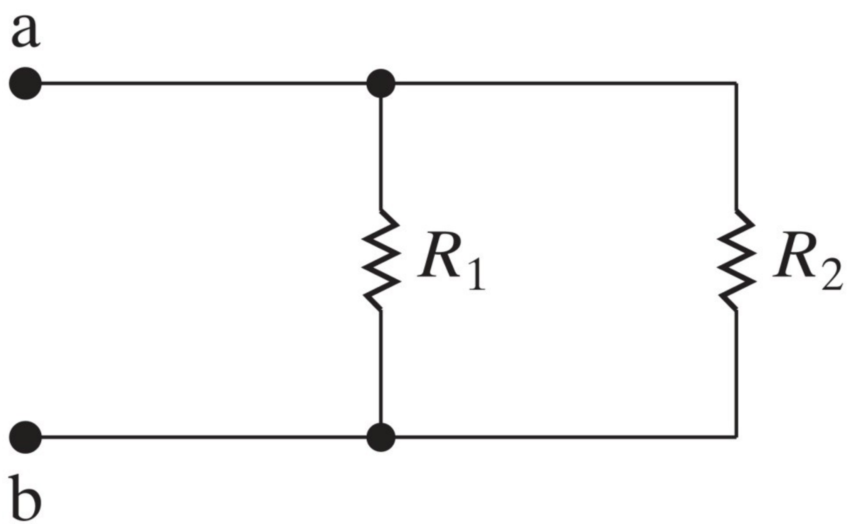


Figure: 03-08

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

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

R_1 (Ω)	R_2 (Ω)	R_{eq} (Ω)
1000	1000	$500 = 0.5R_1 = 0.5R_2$
1000	500	333.333
10,000	100	99.01 (approx. 100)
10^6	100	99.99 (approx. 100)

$\}$ ≈ **Smallest**

$R_{eq} < R_1$
and
$R_{eq} < R_2$

Drill Exercise: Find Voltage v

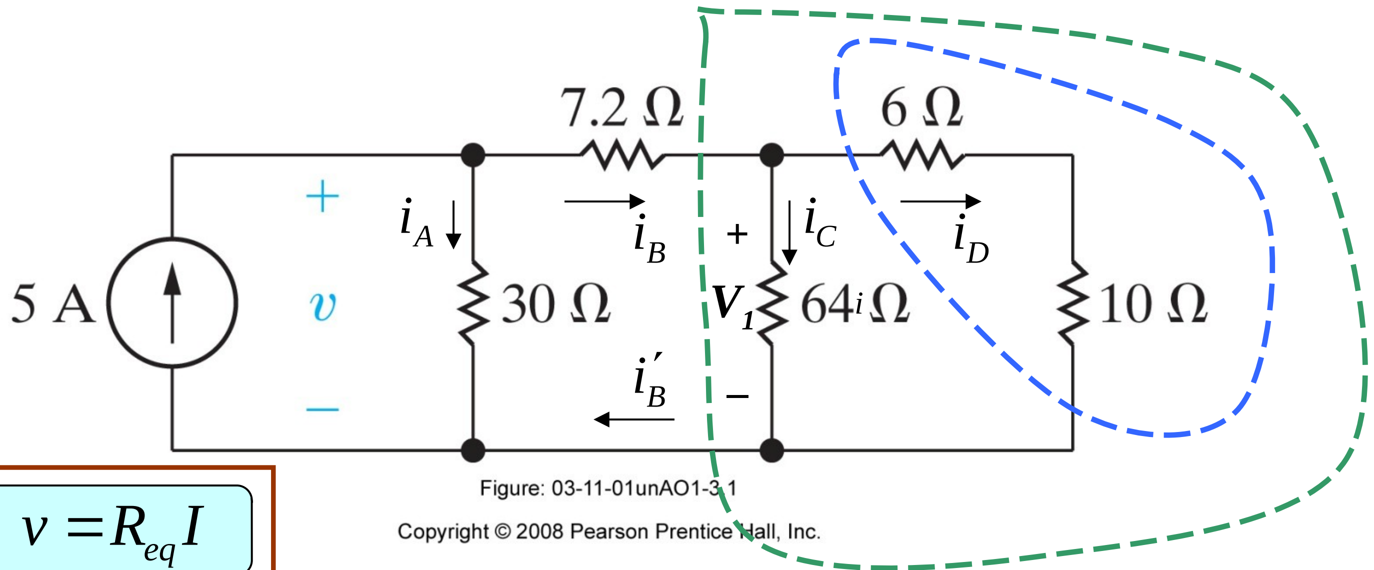


Figure: 03-11-01unAO1-3.1

Side Note

$$\left.i_B = i_C + i_D\right\}\textbf{KCL}$$

$$\left.i'_B = i_C + i_D\right\}\textbf{KCL}$$

$$i'_B = i_B$$

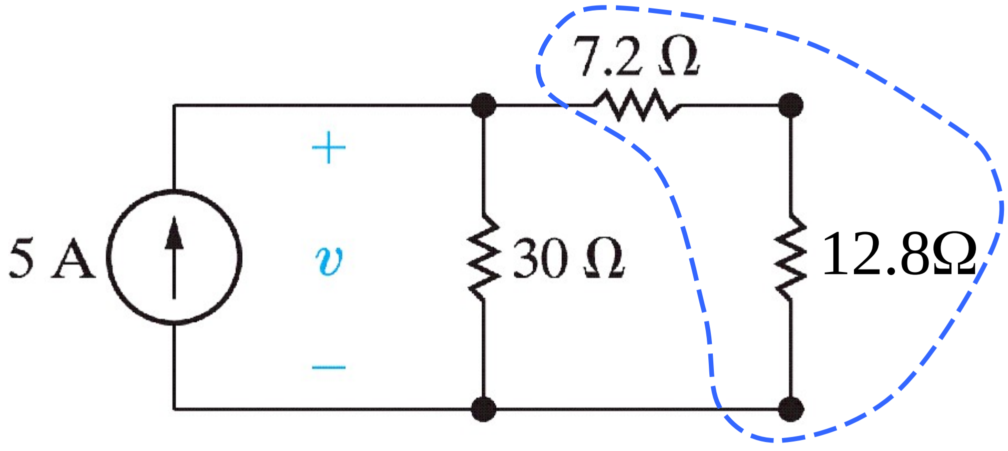
$$v = R_{eq} I$$

Note: $I = 5(A)$

Find R_{eq}

$$\begin{cases} \left.10\Omega + 6\Omega = 16(\Omega)\right\} & \textbf{Add series resistors} \\ \left.16\Omega \parallel 64\Omega = \dfrac{16 \times 64}{16 + 64} = 12.8(\Omega)\right\} & \textbf{Simplify Parallel Resistors} \end{cases}$$

Drill Exercise (Contd.)



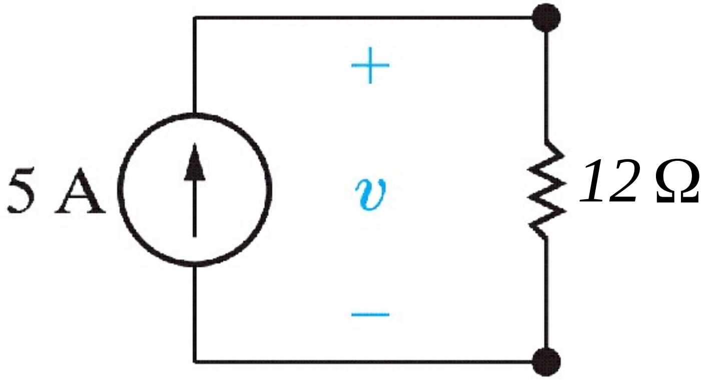
$$12.8\Omega + 7.2\Omega = 20(\Omega)$$

Add series resistors

$$20 \,||\, 30 = \frac{20 \times 30}{20 + 30} = 12(\Omega)$$

Simplify Parallel Resistors

Drill Exercise (Contd.)



$v = IR \Rightarrow$ a) $v = 5A(12\Omega) = 60(V)$

$p = Iv \Rightarrow$ b) $p_{del} = (5\text{A})(60\text{V}) = 300(W) \Big\} \; \boxed{p > 0}$

Same Problem: What is the Power delivered to the 10Ω Resistor?

$v = 60(V)$ } **Found in the previous slide**

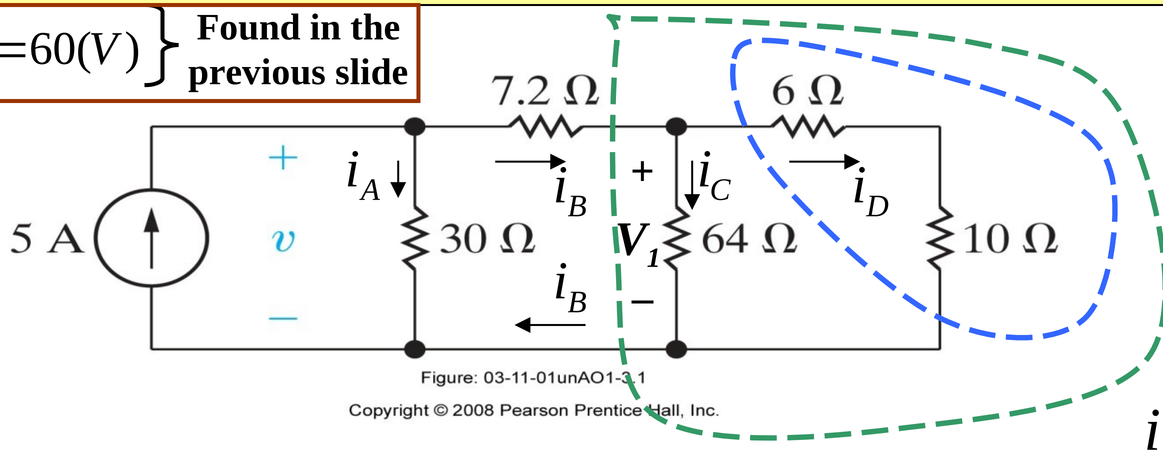


Figure: 03-11-01unAO1-3.1

1 $5(A) = i_A + i_B$ } **KCL**

2 $i_A = \underbrace{\dfrac{v}{30\Omega}}_{\text{Ohm's Law}} = \dfrac{60}{30} = 2(A)$

$$\underbrace{i_B = 5(A) - i_A = 5 - 2 = 3(A)}_{\text{Substitute 2 into 1}}$$

$v = i_B(7.2\Omega) + V_1$ } **Use KVL to find V_1**

$V_1 = v - i_B(7.2\Omega) = 60 - 3(7.2) = 38.4(V)$ } **Solve for V_1**

$i_D = V_1 / (10\Omega + 6\Omega) = 38.4 / 16 = 2.4(A)$ } **Use Ohm's Law to find i_C**

$p_{10\Omega} = i_D^{\,2} \cdot 10 = (2.4)^2 10$

$\boxed{p_{10\Omega} = 57.6(W)}$ } **Find Power**

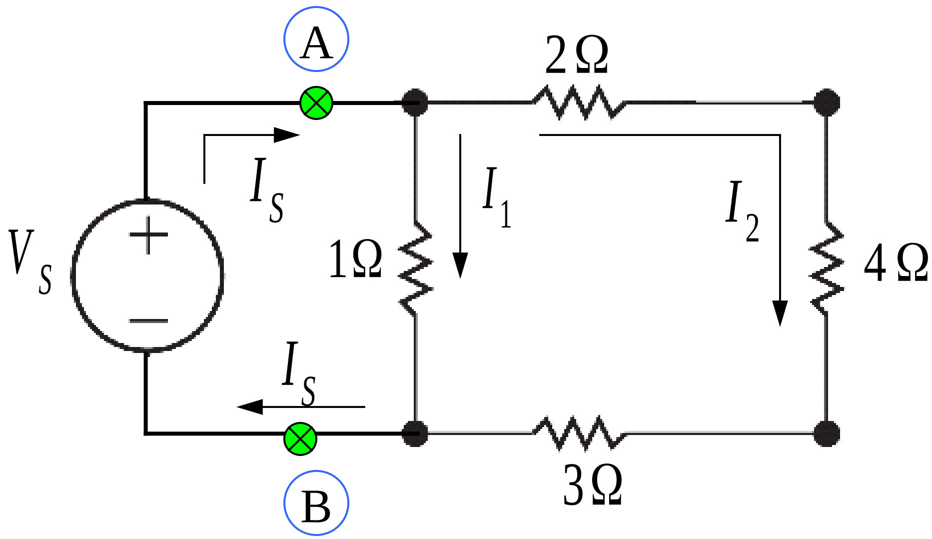
In General

When solving problems at this point,

Ask how I can use:

- Ohms Law
- KVL
- KCL
- R_{eq}
- Knowledge of Current and Voltage
  - Current same in series
  - Voltage same in parallel

Equivalent Resistance Examples



What is R_{eq} at A and B

$$R_{eq} = 1 \,||\, (2+3+4) =$$

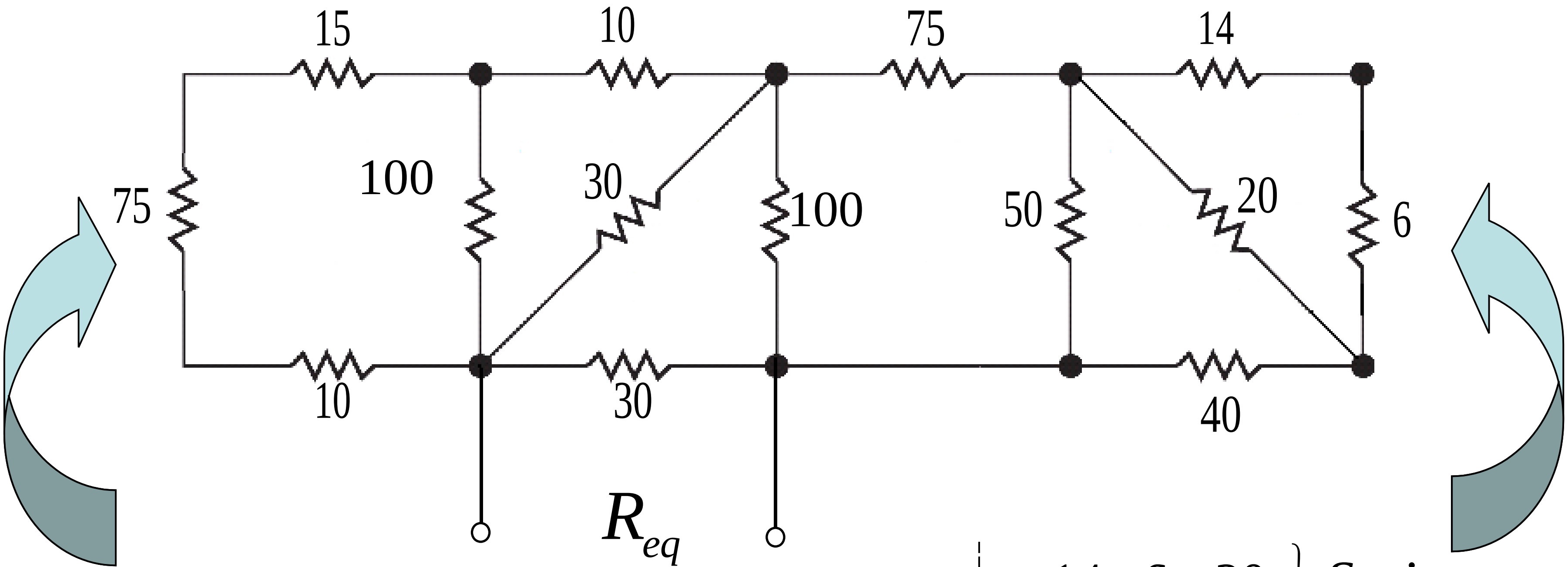
$$\frac{1 \cdot (2+3+4)}{1+(2+3+4)} = \frac{9}{10}(\Omega)$$

Example $V_s = I_s R_{AB} \equiv I_s R_{eq}$

Note: Depending on where you take R_{eq},

You will have to do a different calculation

Example: Find R_{eq}



$$\text{Series} \quad 75+15+10=100$$

$$\text{Parallel} \quad 100||100=50$$

$$\text{Series} \quad 50+10=60$$

$$\text{Parallel} \quad 60||30=\frac{60(30)}{60+30}=\frac{1800}{90}=20$$

$$14+6=20 \quad \text{Series}$$

$$20||20=10 \quad \text{Parallel}$$

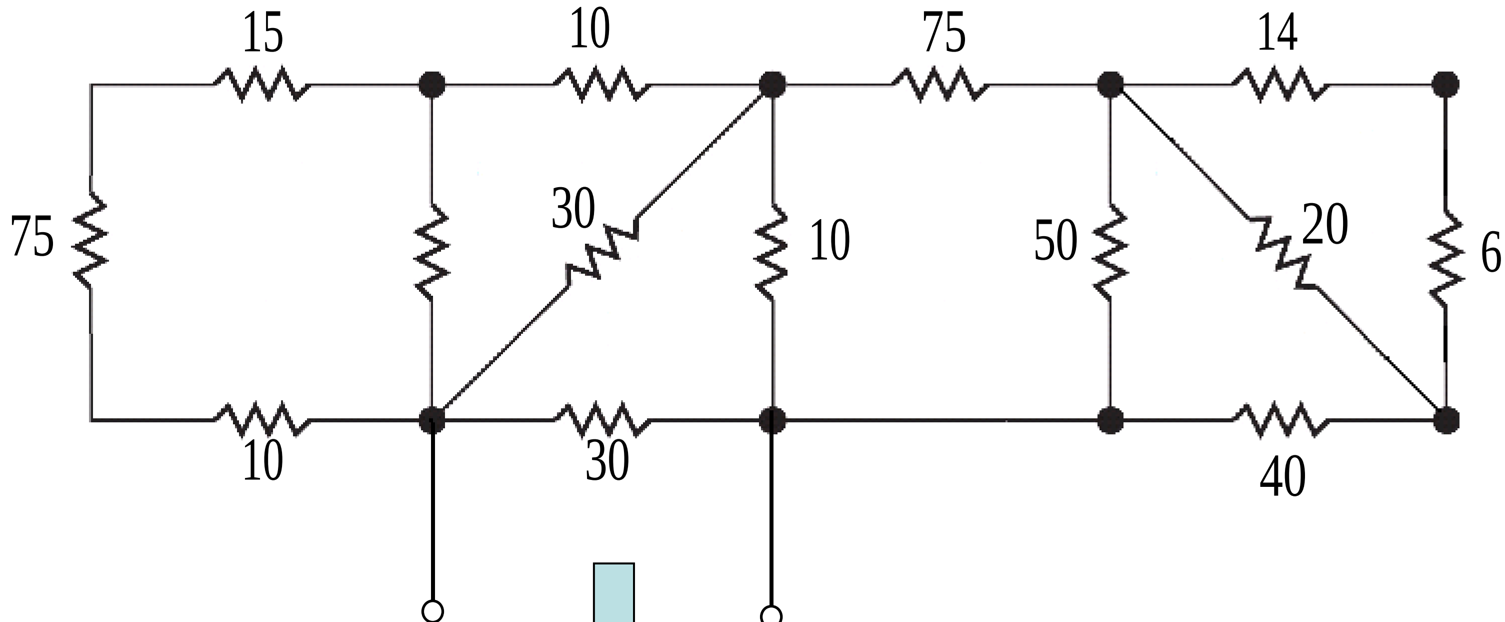
$$10+40=50 \quad \text{Series}$$

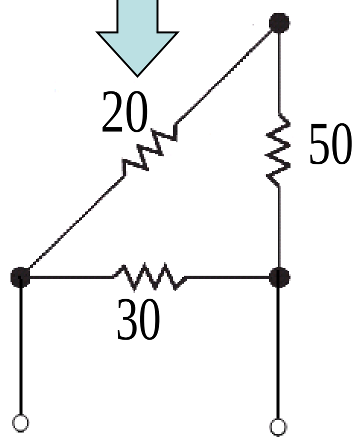
$$50||50=25 \quad \text{Parallel}$$

$$25+75=100 \quad \text{Series}$$

$$100||100=\underline{50} \quad \text{Parallel}$$

Example: Find R_{eq}



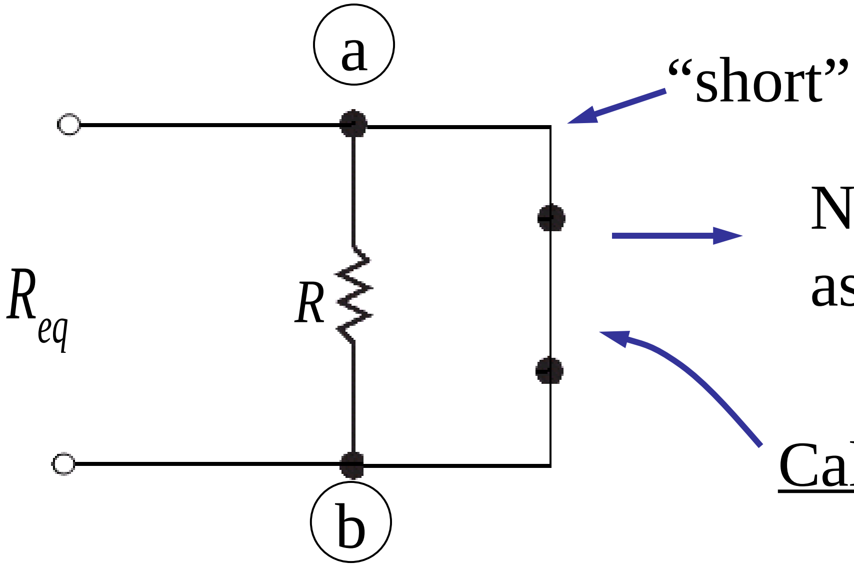


$$R_{eq} = (20+50)||30 = \frac{70(30)}{70+30} = \frac{2100}{100}$$

$$R_{eq} = 21(\Omega)$$

* Have you spotted the error ?

Notes on short circuits



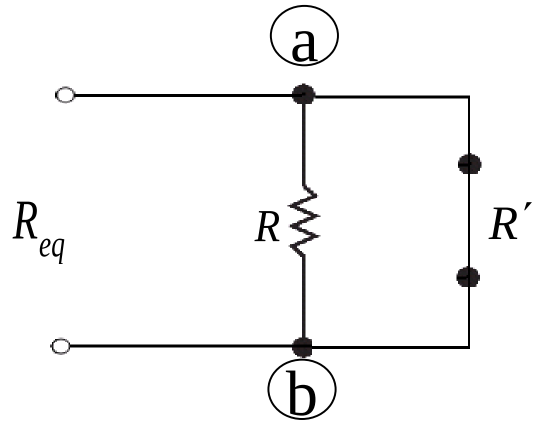
Nodes a and b connected as a Single Node

Call it R'

- All current flows through "wire"
- R is "Shorted Out"

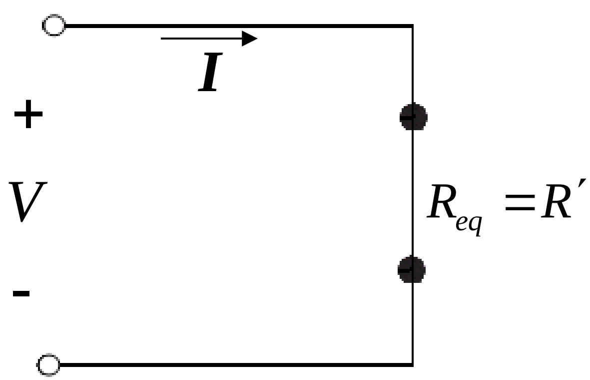
- Short wall socket
- Short power supply

Mathematical Viewpoint



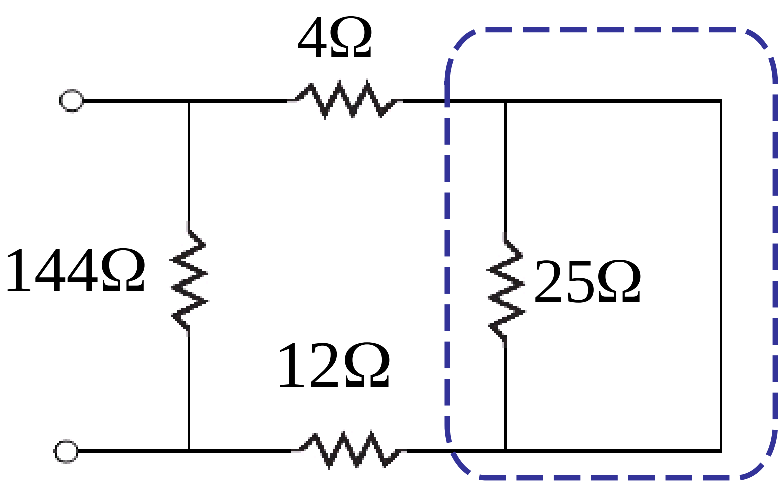
Assume the wire is a perfect conductor

$$R_{eq} = R \parallel R' = \frac{R \cdot R'}{R + R'} \Rightarrow \boxed{R_{eq} = \frac{R(0)}{R+0} = 0}$$



$$I = \frac{V}{R'} \quad \text{as} \quad R' \to 0 \quad \text{and} \quad I \to \infty$$

Example: Find R_{eq}



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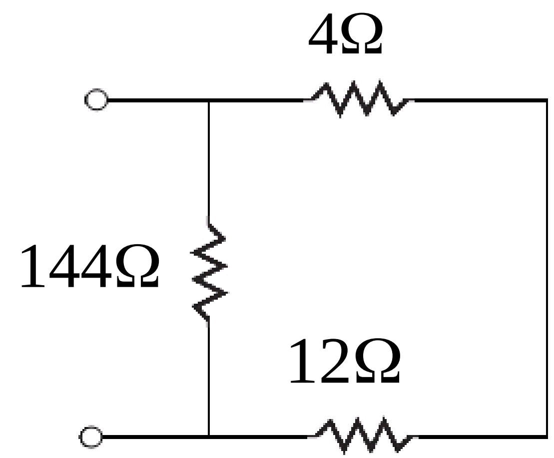
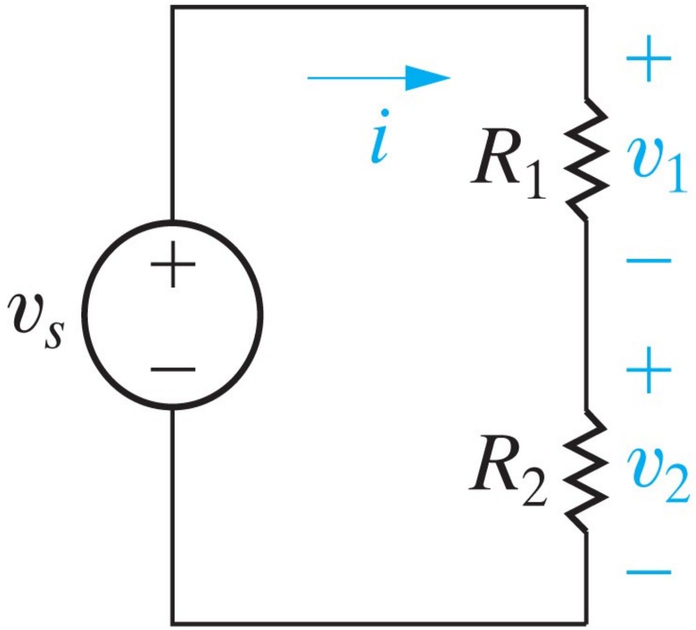


$$R_{eq} = (4+12) \| 144$$

$$R_{eq} = 14.4(\Omega)$$

Voltage Division

Voltage is "proportionally" distributed among resistors in a circuit.



$$v_s = i(R_1 + R_2)$$ **Ohm's Law**

1 $$i = v_s / (R_1 + R_2)$$ **Ohm's Law**

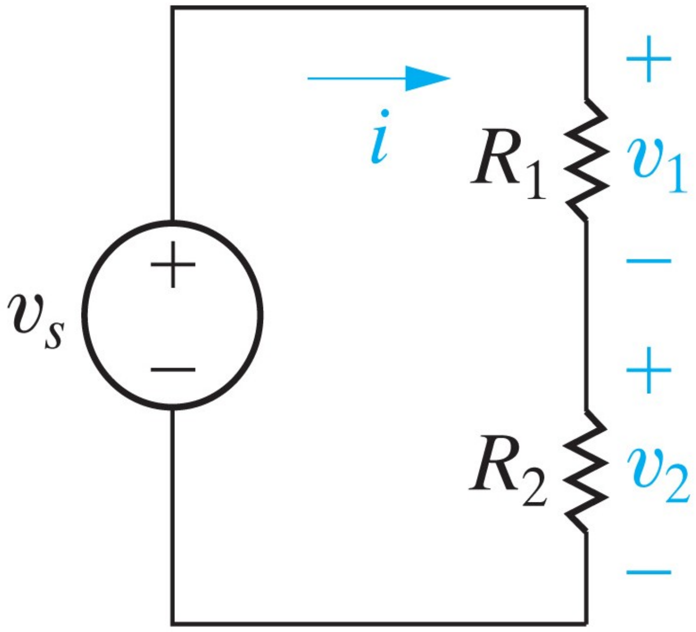
$$v_1 = iR_1 = v_s \frac{R_1}{R_1 + R_2}$$

$$v_2 = iR_2 = v_s \frac{R_2}{R_1 + R_2}$$

Use Ohm's Law and 1

Bigger R's have larger voltages ★ *Voltage Division* ★

Voltage Division (Contd.)

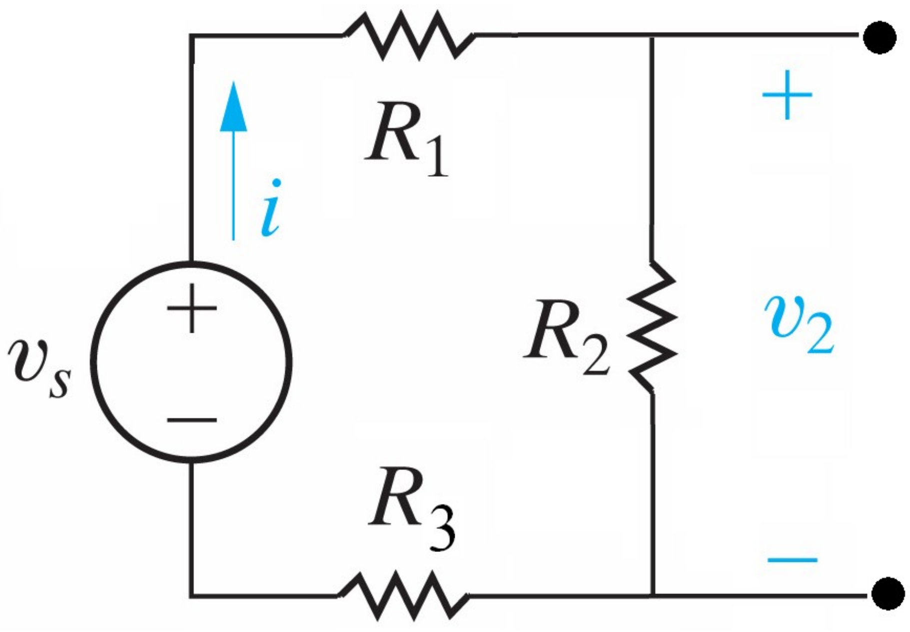


v_1 is a fraction $\left(\dfrac{R_1}{R_1+R_2} \equiv \dfrac{R_1}{R_{Total}}\right)$ of v_s

Special Case

$$R_1 = R_2 ; v_1 = v_2 = \frac{1}{2} v_s$$

Example: Use Voltage Division to Find v_2



$v_s = 10V$ **Given**

$R_1 = 3\Omega;\ R_2 = 4\Omega;\ R_3 = 3\Omega$

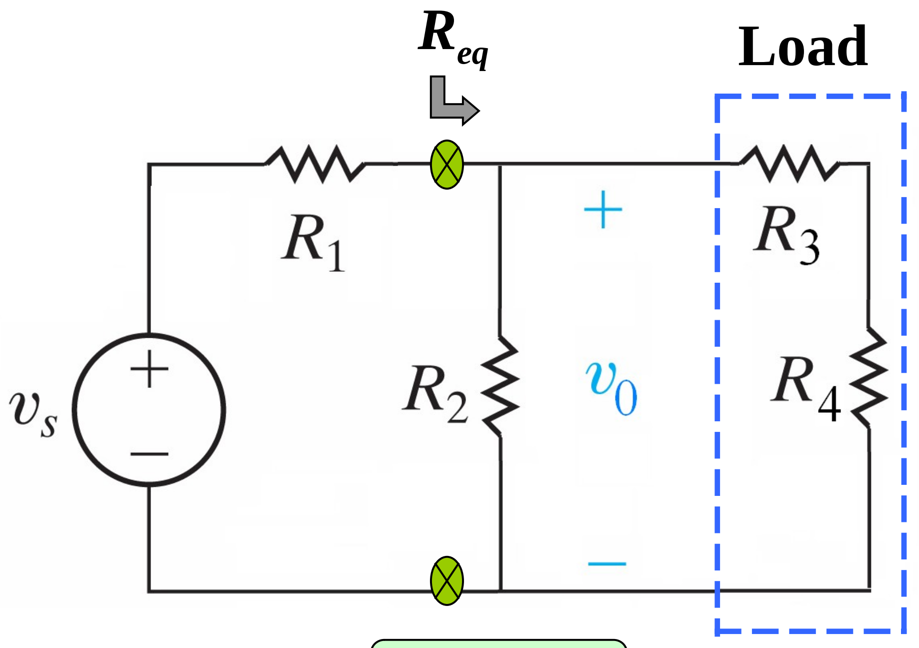
$$v_2 = v_s\left(\frac{R_2}{R_1 + R_2 + R_3}\right)$$ **Voltage across R_2**

$$= 10\left(\frac{4}{3+4+3}\right) = 10\left(\frac{4}{10}\right) = 4(V)$$

$$v_1 = v_s\left(\frac{R_1}{R_1 + R_2 + R_3}\right) = 10\left(\frac{3}{10}\right) = 3(V)$$ **Voltage across R_1**

$$v_3 = v_s\left(\frac{R_3}{R_1 + R_2 + R_3}\right) = 10\left(\frac{3}{10}\right) = 3(V)$$ **Voltage across R_3**

Example: Find v_0



$$v_s = 100V$$
$$R_1 = 5K\Omega;\ R_2 = 50K\Omega$$
$$R_3 = 10K\Omega\ ;\ R_4 = 15K\Omega$$

Given

$$v_0 = v_s \frac{R_{eq}}{R_1 + R_{eq}}$$

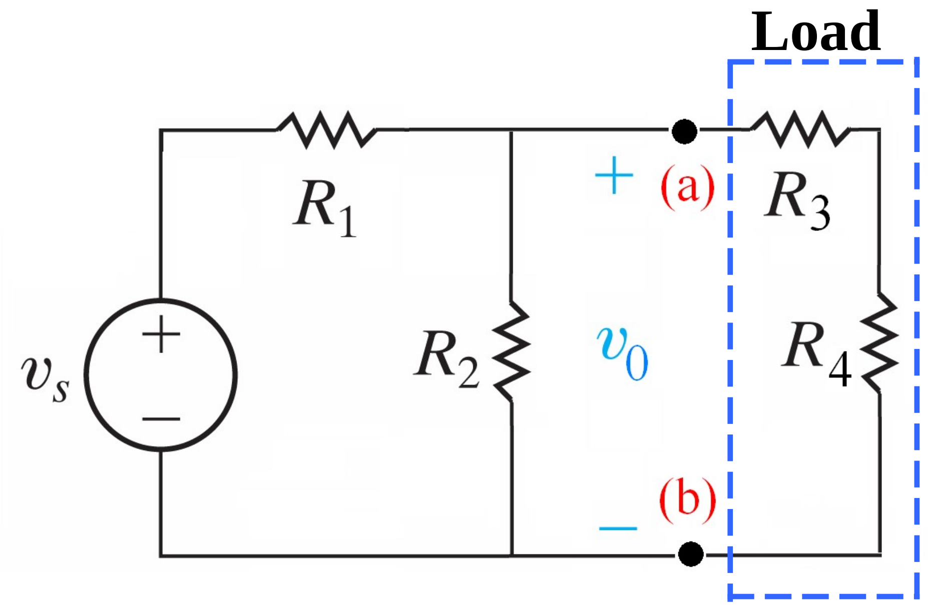
Voltage Division

Find R_{eq}

$$R_{eq} = R_2 \| (R_3 + R_4) = 50K \| (10K + 15K)$$
$$= \frac{50K(25K)}{50K + 25K} = \mathbf{16.67(K\Omega)}$$

$$v_0 = 100[16.67/ (5+16.67)]$$
$$v_0 = 100(0.769) = 76.9\ (V)$$

A Side Note



Load: Anything that draws power from a circuit.
Example: (R_3 + R_4) is the *"Load"*

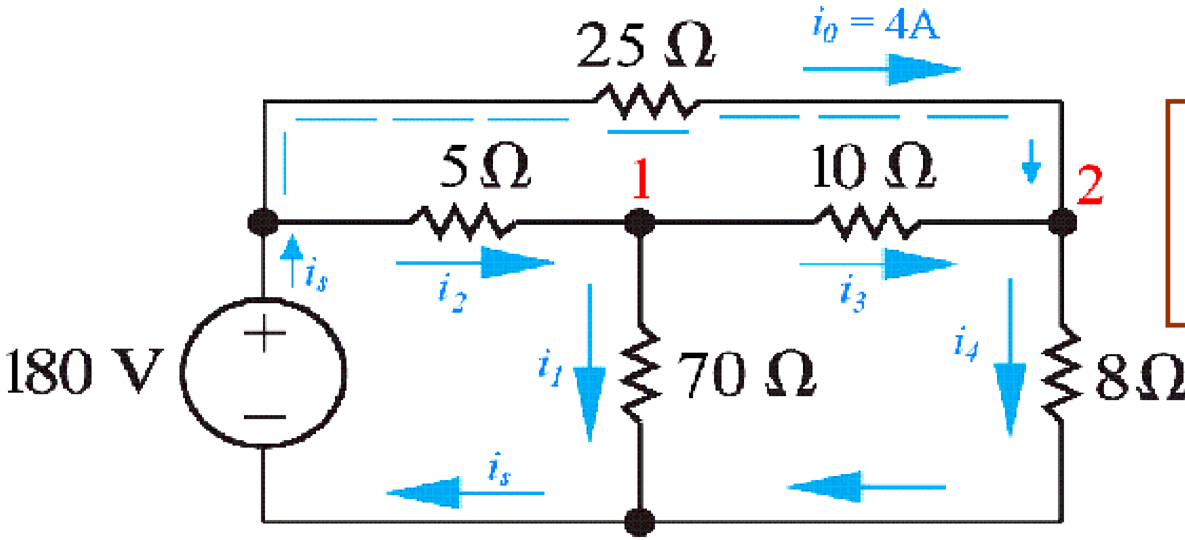
No-Load means that we disconnect the circuit at (a) and (b)

$$v_{0\ (no\ load)} = v_s \frac{R_2}{R_1 + R_2} = 100\left(\frac{50K}{5K + 50K}\right) = 90.91(V)$$

Disconnect the load

"*No-Load*" value of v_0 is without ($\boldsymbol{R_3} + \boldsymbol{R_4}$)

Example: Find i_4 ; Given $i_0 = 4(A)$



- **Current directions can be arbitrary**
- **However, these are logical**

Solution: **Two inner loops have too many unknowns – Try outer loop**

$$180 = 25i_0 + 8i_4$$ **KVL**

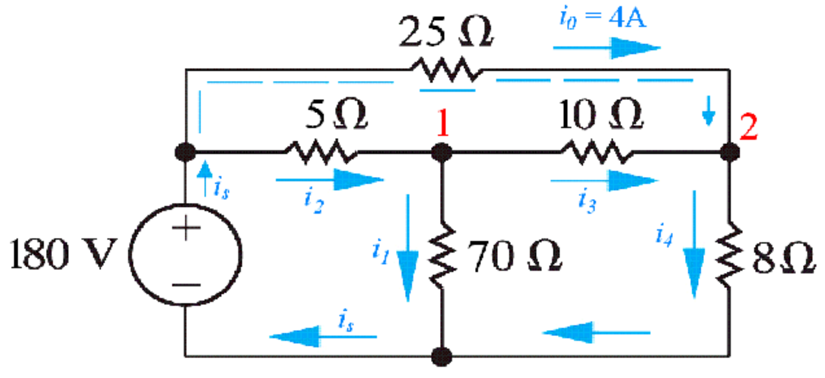
$$i_4 = \frac{180 - 25i_0}{8} = \frac{180 - 25(4)}{8}$$ **Solve for i_4**

$$\boxed{i_4 = 10\ (A)}$$

(Contd..)

Same Example: Find i_3 and i_1

$i_4 = 10(A)$ } **From the previous slide**



KCL @ node (2)

$$i_0 + i_3 = i_4$$ **KCL**

$$i_3 = i_4 - i_0 = 10 - 4$$ **Solve for i_3**

$$i_3 = 6\ (A)$$

KVL for "Bottom-Right" loop has only 1 unknown: Clockwise from node (1)

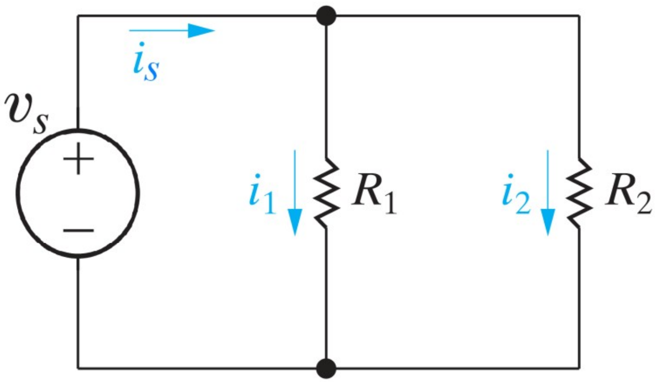
$$10i_3 + 8i_4 - 70i_1 = 0$$ **KVL**

$$i_1 = \frac{10i_3 + 8i_4}{70} = \frac{10(6) + 8(10)}{70}$$ **Solve for i_1**

$$i_1 = 2\ (A)$$

Current Division

Current is "proportionally" distributed through resistors in a circuit



Ohm's Law:

(1) $$v_s = i_1R_1 = i_2R_2 = i_s\underbrace{(R_1||R_2)}_{R_{eq}}$$

(2) $$v_s = i_s \underbrace{\frac{R_1 R_2}{R_1+R_2}}_{R_{eq}}$$

Book uses ↑ i_s
Works either way

Use (1) and (2) to eliminate v_s

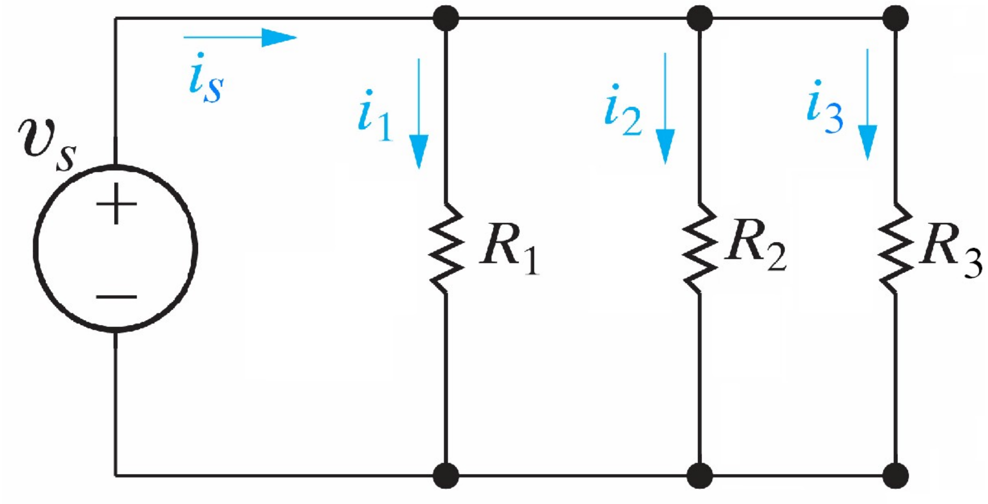
$$i_1 = \frac{v_s}{R_1} = i_s \frac{R_2}{R_1 + R_2}$$

$$i_2 = \frac{v_s}{R_2} = i_s \frac{R_1}{R_1 + R_2}$$

★ ***Current Division*** ★

- **"Fraction" is <u>OPPOSITE</u> to that of Voltage Division.**
- **Current "seeks" the path of <u>least</u> Resistance; i.e., more current flows through the smaller *R*.**
- **If $R_1 = R_2$; then, $i_1 = i_2 = 0.5\, i_s$**
- **As R_1 becomes > R_2; more current flows through R_2**
- **i_1 is a fraction, $\left(\frac{R_2}{R_1 + R_2} \equiv \frac{R_2}{R_{Total}}\right)$, of i_s.**

Example



Find i_2_

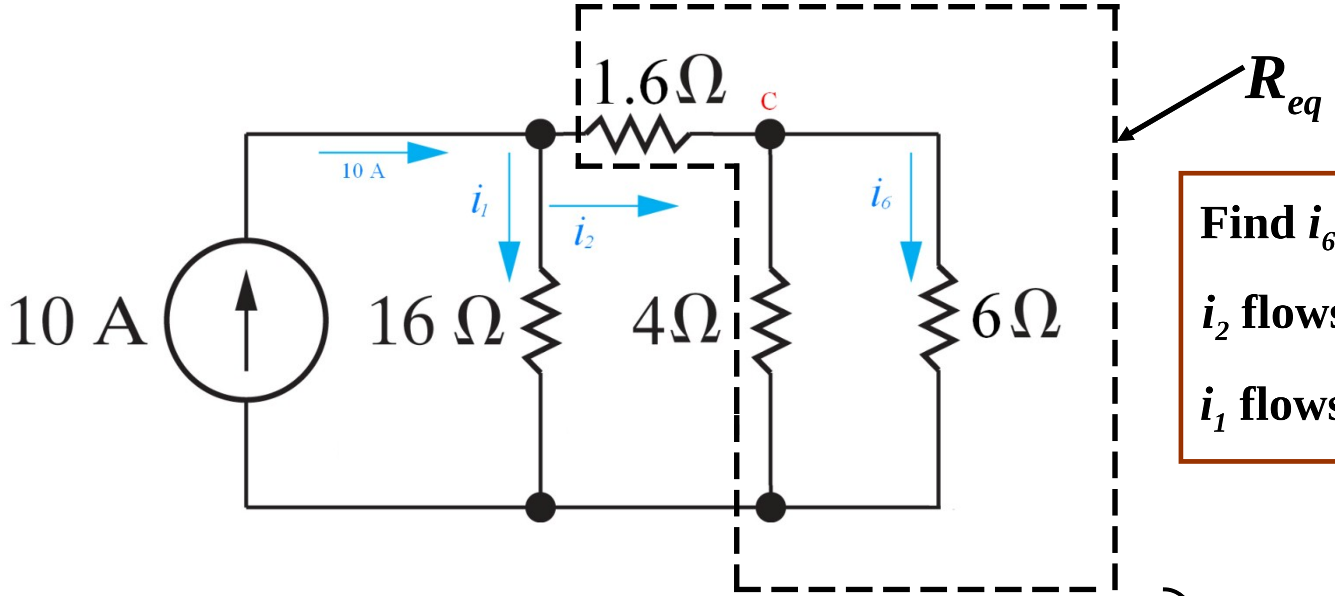
Using Current Division:

$$i_2 = i_s \cdot \left(\frac{R_1 \parallel R_3}{R_1 \parallel R_3 + R_2} \right)$$

i_2 flows through R_2

$i' = (i_1 + i_3)$ flows through $(R_1 \parallel R_3)$

Example: Find i_6 using current division



Find i_6 by finding i_2

i_2 flows through R_{eq}

i_1 flows through (16Ω)

$$i_2 = 10\left(\frac{16\Omega}{16\Omega + R_{eq}}\right)$$

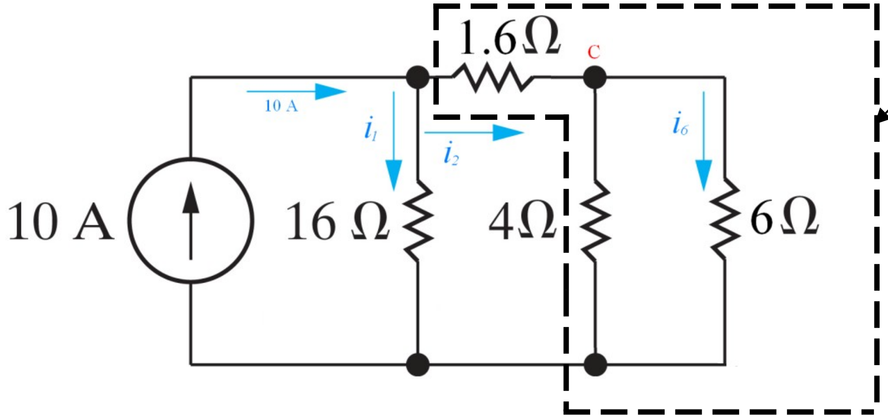
Find i_2 with current division

$$R_{eq} = (6 \,||\, 4) + 1.6 = \frac{24}{10} + 1.6 = 2.4 + 1.6$$

$$R_{eq} = 4\ (\Omega)$$

(Contd..)

Example: Find i_6 using current division (Contd.)



$R_{eq} = 4(\Omega)$

$$i_2 = 10\left(\frac{16}{16+4}\right)$$

$i_2 = 8\ (A)$ → **Flows through 1.6Ω resistor and into node C**

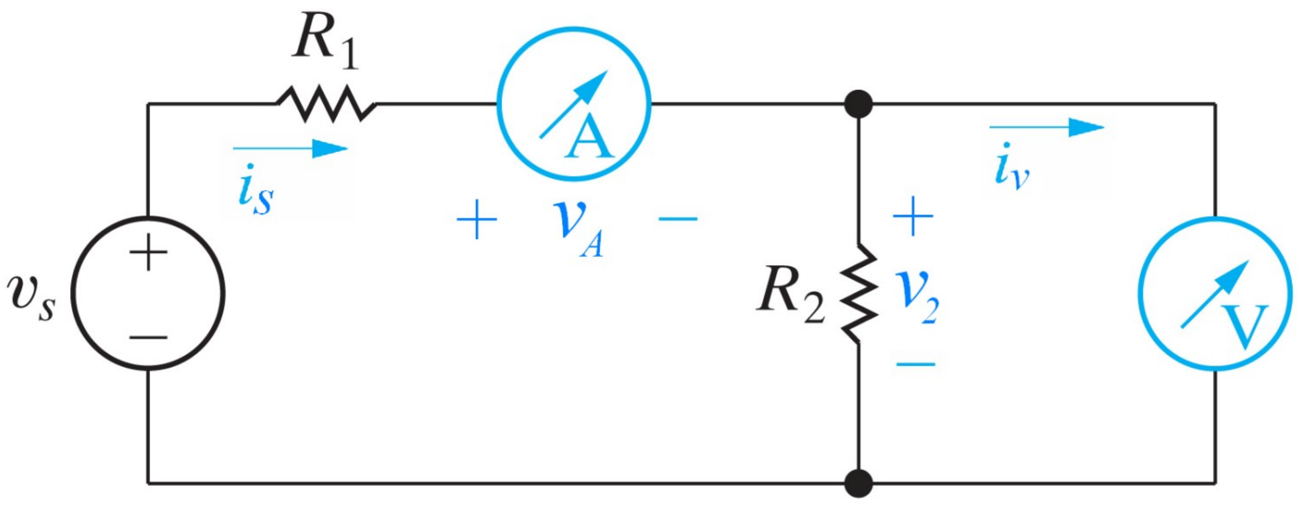
***i_2* Flows into node C**

$$i_6 = i_2\left(\frac{4}{4+6}\right) = 8\left(\frac{4}{10}\right)$$

$i_6 = 3.2\ (A)$

Use Current Division to find *i_6*

METERS To measure Current and Voltage



Meters Affect the Circuit

A in series Want ≈ 0 Internal Resistance; otherwise, i_s is reduced.
⇨ Loads the circuit.

V in parallel Want ≈ ∞ Internal Resistance; otherwise, v_2 is reduced.
⇨ Loads the circuit.

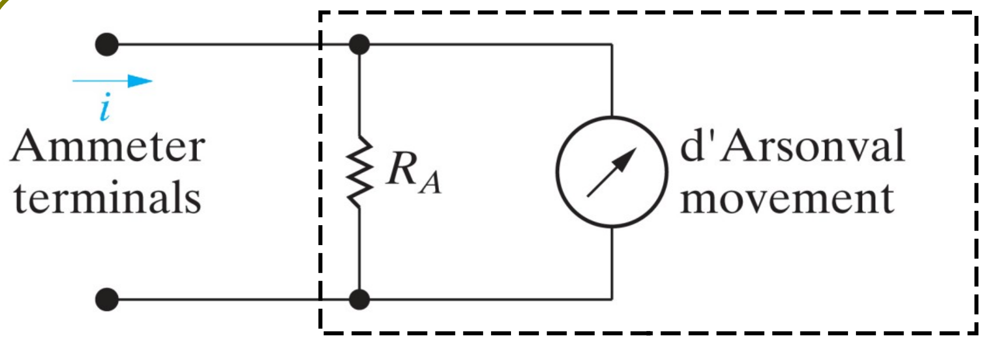
d’Arsonval Meter

Movable coil in the field of a Permanent Magnet

i **in coil ⇨ Torque which moves a dial**

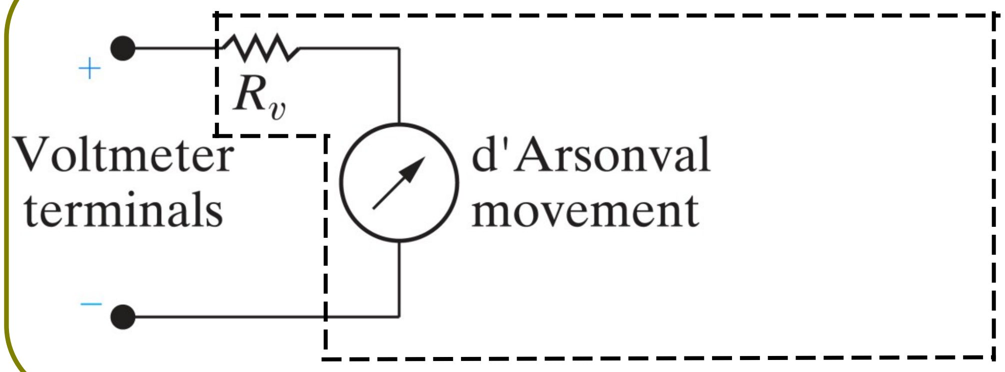
Rating of 50 mV and 1 mA. **1 mA in coil ⇨ 50 mV across coil ⇨ Full deflection**

Limits of d’Arsonval meters can measure



R_A Limits Current Through Movement.

<Current Divider>



R_v Limits Voltage Across Movement.

<Voltage Divider>

Resistor Determines Full-Scale Reading

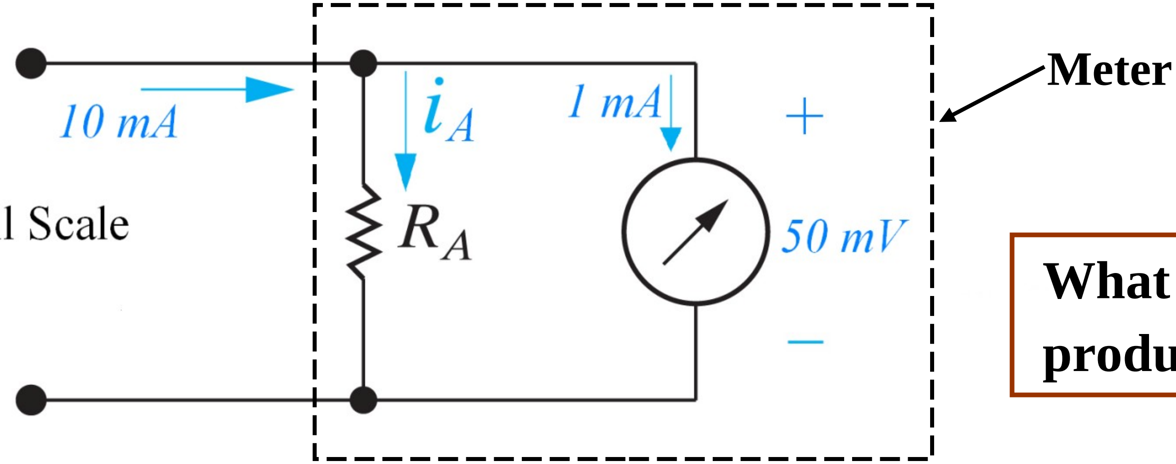
Example: Find the correct value for R_A

Movement Specification   Ammeter Specification

a) Rating **50 (*mV*) and 1 (*mA*).** **Full-Scale Reading: 10 (*mA*).**

Can measure up to 10 mA

at Full Scale



What value of R_A will produce this result?

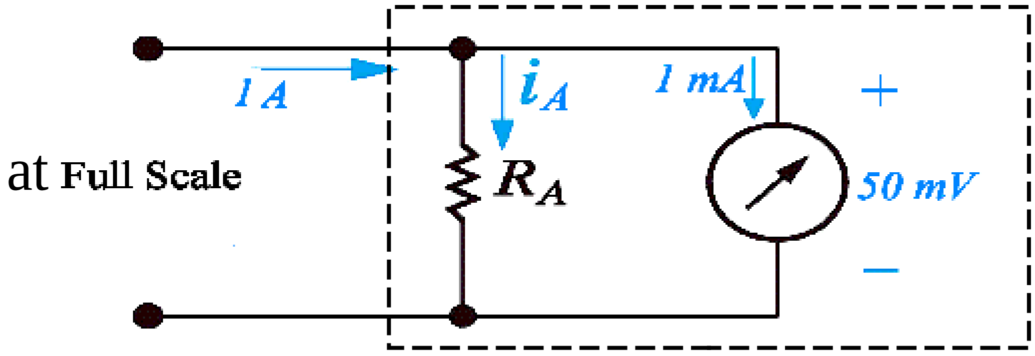
$$\left.\begin{aligned} 10\ (mA) &= i_A + 1\ (mA) \\ i_A &= 10\ (mA) - 1(mA) = 9\ (mA) \end{aligned}\right\}$$ KCL @ Full Scale

$$\left.V_{R_A} = 50\ (mV) = i_A R_A\right\}$$ Ohm's Law

$$\boldsymbol{R_A} = 50\ (mV)/9\ (mA) \Rightarrow \boxed{R_A = 5.556\ (\Omega)}$$

(Contd..)

Example: Find the correct value for R_A



b) Full-Scale Reading **1A for Ammeter**

$$i_A = 1(A) - 1(mA) = 1 - 0.001 = 0.999(A)$$ **KCL**

$$R_A = V_{R_A} / i_A = 50\ (mV)/999\ (mA)$$ **Ohm's Law**

$$\boxed{R_A = 50.05\ (m\Omega)}$$

(Contd..)

Example: Find the Equivalent Resistance of the meter

c) R_m is Equivalent Resistance at Ammeter Terminals <10 (mA) Meter>

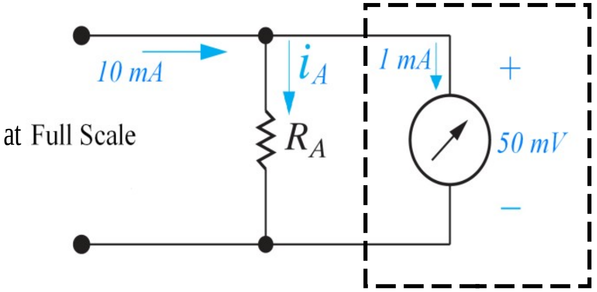
Effective resistance of movement $\equiv R_{mov} = 50\,(mV)\,/1(mA) = 50(\Omega)$

$$R_m = R_A \parallel R_{mov} = \frac{R_A R_{mov}}{R_A + R_{mov}} = \frac{5.556(50)}{5.556+50} \Rightarrow$$

$R_A = 5.56(\Omega)$

$R_{mov} = 50(\Omega)$

$R_m = 5\ (\Omega)$



d) 1A Meter

$R_A = 50.05(m\Omega)$

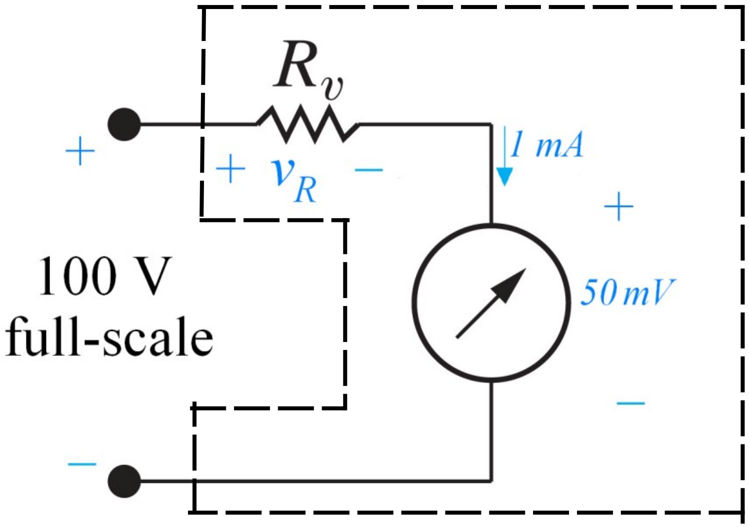
$R_{mov} = 50(\Omega)$

$$R_m = \frac{50.05\times10^{-3}(50)}{50.05\times10^{-3}+50}$$

$R_m = 0.05\ (\Omega)$

Voltmeter Example: d'Arsonval Movement: 50 (mV) @ 1(mA)

Find R_V for Full-scale Reading of 100(V)



Full Scale

$V_R = 100(V) - 50(mV) = 99.95\ (V)$ } **KVL**

$R_v = V_R/1(mA) = 99.95/10^3$ } **Ohm's Law**

$$\boxed{R_v = 99{,}950\ (\Omega)}$$

Series

Voltmeter Resistance: $R_m = R_v + R_{mov}$

$= 99{,}950 + 50(mV)\ /\ 1(mA) = 99{,}950 + 50$

$$\boxed{R_m = 100\ (K\Omega)}$$

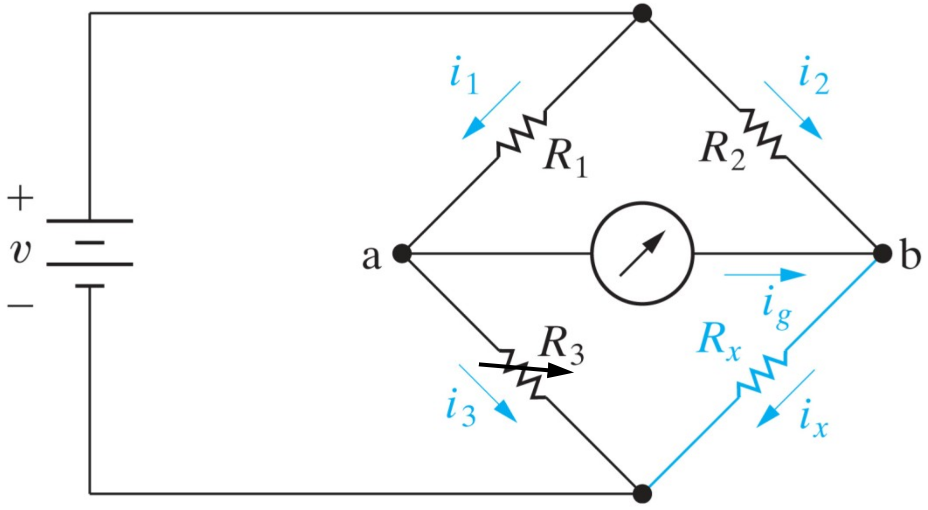
OR

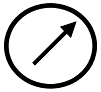
$$\boxed{R_m = 100(V)/1(mA) = 100\ (K\Omega)}$$

Compare to Ammeter: $R_m = 5(\Omega),\ 0.05(\Omega)$

WHEATSTONE BRIDGE

Used to Measure Resistance



 **≡ detector; d'Arsonval movement**

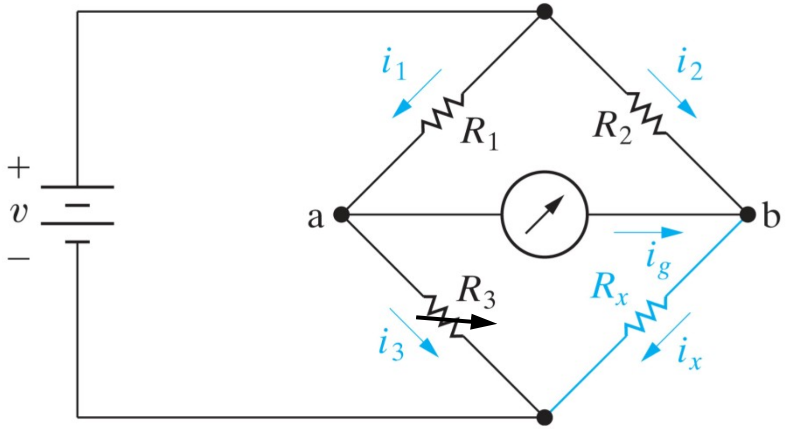
R_x ≡ Unknown Resistance

To find R_x:

Adjust R_3 until $i_g = 0$ ⟶ Bridge is "Balanced"

When $i_g = 0$, a and b are "effectively" the same node, or $V_{a\text{-}b} = 0$

WHEATSTONE BRIDGE: (Contd.) Find R_x when $i_g = 0$



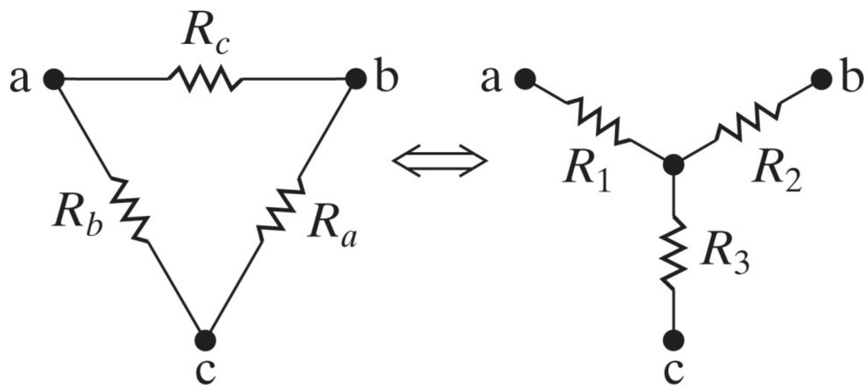
$$(1)\quad i_1 = i_3; \quad i_2 = i_x \quad \Big\}\; i_g = 0$$

$$(2)\quad i_3 R_3 = i_x R_x; \quad i_1 R_1 = i_2 R_2 \quad \Big\}\; V_{ab} = 0$$

$$(3)\quad \frac{i_3 R_3}{i_x R_x} = \frac{i_1 R_1}{i_2 R_2} = 1 \Bigg\}$$ From (2)

From (1) $\left\{ \begin{pmatrix} i_3 = i_1 \\ i_x = i_2 \end{pmatrix} \right. \Longrightarrow \boxed{R_x = \frac{R_2}{R_1} R_3} \Big\}$ Solve (3) for R_x

DELTA-WYE EQUIVALENT CIRCUITS [Δ - Y]:



In the Δ Circuit	Compared to Y Circuit
[1] $R_{ab} = R_c \| \| (R_a + R_b)$	$R_{ab} = R_1 + R_2$ {R_3 is floating}
[2] $R_{bc} = R_a \| \| (R_b + R_c)$	$R_{bc} = R_2 + R_3$ {R_1 is floating}
[3] $R_{ca} = R_b \| \| (R_c + R_a)$	$R_{ca} = R_1 + R_3$ {R_2 is floating}

Voltages and Currents are the same at each node in both Δ and Y connections

Derivation of Y: resistors in terms of Δ-resistors

1. Solve for R_1

$$R_1 = R_c \parallel (R_a + R_b) - R_2$$

Using [1]

$$R_1 = R_c \parallel (R_a + R_b) - \left[R_a \parallel (R_b + R_c) - R_3 \right]$$

Using [2]

Using [3]

$$R_1 = R_c \parallel (R_a + R_b) - R_a \parallel (R_b + R_c) + \left[R_b \parallel (R_c + R_a) - R_1 \right]$$

Solve for R_1

$$2R_1 = \frac{R_c(R_a + R_b)}{(R_a + R_b + R_c)} - \frac{R_a(R_b + R_c)}{(R_a + R_b + R_c)} + \frac{R_b(R_c + R_a)}{(R_a + R_b + R_c)}$$

Same denominators

$$2R_1 = \left[\frac{\cancel{R_a R_c} + R_b R_c - \cancel{R_a R_b} - \cancel{R_a R_c} + R_b R_c + \cancel{R_a R_b}}{R_a + R_b + R_c} \right]$$

$$2R_1 = \frac{2R_b R_c}{R_a + R_b + R_c} \quad \Rightarrow \quad \boxed{R_1 = \frac{R_b R_c}{R_a + R_b + R_c}}$$

Simplify

Derivation of Y: resistors in terms of Δ-resistors (Contd.)

2. Solve for R_2: Using [1]

$$R_2 = \frac{R_c(R_a + \cancel{R_b})}{R_a + R_b + R_c} - \overbrace{\frac{\cancel{R_b R_c}}{R_a + R_b + R_c}}^{R_1} = \boxed{\frac{R_a R_c}{R_a + R_b + R_c}}$$

Using R_1 from previous slide

3. Solve for R_3: Using [3]

$$R_3 = \frac{R_b(\cancel{R_c} + R_a)}{R_a + R_b + R_c} - \underbrace{\frac{\cancel{R_b R_c}}{R_a + R_b + R_c}}_{R_2} = \boxed{\frac{R_a R_b}{R_a + R_b + R_c}}$$

Balanced Loads [3-Φ Power Applications]

Loads are balanced when:

$\Delta: \; R_a = R_b = R_c \equiv R_\Delta$

$Y: \; R_1 = R_2 = R_3 \equiv R_Y$

Δ-Y:

$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c} = \frac{R_\Delta^2}{3R_\Delta} = \frac{R_\Delta}{3}$$

$$\therefore \boxed{R_1 = R_2 = R_3 = \frac{1}{3} R_\Delta} \quad \text{———} \quad (1)$$

Y- Δ:

$$R_a = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_1} = \frac{3R_Y^2}{R_Y} = 3R_Y$$

$$\therefore \boxed{R_a = R_b = R_c = 3R_Y} \quad \text{———} \quad (2)$$

Similarly this can be derived

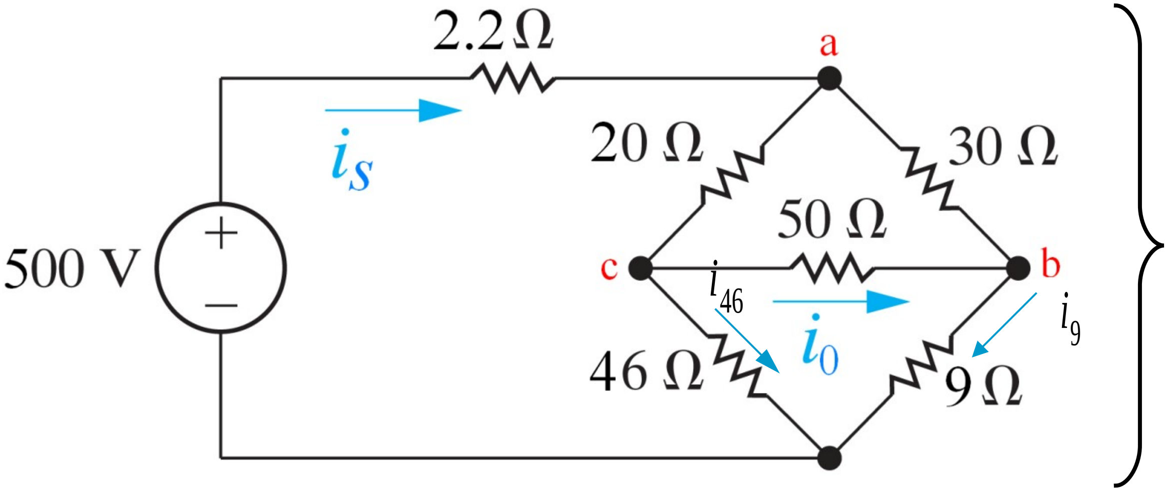
$$R_1 = R_Y = \frac{1}{3} R_\Delta$$

For "balanced loads"

$$\boxed{R_\Delta = 3R_Y}$$

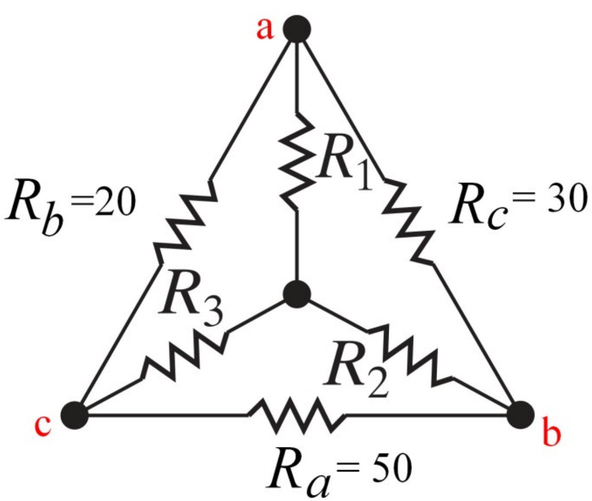
$$R_a = R_\Delta = 3R_Y$$

Example: Find i_0

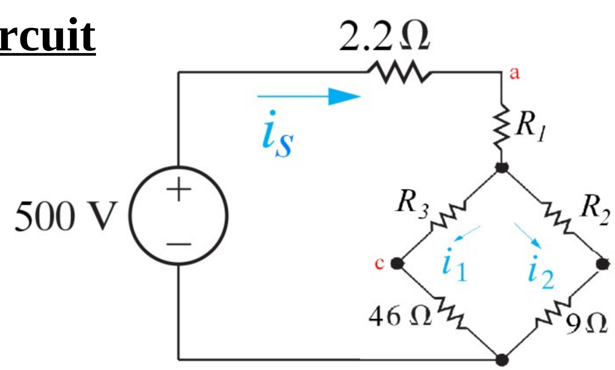


Use Δ-Y transformation to solve the circuit

$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c} = \frac{20(30)}{20 + 50 + 30}$$

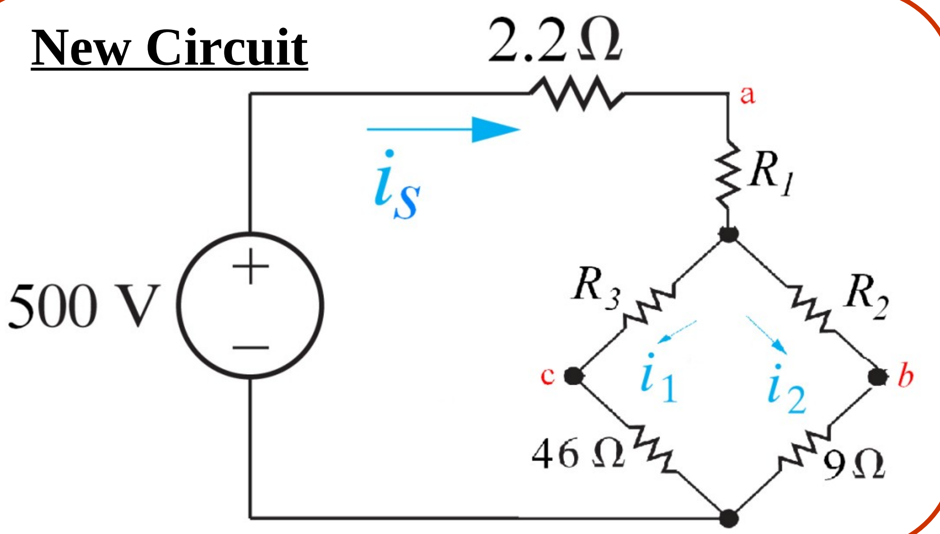


New Circuit



(Contd..)

Example: Find i_0 (Contd.)



$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c} = \frac{20(30)}{100} = 6(\Omega)$$

$$R_2 = \frac{R_c R_a}{R_a + R_b + R_c} = \frac{30(50)}{100} = 15(\Omega)$$

$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c} = \frac{50(20)}{100} = 10(\Omega)$$

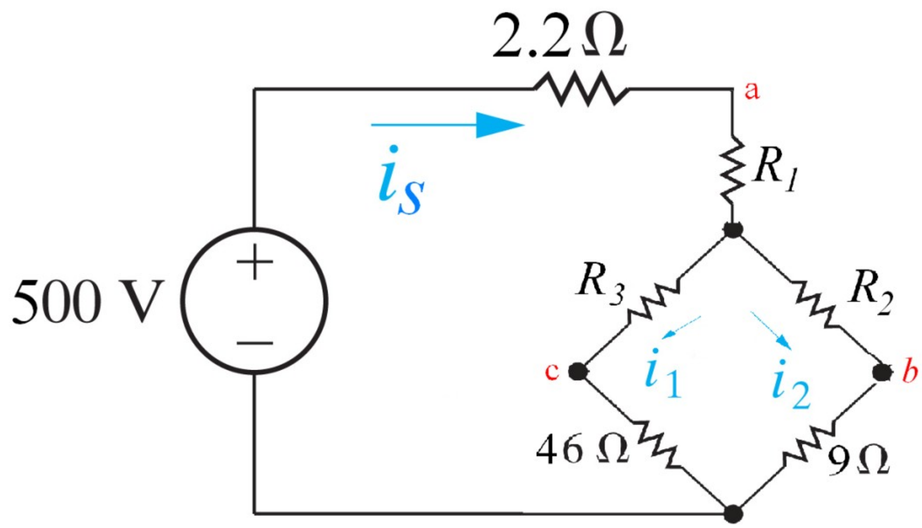
$\left.\begin{matrix} \boldsymbol{i_1 = i_{46}} \\ \boldsymbol{i_2 = i_9} \end{matrix}\right\}$ **Must be true for Δ-Y Transformation to be valid**

$$\left.R_{eq} = 2.2 + 6 + \frac{(R_3 + 46)(R_2 + 9)}{(R_3 + 46) + (R_2 + 9)} = 25(\Omega)\right\}$$ **Simplify Resistive Circuit**

$$\left.i_s = \frac{500V}{R_{eq}} = \frac{500}{25} = 20\ (A)\right\}$$ **Ohm's Law**

(Contd..)

Example: Find i_0 (Contd.)



$$i_s = 20(A)$$
$$R_1 = 6(\Omega)$$
$$R_2 = 15(\Omega)$$
$$R_3 = 10(\Omega)$$

Find all the Currents

$$i_1 = i_s\left[\frac{(R_2+9)}{(R_2+9)+(46+R_3)}\right] = 20\left[\frac{24}{80}\right] = 6\ (A)$$

Find i_1 with Current Division

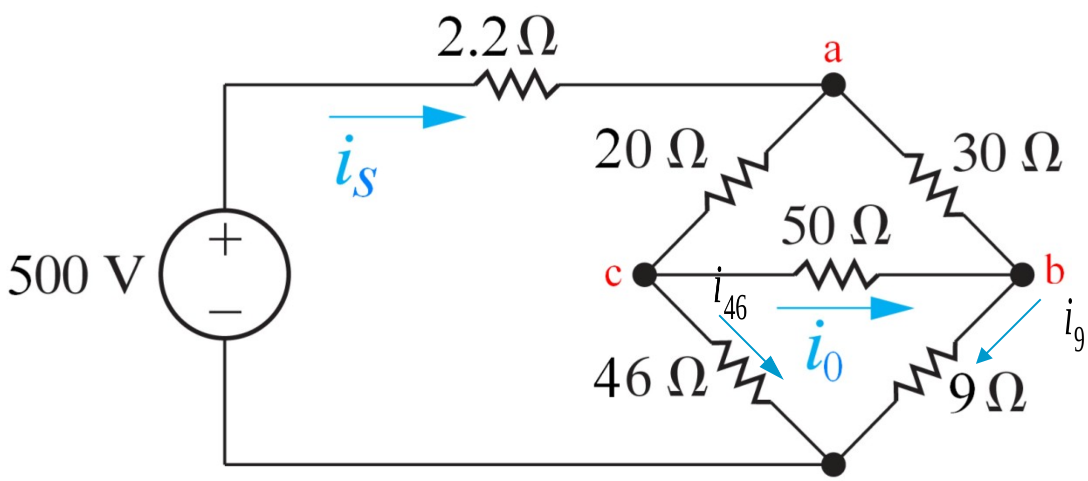
$$i_s = i_1 + i_2 \quad \text{KCL}$$

$$i_2 = i_s - i_1 = 20 - 6$$

Solve for i_2

$$\boxed{i_2 = 14\ (A)}$$

Example: Find i_0 (Contd.)



Go back to the original circuit (KVL from c-b through lower delta)

$$(i_{46}.46) - (i_9.9) - i_0.50 = 0 \quad \text{KVL}$$

Solve for i_0

$$i_0 = \frac{1}{50}\left[6(46) - 14(9)\right]$$

$$i_{46} = i_1 = 6(A)$$

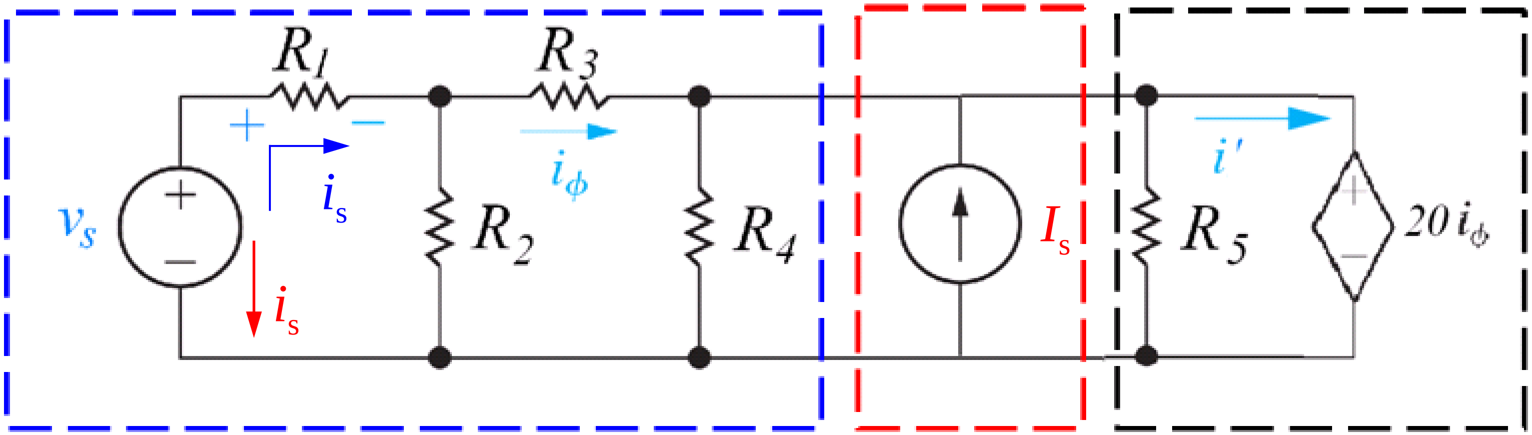
$$i_9 = i_2 = 14(A)$$

Must be true if Δ-Y transformation is valid

$$\boxed{i_0 = 3(A)}$$

Special Note on Power

Power: **1. Absorbed, Dissipated, Delivered to, extracts**
2. Developed, Produced, Delivered by



- **<u>Resistors:</u>** Always "absorb" power. They <u>can't</u> "deliver" power.
- **<u>Blue Circuit:</u>** <u>One</u> Energy Source, v_s, (power supply).
  v_s "delivers" power to circuit because i_s goes through a "rise" in voltage.
- **<u>Blue and red Circuit:</u>** If I_s overwhelms v_s, then i_s may reverse.
  v_s "absorbs" power, i_s goes through a "drop" in voltage.
- **<u>Blue, Red, and Black Circuit:</u>** $20i_\Phi$ is a source.
  it delivers or absorbs depending on polarity of i'