Schedule…

Date	Day	Class No.	Title	Chapters	HW Due date	Lab Due date	Exam
8 Sept	Mon	2	Kirchoff's Laws	2.2 – 2.3		NO LAB	
9 Sept	Tue					NO LAB	
10 Sept	Wed	3	Power	2.4 – 2.5			
11 Sept	Thu					NO LAB	
12 Sept	Fri		Recitation		HW 1		
13 Sept	Sat						
14 Sept	Sun						
15 Sept	Mon	4	Ohm's Law	2.5 – 2.6		LAB 1	
16 Sept	Tue						

Divine Source

2 Nephi 25:26

26 And we talk of Christ, we rejoice in Christ, we preach of Christ, we prophesy of Christ, and we write according to our prophecies, that our children may know to what **source** they may look for a remission of their sins.

Lecture 2 – Kirchhoff's Current and Voltage Laws

Charge

- **<u>Elektron</u>**: Greek word for amber
  - ~600 B.C. it was discovered that static charge on a piece of **amber** could attract light objects (feathers)
- **<u>Charge (*q*)</u>**: fundamental electric quantity
  - Smallest amount of charge is that carried by an electron/proton (**elementary charges**):

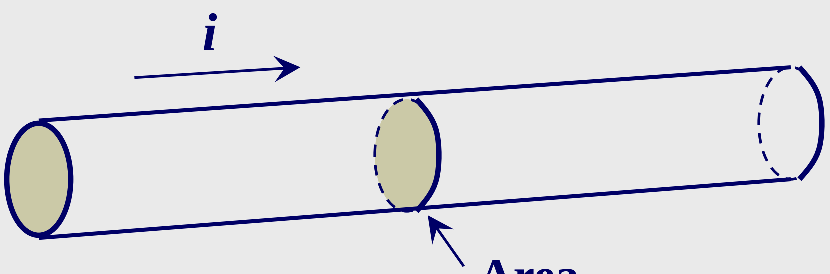
$$q_e / q_p = -/+1.602 \times 10^{-19} C$$

<u>Coulomb (C)</u>: basic unit of charge.

Electric Current

- **Electric current (*i*)**: the rate of change (in time) of charge passing through a predetermined area (IE the cross-sectional area of a wire).
  - Analogous to ***volume flow rate*** in hydraulics
  - Current (***i***) refers to Δ***q*** (***dq***) units of charge that flow through a cross-sectional area (**Area**) in Δ***t*** (***dt***) units of time

$$i = \frac{\Delta q}{\Delta t} = \frac{dq}{dt}\, A$$



Ampere (*A*): electric current unit.
1 ampere = 1 coulomb/second (C/s)

Positive current flow is in the direction of positive charges (the opposite direction of the actual electron movement)

Charge and Current Example

- For a metal wire, find:
  - The total charge (***q***)
  - The current flowing in the wire (***i***)

Given Data:

- wire length = 1m
- wire diameter = 2 x 10^{-3}m
- charge density = n = 10^{29} carriers/m^3
- charge of an electron = q_e = -1.602 x 10^{-19}
- charge carrier velocity = u = 19.9 x 10^{-6} m/s

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$$\begin{aligned}\text{Volume} &= \text{length} \times \text{area} \\ &= L \times \pi r^2 \\ &= (1m)\left[\pi\left(\frac{2\times 10^{-3}}{2}\right)^2 m^2\right] \\ &= \pi \times 10^{-6} m^3\end{aligned}$$

$$\begin{aligned}\text{Number of carriers} &= \text{volume} \times \text{carrier density} \\ N &= V \times n \\ &= \left(\pi \times 10^{-6} m^3\right)\left(10^{29}\frac{carriers}{m^3}\right) \\ &= \pi \times 10^{23} carriers\end{aligned}$$

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$$\text{Charge} = \text{number of carriers} \times \text{charge/carrer}$$

$$q = N \times q_e$$

$$= \left(\pi \times 10^{23} \, carriers\right) \times \left(-1.602 \times 10^{-19} \, C/carrier\right)$$

$$= -50.33 \times 10^{3} \, C$$

Charge and Current Example

- For a metal wire, find:
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$$\text{Current} = \text{carrier charge density per unit length} \times \text{carrier velocity}$$

$$i = \left(\frac{q}{L}(C/m)\right) \times u(m/s)$$

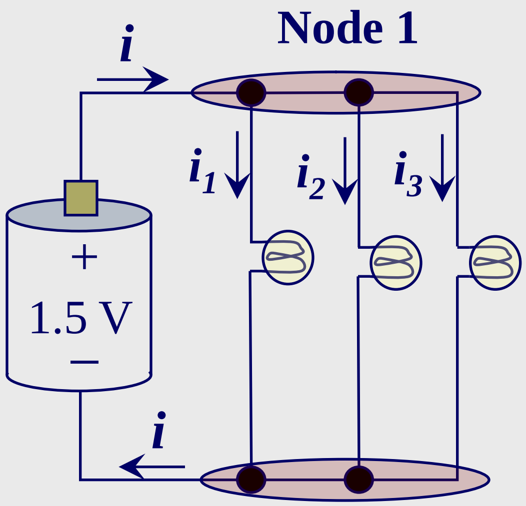
$$= \left(-50.33\times10^{3}C/m\right)\left(19.9\times10^{-6}m/s\right)$$

$$= -1A$$

Kirchhoff's Current Law (KCL)

- **KCL**: charge must be conserved – the sum of the currents at a node must equal zero.

$$\sum_{n=1}^{N} i_n = 0$$

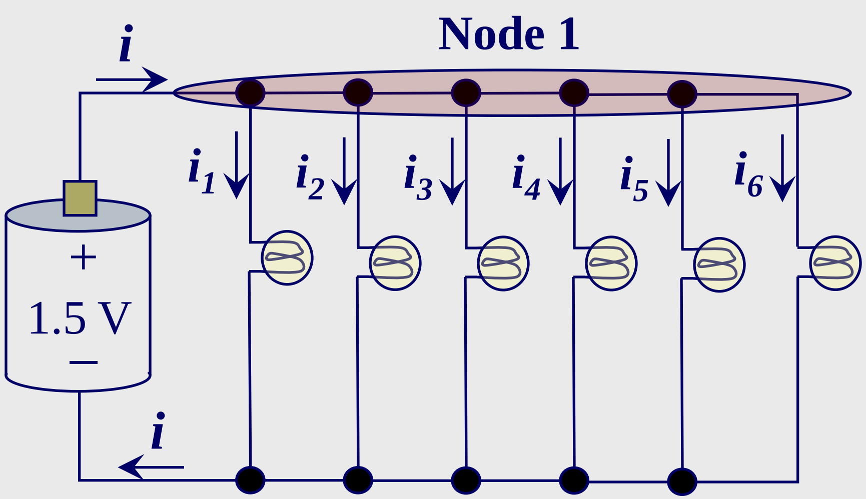


At **Node 1**:
$-i + i_1 + i_2 + i_3 = 0$
OR:
$i - i_1 - i_2 - i_3 = 0$

NB: a circuit must be **CLOSED** in order for current to flow

Kirchhoff's Current Law (KCL)

- Potential problem of too many branches on a single node:
  - not enough current getting to a branch

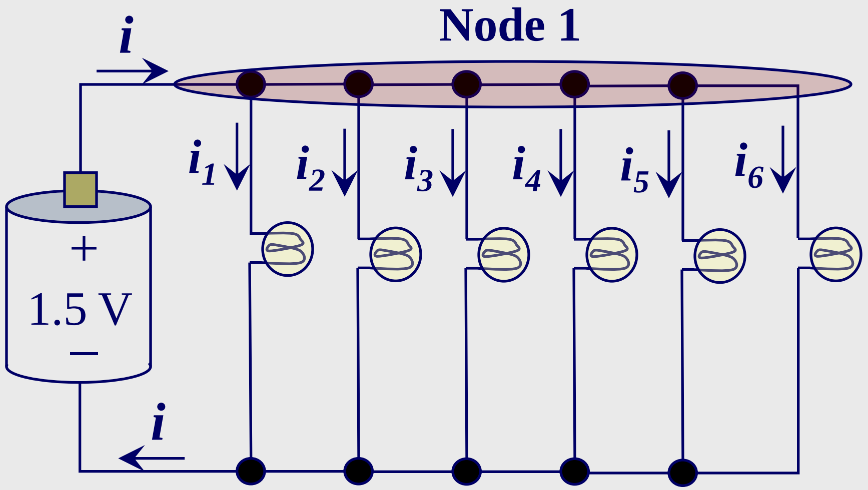


Suppose:
- all lights have the same resistance
- i_4 needs 1A

What must the value of ***i*** be?

Kirchhoff's Current Law (KCL)

- Potential problem of too many branches on a single node:
  - not enough current getting to a branch



$-i + i_1 + i_2 + i_3 + i_4 + i_5 + i_6 = 0$

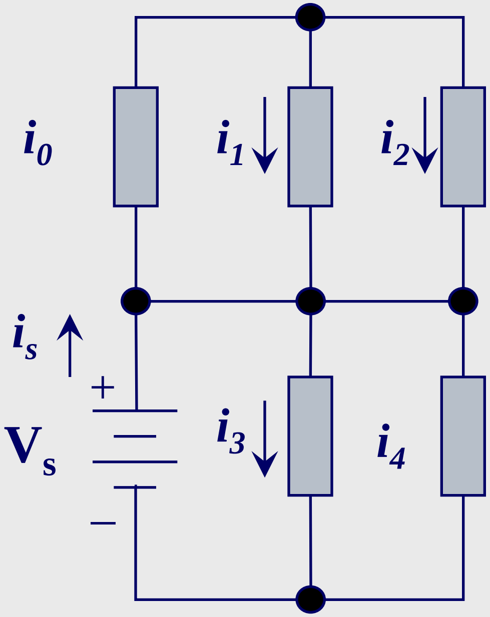
BUT: since all resistances are the same:

$i_1 = i_2 = i_3 = i_4 = i_5 = i_6 = i_n$

$$\begin{aligned} -i + 6i_n &= 0 \\ 6i_n &= i \\ 6(1\text{A}) &= i \\ i &= 6\text{A} \end{aligned}$$

Kirchhoff's Current Law (KCL)

- **Example1**: find $\boldsymbol{i_0}$ and $\boldsymbol{i_4}$
  - $\boldsymbol{i_s}$ = 5A, $\boldsymbol{i_1}$ = 2A, $\boldsymbol{i_2}$ = -3A, $\boldsymbol{i_3}$ = 1.5A



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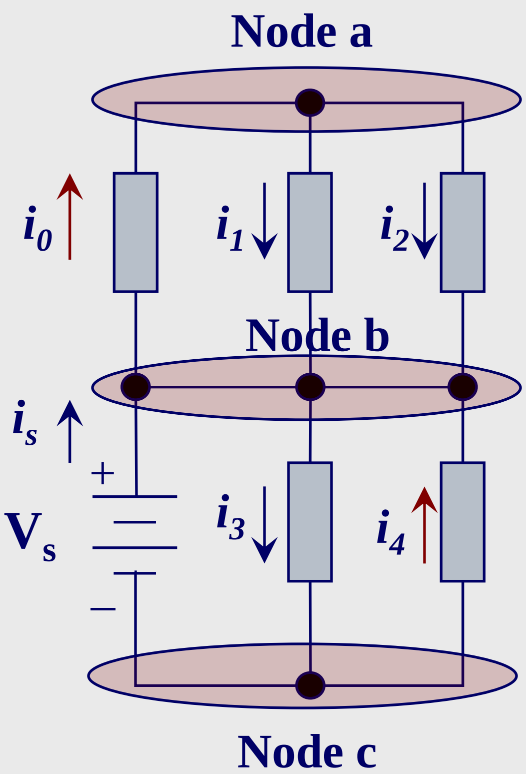

NB: First thing to do – decide on **unknown** current directions.

- If you select the wrong direction it won't matter
  - a negative current indicates current is flowing in the opposite direction.
- Must be consistent
  - Once a current direction is chosen must keep it

Kirchhoff's Current Law (KCL)

- **Example1**: find $\boldsymbol{i_0}$ and $\boldsymbol{i_4}$
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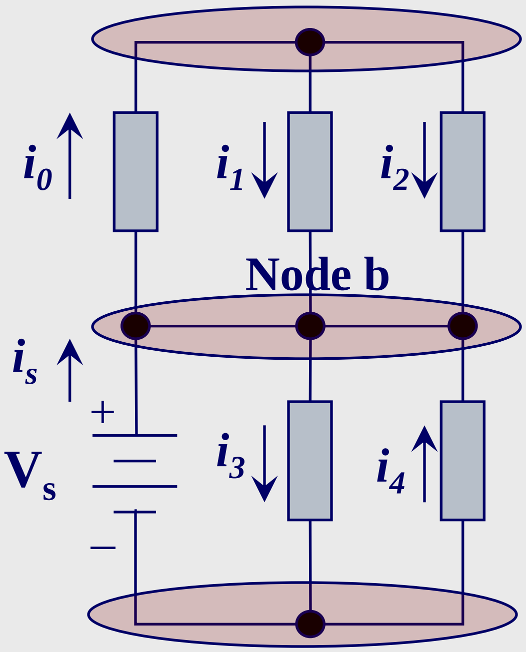


Find i_0 at Node a:

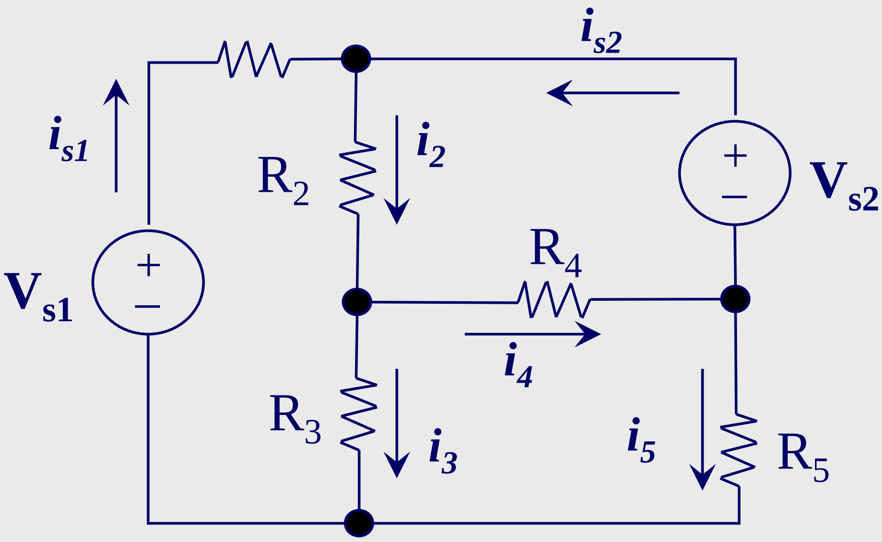
$$i_0 - i_1 - i_2 = 0$$
$$i_0 = i_1 + i_2$$
$$= 2 - 3$$
$$= -1A$$

Find i_4 at Node c:

$$i_4 + i_s - i_3 = 0$$
$$i_4 = i_3 - i_s$$
$$= 1.5 - 5$$
$$= -3.5A$$

Kirchhoff's Current Law (KCL)

- **Example2**: using KCL find $\boldsymbol{i_{s1}}$ and $\boldsymbol{i_{s2}}$
  - $\boldsymbol{i_3} = 2A$, $\boldsymbol{i_5} = 0A$, $\boldsymbol{i_2} = 3A$, $\boldsymbol{i_4} = 1A$



Kirchhoff's Current Law (KCL)

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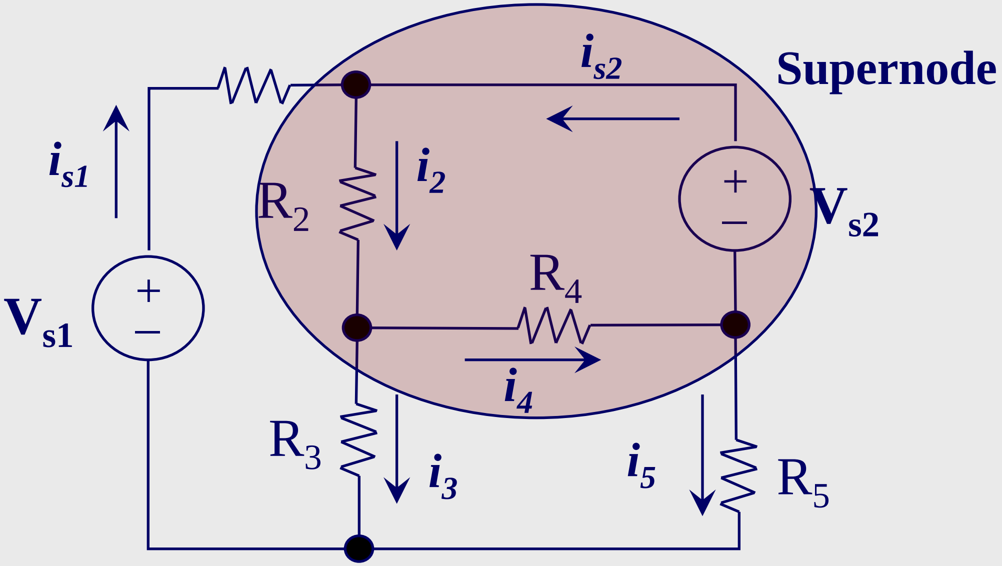


KCL at supernode :

$$i_{s1} - i_3 - i_5 = 0$$

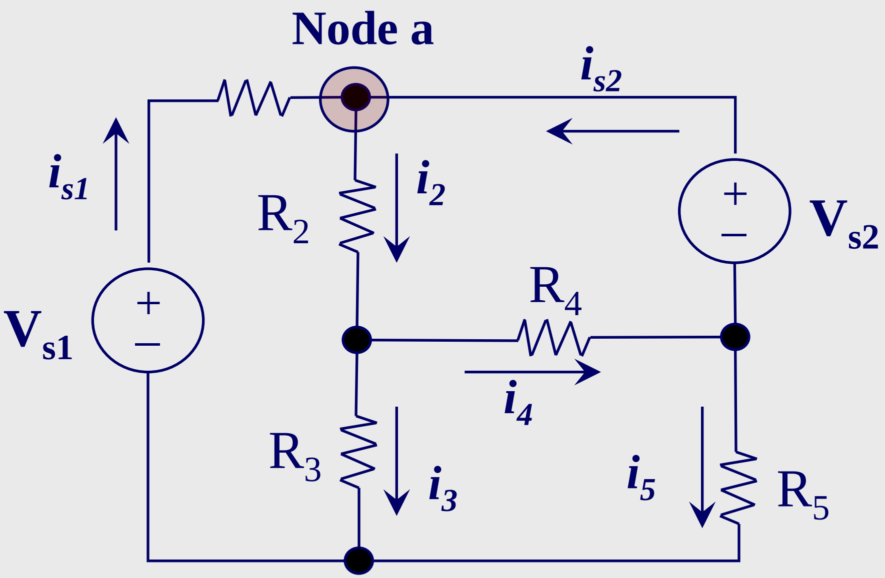
$$i_{s1} = i_3 + i_5$$

$$= 2 + 0$$

$$= 2A$$

Kirchhoff's Current Law (KCL)

- **Example2**: using KCL find $\boldsymbol{i_{s1}}$ and $\boldsymbol{i_{s2}}$
  - $\boldsymbol{i_3}$ **=** 2A, $\boldsymbol{i_5}$ = 0A, $\boldsymbol{i_2}$ = 3A, $\boldsymbol{i_4}$ = 1A



KCL at Node a :

$$i_{s2} + i_{s1} - i_2 = 0$$

$$i_{s2} = i_2 - i_{s1}$$

$$= 3 - 2$$

$$= 1A$$

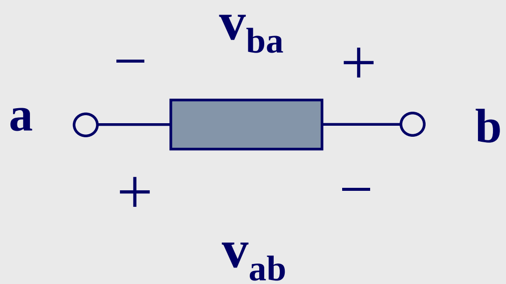
Voltage

- Moving charges in order to produce a current requires work
- **Voltage**: the work (energy) required to move a unit charge between two points
- **Volt (V)**: the basic unit of voltage (named after Alessandro Volta)

> **Volt (V)**: voltage unit.
> 1 Volt = 1 joule/coulomb (J/C)

Voltage

- Voltage is also called **potential difference**
  - Very similar to gravitational potential energy
  - Voltages are **relative**
    - voltage at one node is measured *relative* to the voltage at another node
    - Convenient to set the **reference voltage** to be zero



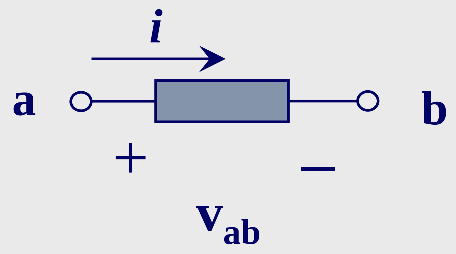
$v_{ab} = va - vb$

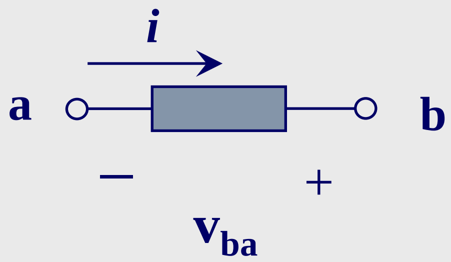
v_{ab} => the work required to move a positive charge from terminal **a** to terminal **b**
v_{ba} => the work required to move a positive charge from terminal **b** to terminal **a**

$v_{ba} = - v_{ab}$

Voltage

- **Polarity** of voltage direction (for a given current direction) indicates whether energy is being absorbed or supplied





- Since ***i*** is going from + to – energy is being **absorbed** by the element (**passive element**)

- Since ***i*** is going from – to + energy is being **supplied** by the element (**active element**)

Voltage

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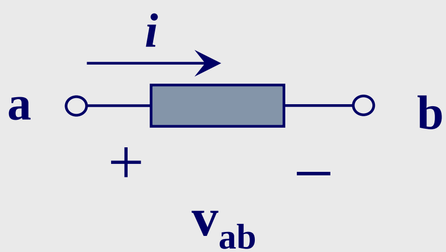
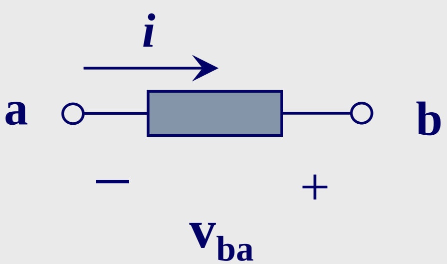
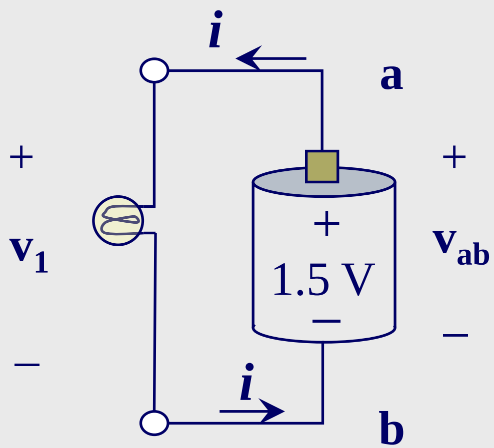




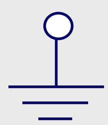
Absorbing energy
(**load**)
(**passive** element)
POSITIVE voltage



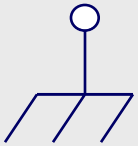
Supplying energy
(**source**)
(**active** element)
NEGATIVE voltage

Voltage

- **<u>Ground</u>**: represents a specific reference voltage
  - Most often ground is physically connected to the earth (the ground)
  - Convenient to assign a voltage of 0V to ground



The ground symbol we'll use
(earth ground)

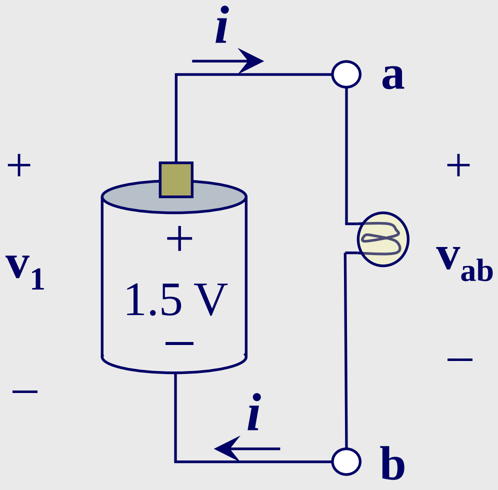


Another ground symbol
(chasis ground)

Kirchhoff's Voltage Law (KVL)

- **KVL**: energy must be conserved – the sum of the voltages in a closed circuit must equal zero.

$$\sum_{n=1}^{N} v_n = 0$$



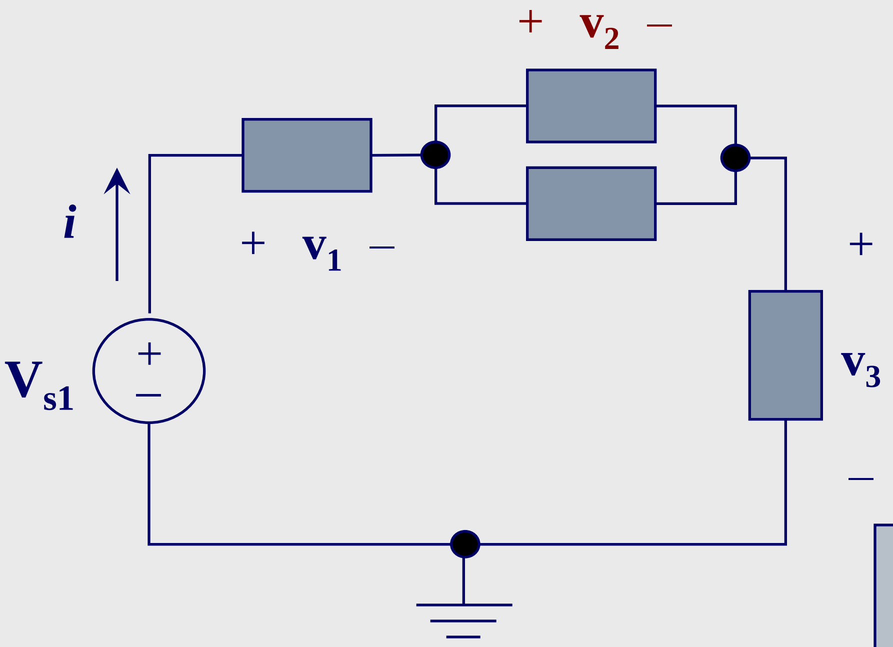
Use **Node b** as the reference voltage (ground): $\mathbf{v_b} = 0$

$$v_{ab} - v_1 = 0$$
$$v_{ab} = v_1$$
$$= 1.5V$$

$$v_{ab} = v_a - v_b$$
$$v_a = v_{ab} + 0$$
$$= 1.5 + 0$$
$$= 1.5V$$

Kirchhoff's Voltage Law (KVL)

- **Example3**: using KVL, find $\mathbf{v_2}$
  - $\mathbf{v_{s1}} = 12V$, $\mathbf{v_1} = 6V$, $\mathbf{v_3} = 1V$



Source: loop travels from **– to +** terminals
- Sources have **negative** voltage

Load: loop travels from **+ to –** terminals
- Loads have **positive** voltage

Kirchhoff's Voltage Law (KVL)

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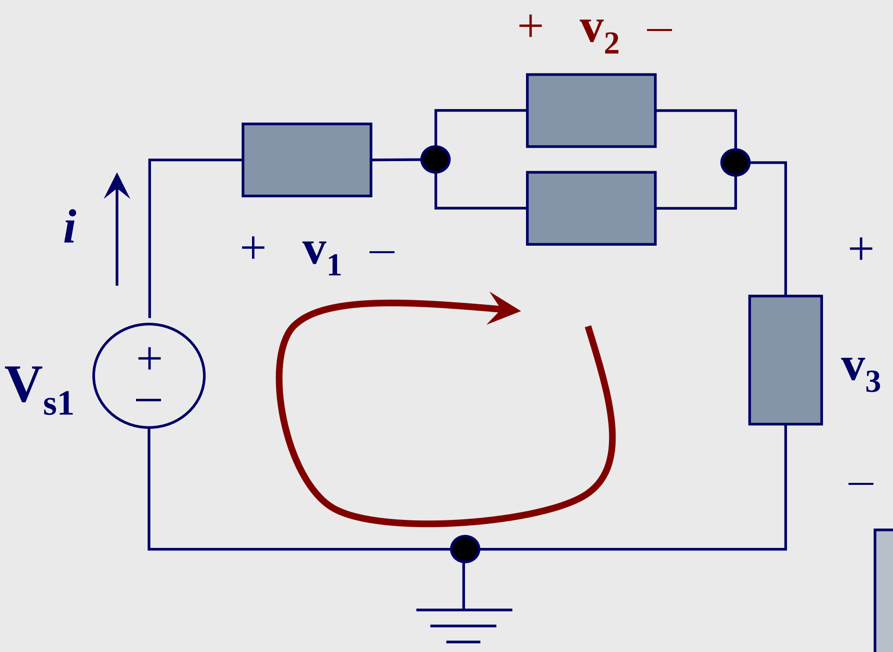

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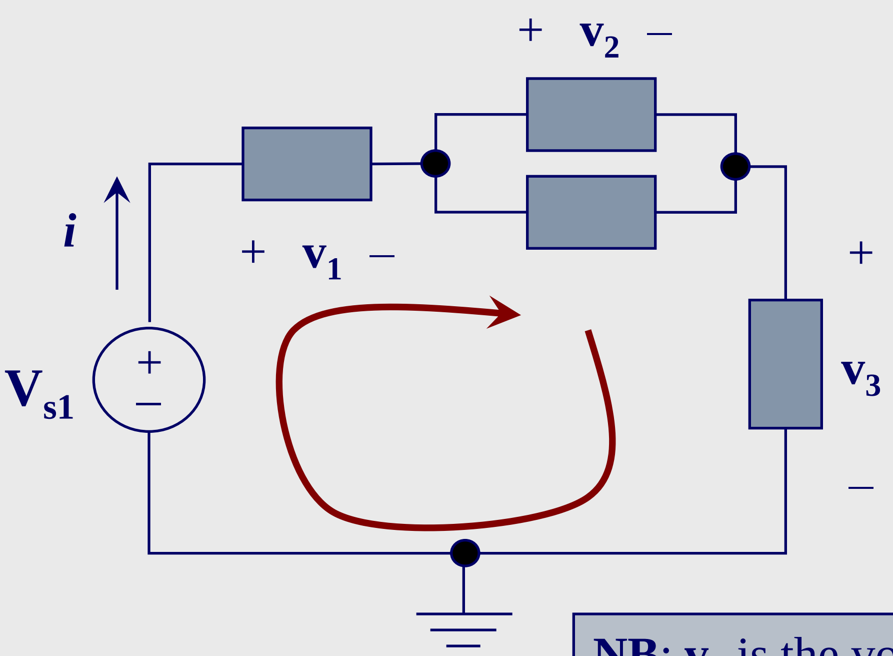
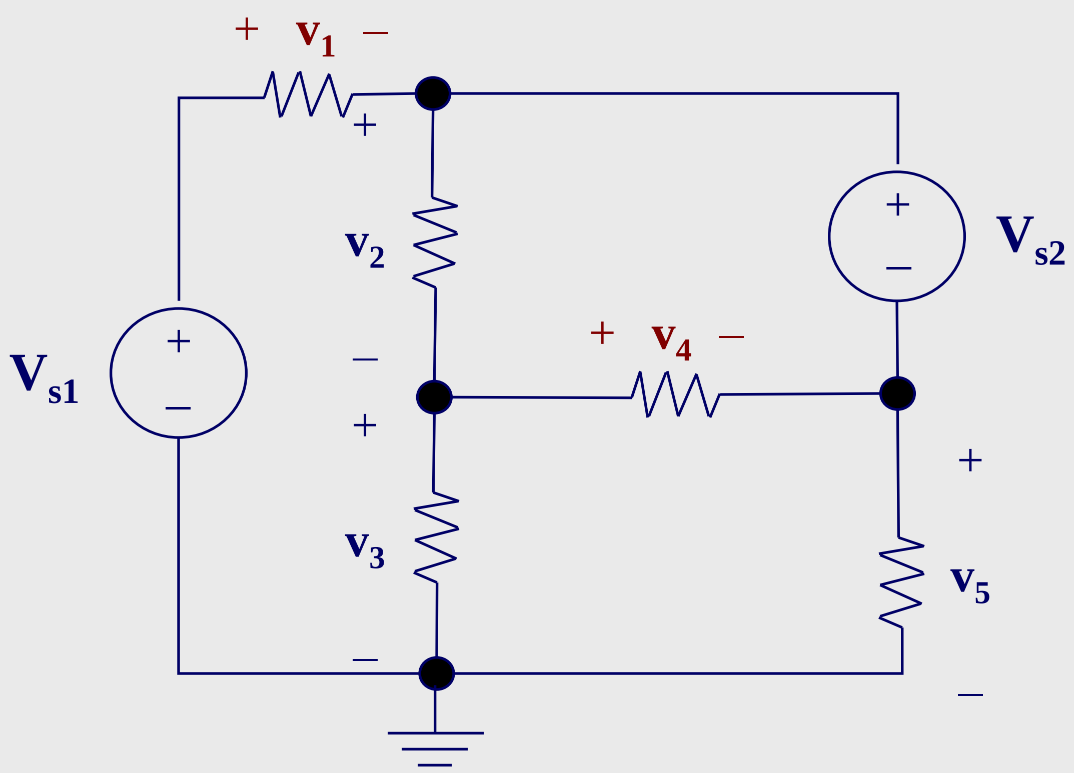


$$\begin{aligned} -v_{s1} + v_1 + v_2 + v_3 &= 0 \\ v_2 &= v_{s1} - v_1 - v_3 \\ &= 12 - 6 - 1 \\ &= 5V \end{aligned}$$

NB: $\mathbf{v_2}$ is the voltage across two elements in parallel branches. The voltage across both elements is the same: $\mathbf{v_2}$

Kirchhoff's Voltage Law (KVL)

- **Example4**: using KVL find $\mathbf{v_1}$ and $\mathbf{v_4}$
  - $\mathbf{v_{s1}} = 12V$, $\mathbf{v_{s2}} = -4V$, $\mathbf{v_2} = 2V$, $\mathbf{v_3} = 6V$, $\mathbf{v_5} = 12V$



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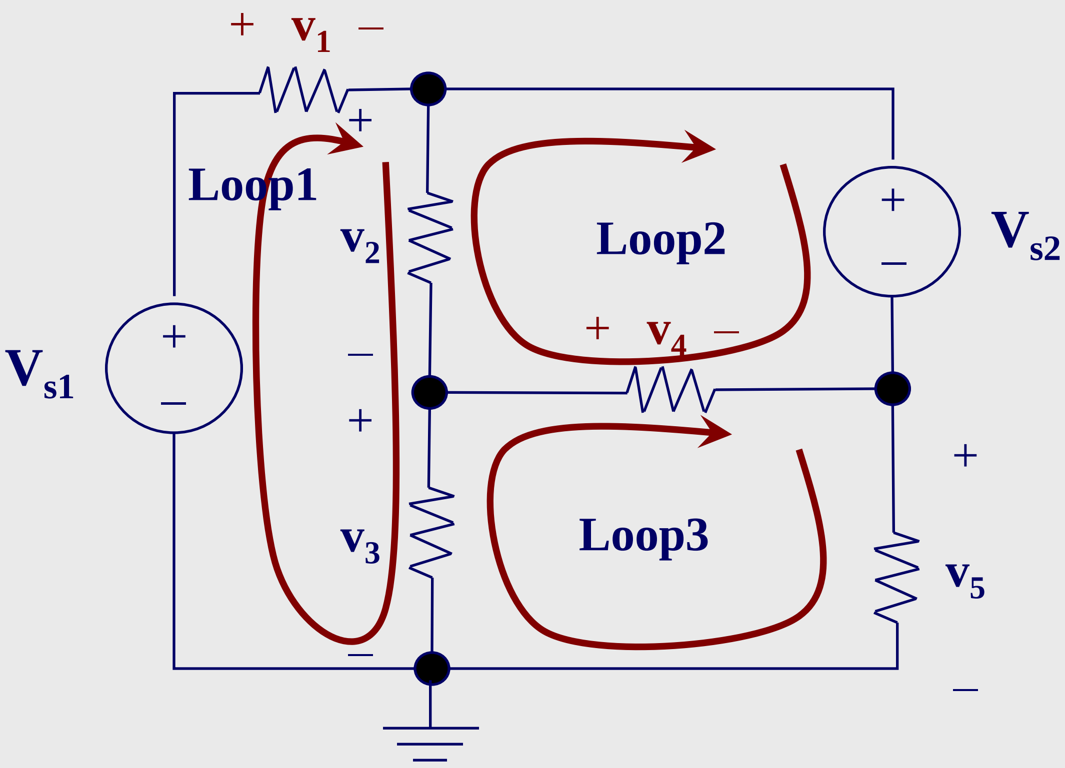

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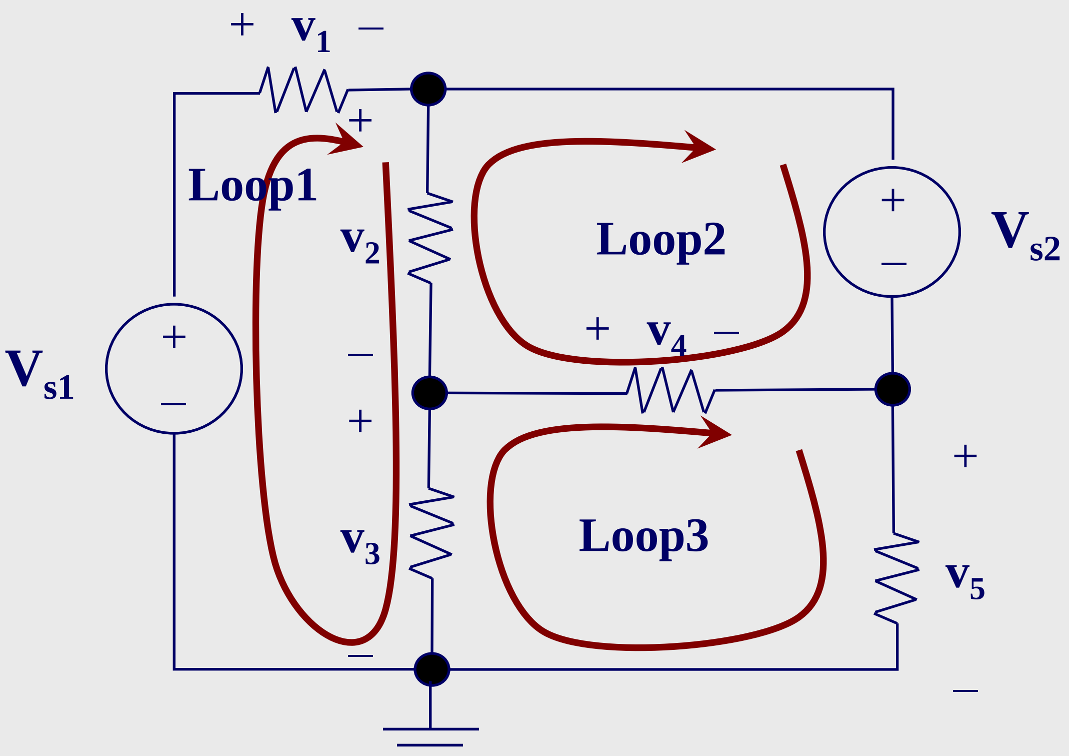

Loop 1:

$$-v_{s1} + v_1 + v_2 + v_3 = 0$$

$$v_1 = v_{s1} - v_2 - v_3$$

$$= 12 - 2 - 6$$

$$= 4V$$

Kirchhoff's Voltage Law (KVL)

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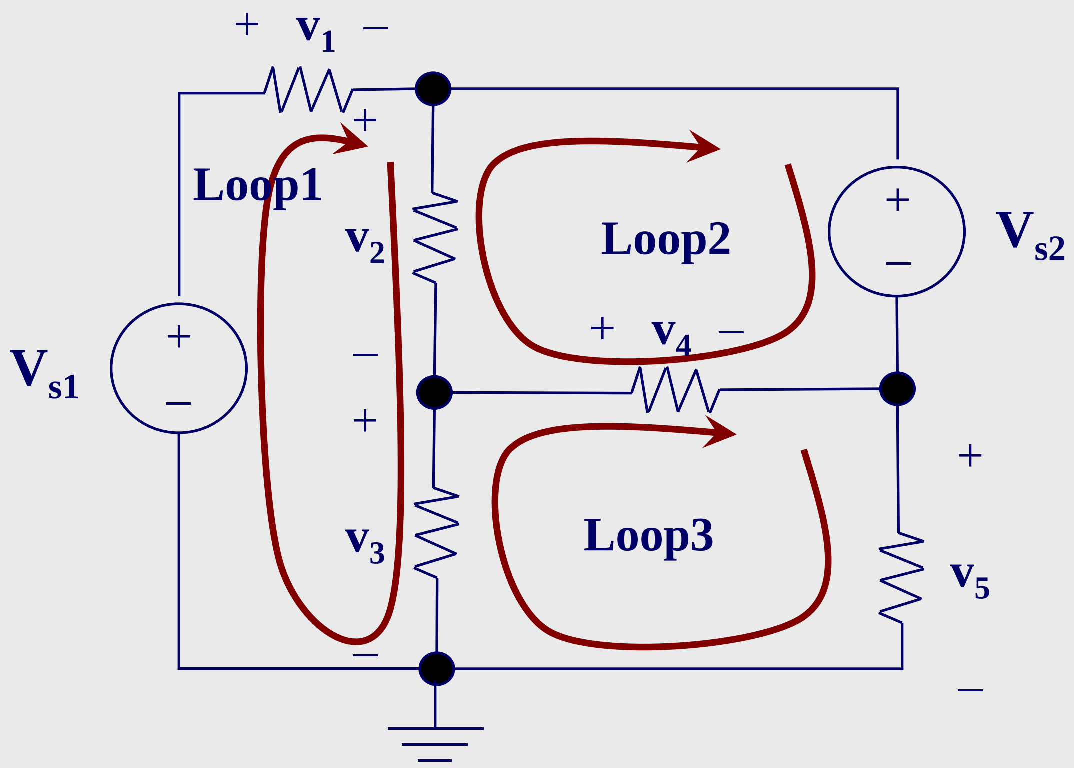

Loop 2:

$$v_{s2} - v_4 - v_2 = 0$$

$$v_4 = v_{s2} - v_2$$

$$= -4 - 2$$

$$= -6V$$