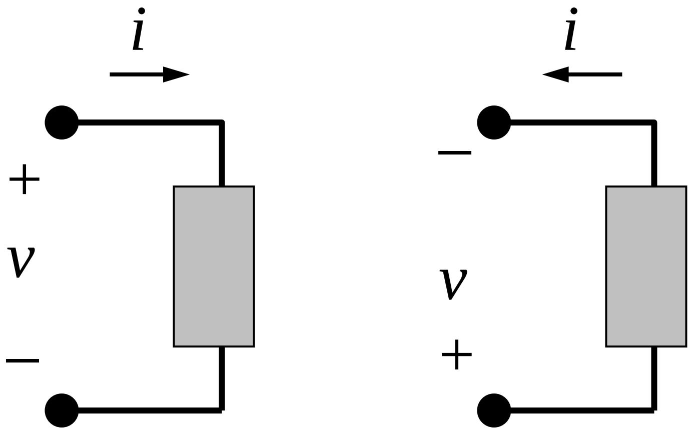
EE100 Su08 Lecture #2 (June 25th 2008)

- For today:
  - Bart: slight change in office hours:
    - Check website
  - Student accounts
    - Handed out in class. If you are in EE100, pick up account from TA in lab. If you are in EE42, pick up account forms in my office hours.
  - Remote access
  - Reading for this week and next: Chapters 1, 2, 3 (except 3.7) and 4
  - Questions and/or comments on previous material?
  - **New material: wrap up chapters 1 and 2**
  - MultiSim demo

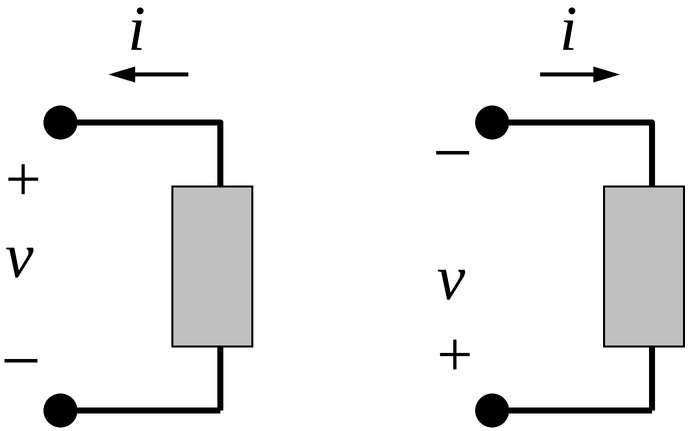
Sign Convention for Power

Passive sign convention

$$p = vi$$



$$p = -vi$$

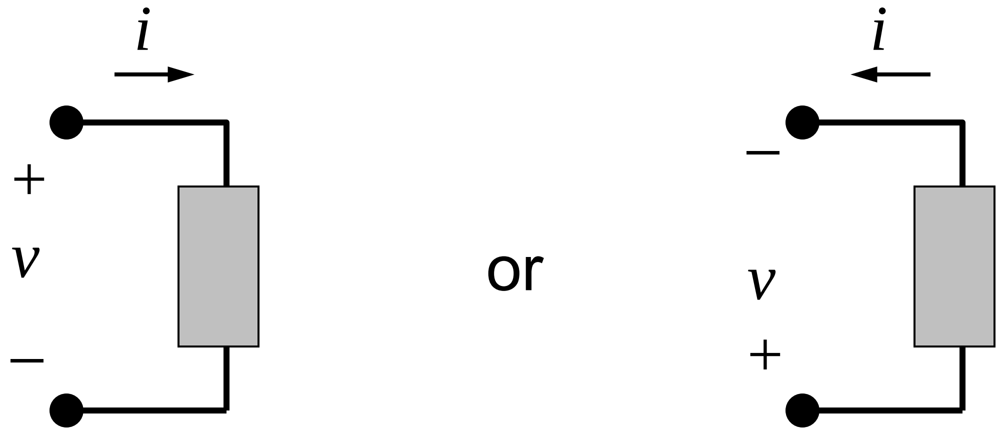


- **If $p > 0$, power is being delivered to the box.**
- **If $p < 0$, power is being extracted from the box.**

Power

If an element is absorbing power (*i.e.* if $p > 0$), positive charge is flowing from higher potential to lower potential.

$\boldsymbol{p = vi}$ if the "passive sign convention" is used:

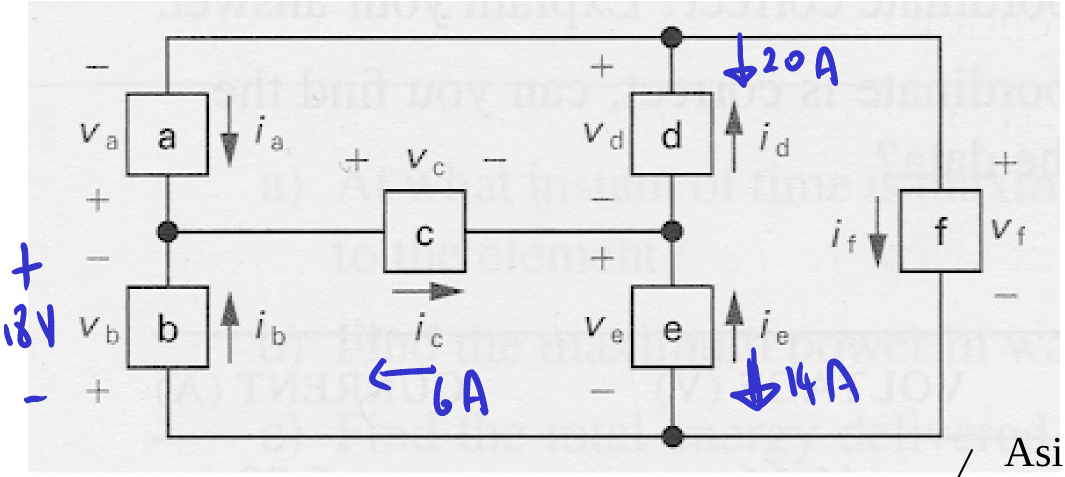


How can a circuit element absorb power?

By converting electrical energy into heat (resistors in toasters), light (light bulbs), or acoustic energy (speakers); by storing energy (charging a battery).

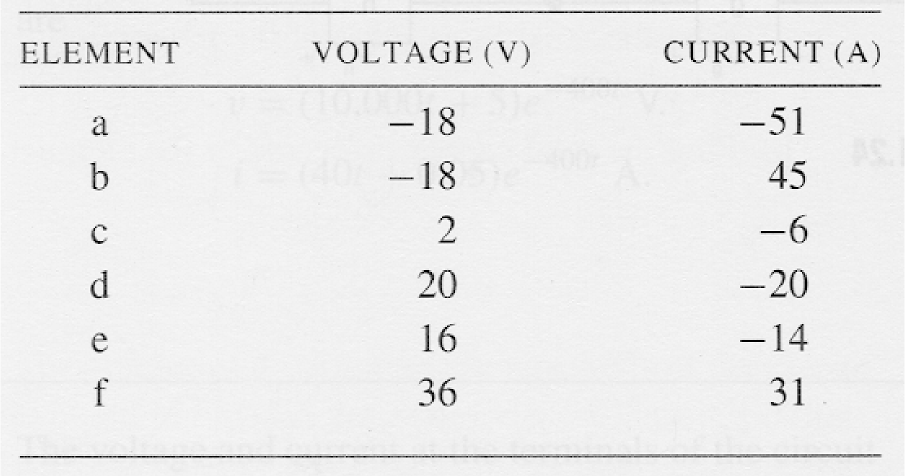
Power Calculation Example

Find the power absorbed by each element:



Conservation of energy
➔ total power delivered
equals
total power absorbed

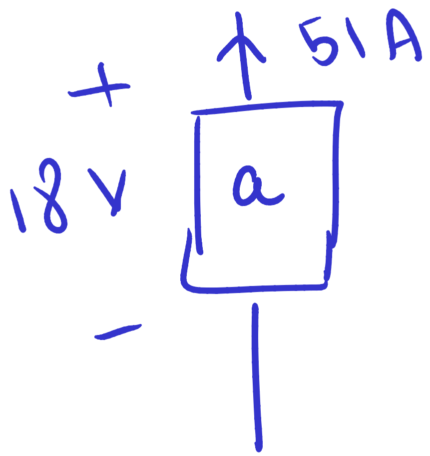
Aside: For electronics these are unrealistically large currents – milliamperes or smaller is more typical



ELEMENT	VOLTAGE (V)	CURRENT (A)
a	−18	−51
b	−18	45
c	2	−6
d	20	−20
e	16	−14
f	36	31

***vi* (W)**	***p* (W)**
918	−918 W
- 810	−810 W
- 12	−12 W
- 400	400 W
- 224	224 W
1116	1116 W
	0 W??

Power calculations



$$P = -vi$$

$$= -(18)(51)$$

$$= \underline{\underline{-918\ \text{W}}}$$

power associated with device "a"

∴ Power absorbed by device "a" is −918 W

Circuit Elements

- 5 ideal basic circuit elements:
  - voltage source
  - current source
  - resistor
  - inductor
  - capacitor

active elements, capable of generating electric energy (voltage source, current source)

passive elements, incapable of generating electric energy (resistor, inductor, capacitor)

- Many practical systems can be modeled with just sources and resistors
- The basic analytical techniques for solving circuits with inductors and capacitors are similar to those for resistive circuits

Electrical Sources

- An ***electrical source*** is a device that is capable of converting non-electric energy to electric energy and *vice versa*.

<u>Examples</u>:

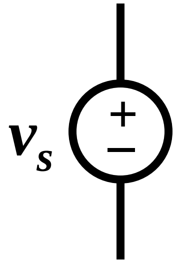
- battery: chemical ⟺ electric
- dynamo (generator/motor): mechanical ⟺ electric
  (Ex. gasoline-powered generator, Bonneville dam)

→ Electrical sources can either deliver or absorb power

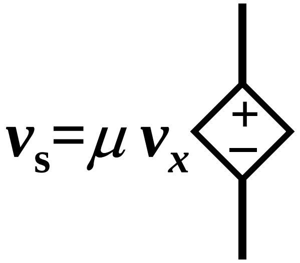
Ideal Voltage Source

- Circuit element that maintains a prescribed voltage across its terminals, **regardless of the current flowing in those terminals**.
  - Voltage is known, but current is determined by the circuit to which the source is connected.
- The voltage can be either **independent** or **dependent** on a voltage or current elsewhere in the circuit, and can be constant or time-varying.

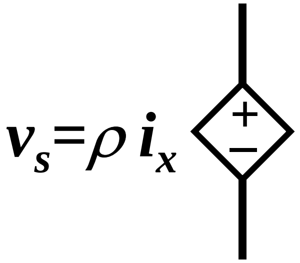
Device symbols:



independent



voltage-controlled

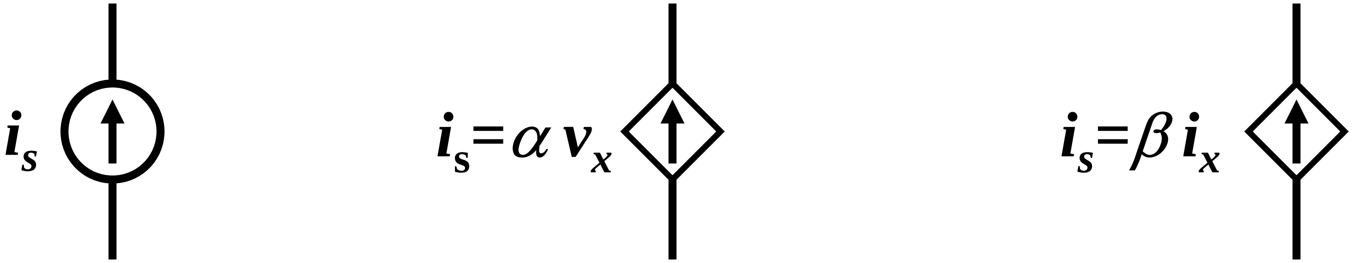


current-controlled

Ideal Current Source

- Circuit element that maintains a prescribed current through its terminals, **regardless of the voltage across those terminals**.
  - Current is known, but voltage is determined by the circuit to which the source is connected.
- The current can be either **independent or dependent** on a voltage or current elsewhere in the circuit, and can be constant or time-varying.

Device symbols:



independent **voltage-controlled** **current-controlled**

Electrical Resistance

- ***Resistance:*** the ratio of voltage drop and current. The circuit element used to model this behavior is the ***resistor***.

<u>Circuit symbol</u>:

<u>Units</u>: Volts per Ampere ≡ ohms (Ω)

Georg Simon Ohm
1789-1854

- The current flowing in the resistor is proportional to the voltage across the resistor:

$v = i\,R$ (Ohm's Law)

where v = voltage (V), i = current (A), and R = resistance (Ω)

<u>Note</u>: $p = vi = i^2R = v^2/R$

Electrical Conductance

- **Conductance** is the reciprocal of resistance.

Symbol: G

Units: **siemens (S) or mhos (℧)**

Example:

→ $\mho = 1/8$

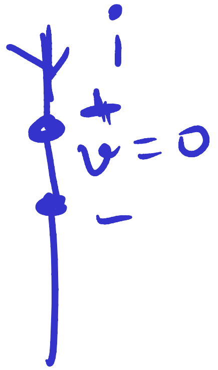
Consider an 8 Ω resistor. *What is its conductance?*

Werner von Siemens
1816-1892

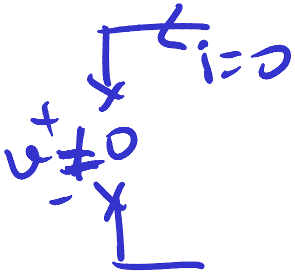
Short Circuit and Open Circuit

- Short circuit
  - R = 0 → no voltage difference exists
  - all points on the wire are at the same potential.
  - Current can flow, as determined by the circuit
- Open circuit
  - R = ∞ → no current flows
  - Voltage difference can exist, as determined by the circuit

Symbol:

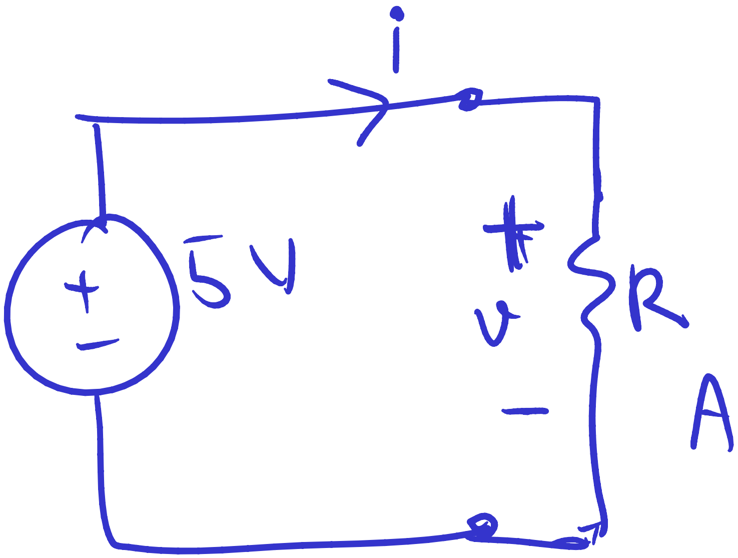


Symbol:



(Q1) Why are short-circuits "bad"?

Ex.



$$i = \frac{v}{R} = \frac{5}{R}$$ (KVL)

Kirchoff's Voltage law

As $R \to 0$, $i \to \infty$

oops, battery doesn't like it

Example: Power Absorbed by a Resistor

$$p = vi = (iR)i = i^2R$$

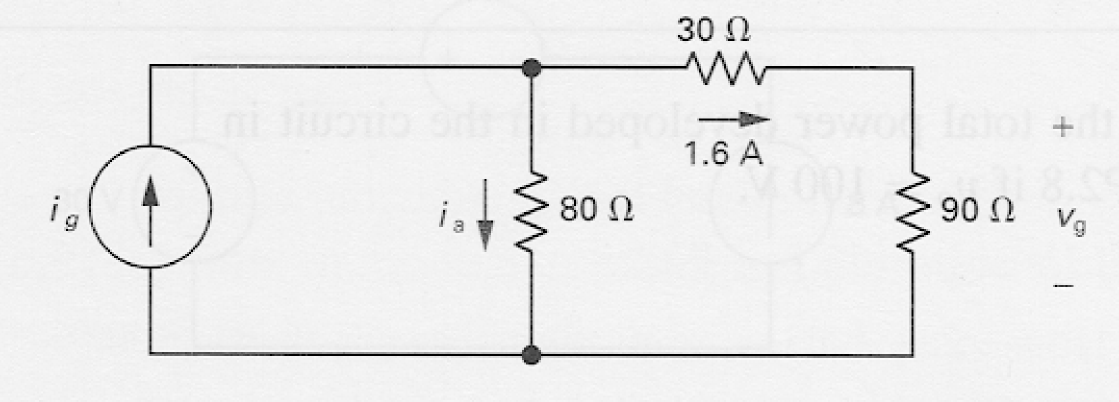
$$p = vi = v(v/R) = v^2/R$$

Note that $p > 0$ always, for a resistor → a resistor dissipates electric energy

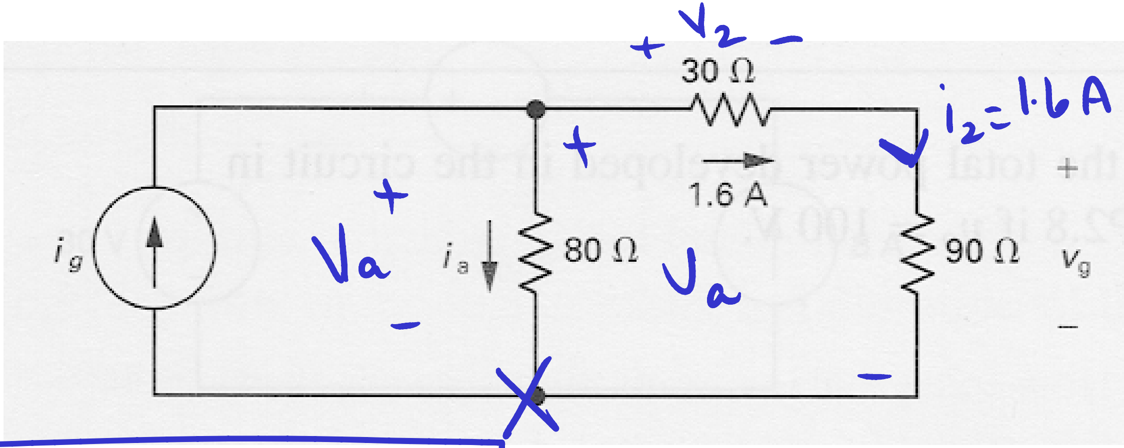
Example:

a) Calculate the voltage v_g and current i_a.

b) Determine the power dissipated in the 80Ω resistor.



Example solution

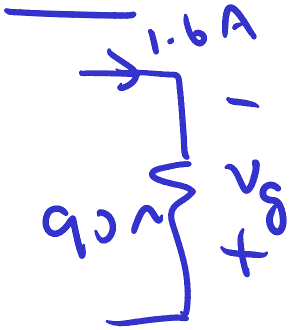


KCL: $i_2 = 1.6\,A$

$\therefore v_g = i_2\, 90$ (Ohm's law)

$= \underline{\underline{144\,V}}$

Note:



$v_g = -(1.6)(90)$

$i_a = \frac{v_a}{80}$ [Ohm's law]

KVL: $V_a = V_2 + V_g$ $\left[\begin{array}{l} +V_a - V_2 - V_g = 0 \\ \text{OR} \\ -V_a + V_2 + V_g = 0 \end{array}\right]$

$= (1.6)(30) + 144 = \underline{\underline{192\,V}}$

$\therefore i_a = \frac{192}{80} = \underline{\underline{2.4\,A}}$. $P = V_a i_a = (192)(2.4)\,W$

Summary

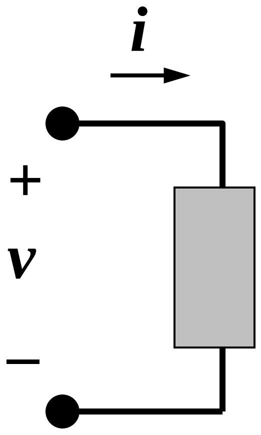
- ***Current*** = rate of charge flow $i = dq/dt$
- ***Voltage*** = energy per unit charge created by charge separation
- ***Power*** = energy per unit time
- ***Ideal Basic Circuit Elements***
  - two-terminal component that cannot be sub-divided
  - described mathematically in terms of its terminal voltage and current
  - An ***ideal voltage source*** maintains a prescribed voltage regardless of the current in the device.
  - An ***ideal current source*** maintains a prescribed current regardless of the voltage across the device.
  - A ***resistor*** constrains its voltage and current to be proportional to each other: $v = iR$ (Ohm's law)

Summary (cont'd)

- ***Passive sign convention***
  - – For a passive device, the reference direction for current through the element is in the direction of the reference voltage drop across the element

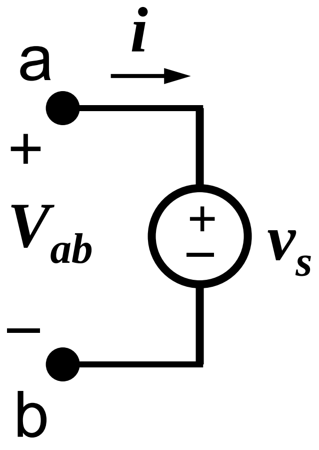
Current *vs.* Voltage (*I-V*) Characteristic

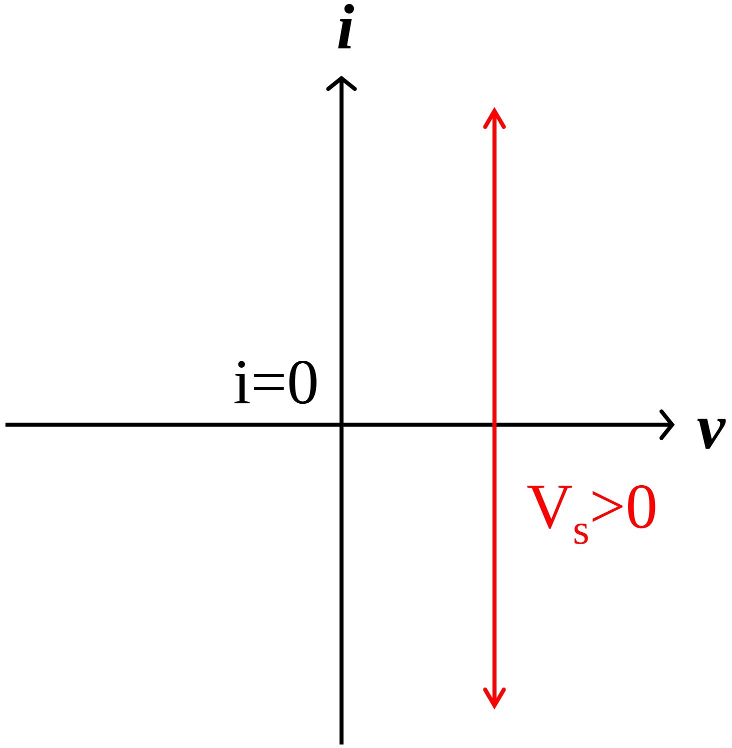
- Voltage sources, current sources, and resistors can be described by plotting the current (***i***) as a function of the voltage (***v***)



Passive? Active?

I-V Characteristic of Ideal Voltage Source

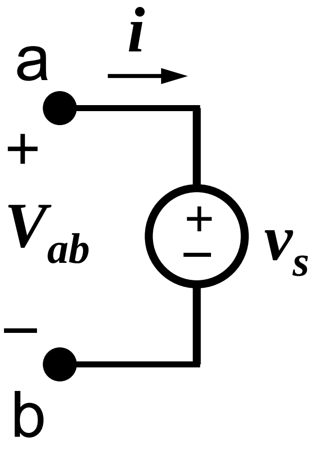


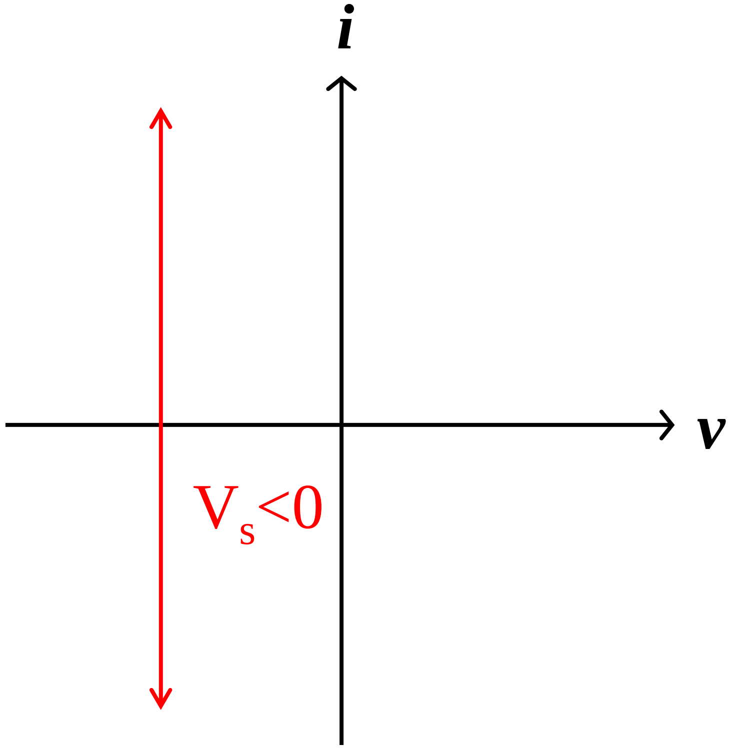


1. Plot the *I-V* characteristic for $v_s > 0$. For what values of i does the source absorb power? For what values of i does the source release power?

$V_s>0$ → i<0 release power; i>0 absorb power

I-V Characteristic of Ideal Voltage Source

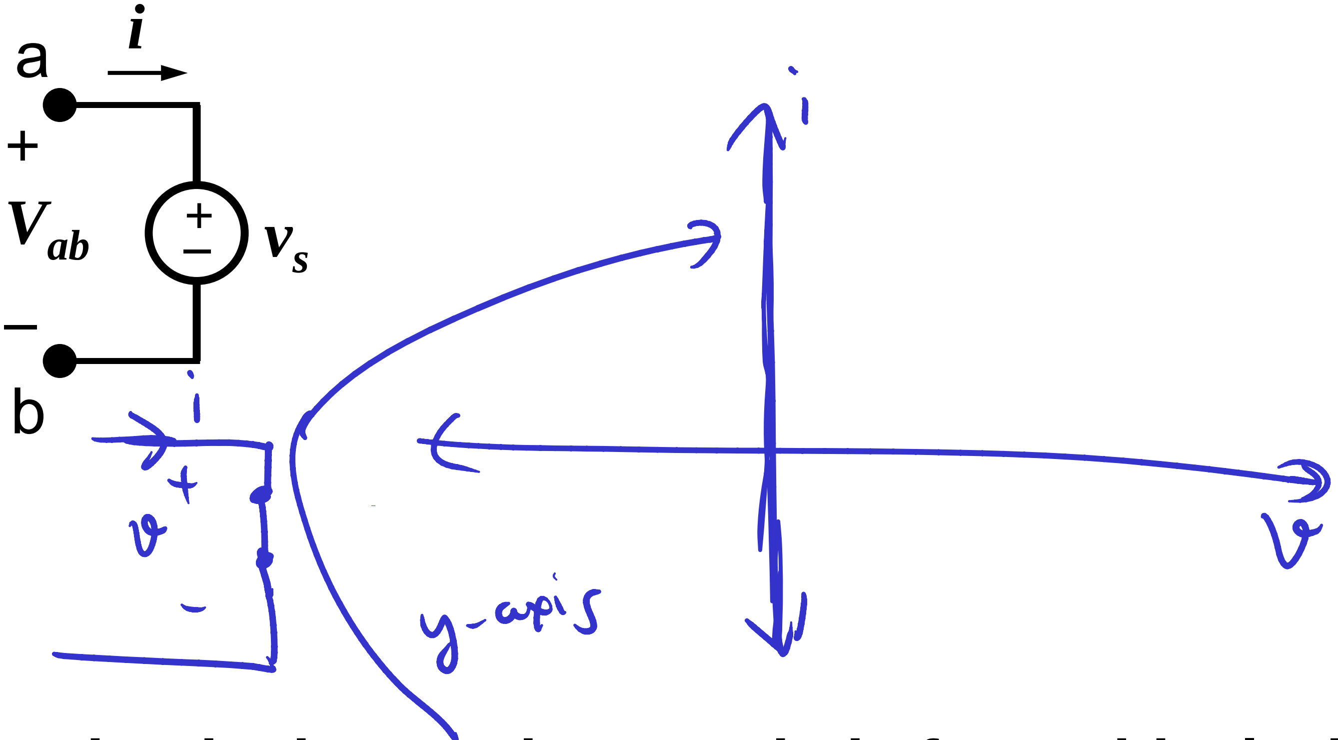




2. Plot the *I-V* characteristic for $v_s < 0$. For what values of i does the source absorb power? For what values of i does the source release power?

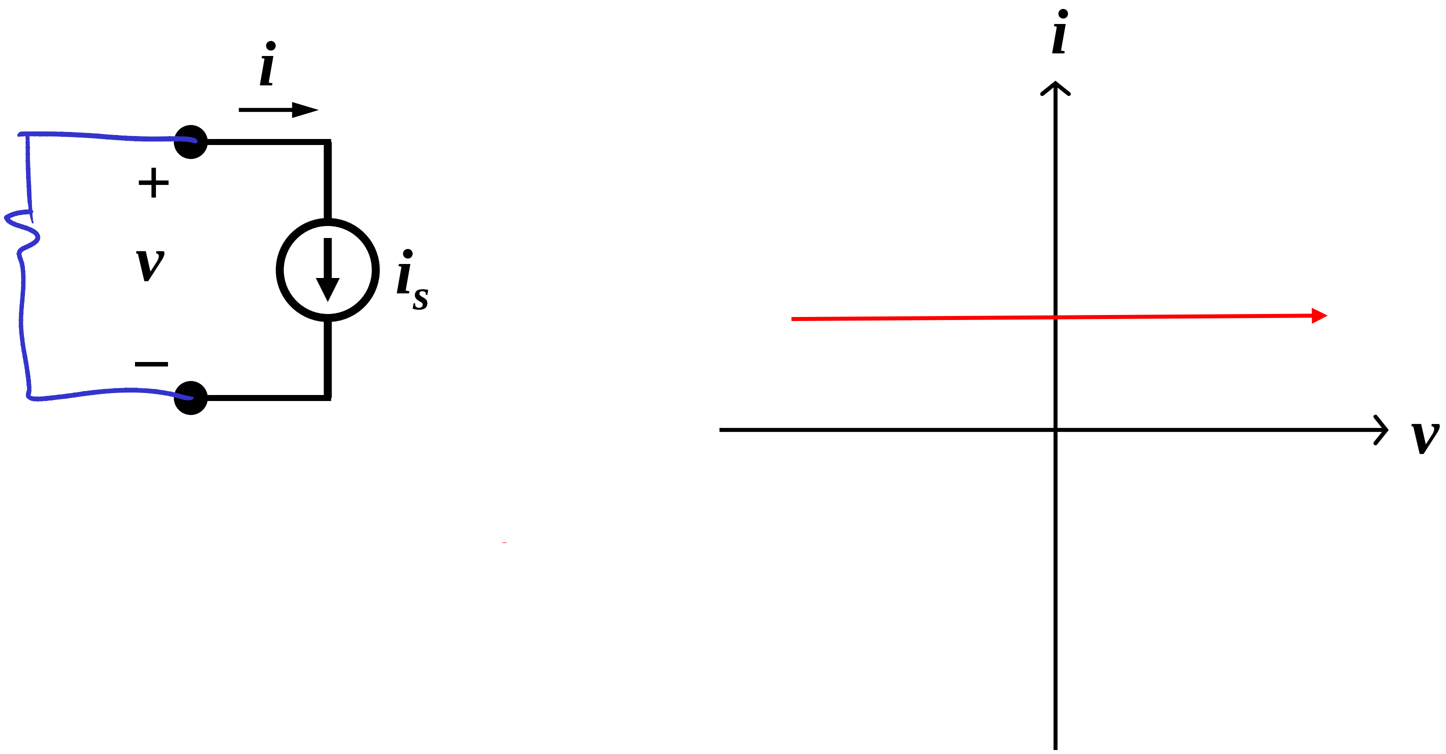
$V_s<0$ → i>0 release power; i<0 absorb power

I-V Characteristic of Ideal Voltage Source



3. What is the *I-V* characteristic for an ideal wire?

I-V Characteristic of Ideal Current Source



1. **Plot the *I-V* characteristic for $i_s > 0$. For what values of v does the source absorb power? For what values of v does the source release power?**

V>0 absorb power; V<0 release power

Short Circuit and Open Circuit

Wire ("short circuit"):

- $R = 0$ → **no voltage difference exists**
  (all points on the wire are at the same potential)
- Current can flow, as determined by the circuit

Air ("open circuit"):

- $R \overset{\rightarrow}{\cancel{=}} \infty$ → **no current flows**
- Voltage difference can exist, as determined by the circuit

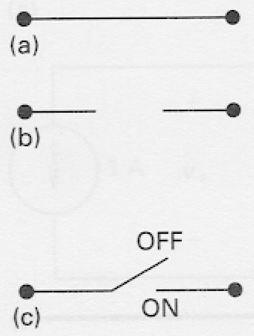
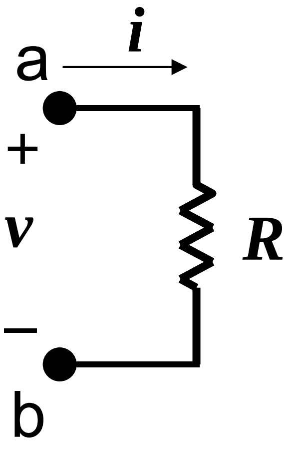


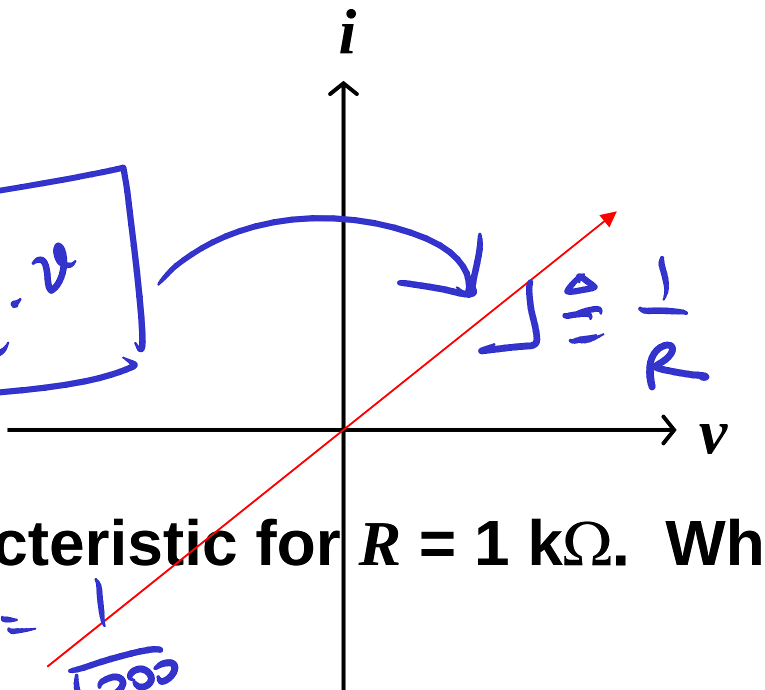
Figure 2.10 Circuit symbols. (a) Short circuit. (b) Open circuit. (c) Switch.

I-V Characteristic of Ideal Resistor



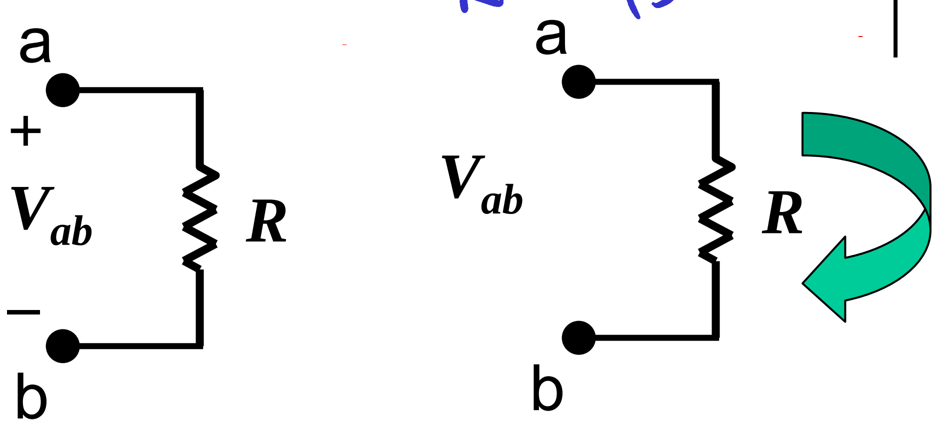
$v = iR$

$\Rightarrow \boxed{i = \frac{1}{R} \cdot v}$



$\triangleq \frac{1}{R}$

1. **Plot the *I-V* characteristic for R = 1 kΩ. What is the slope?** slope $\triangleq \frac{1}{R} = \frac{1}{1000}$

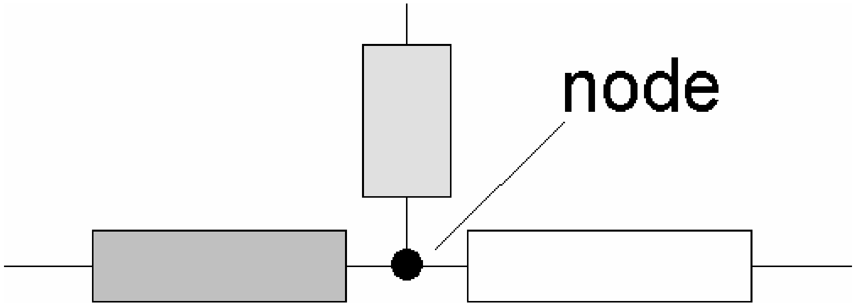


Construction of a Circuit Model

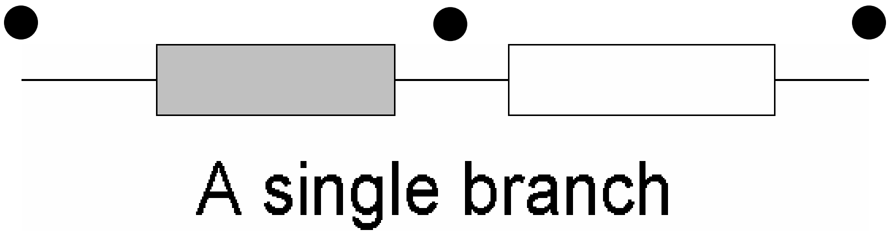
- The electrical behavior of each physical component is of primary interest.
- We need to account for undesired as well as desired electrical effects.
- Simplifying assumptions should be made wherever reasonable.

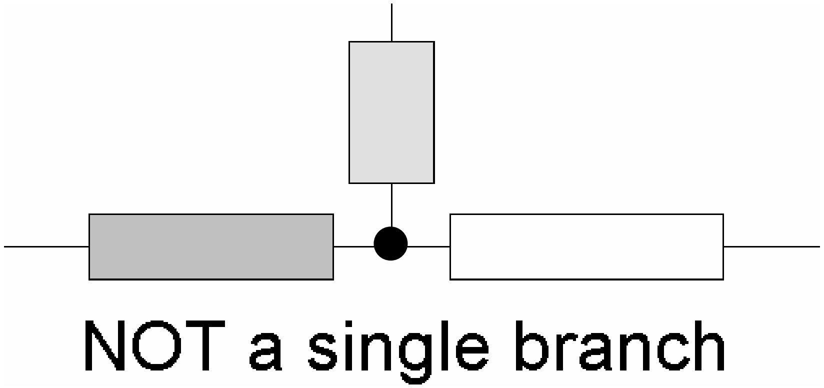
Terminology: Nodes and Branches

Node: A point where two or more circuit elements are connected



Branch: A path that connects two nodes



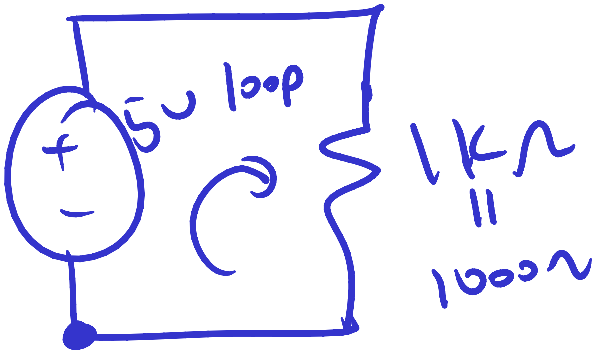


Circuit Nodes and Loops

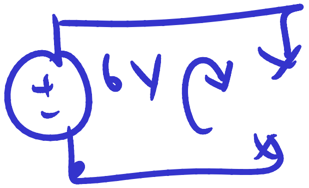
- A ***node*** is a point where two or more circuit elements are connected.
- A ***loop*** is formed by tracing a ~~closed~~ path in a circuit through selected basic circuit elements without passing through any intermediate node more than once.

Ex:

loop:



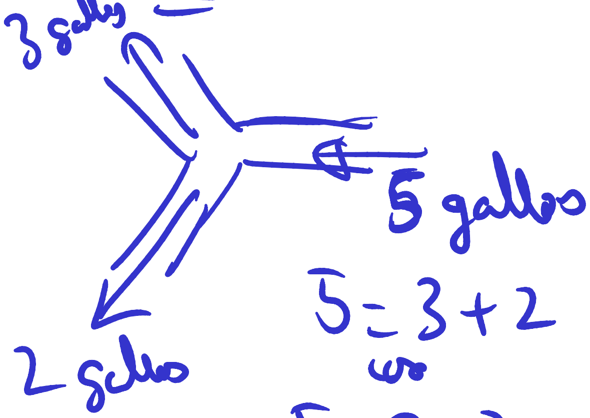
loop:



Kirchhoff's Laws

- **Kirchhoff's Current Law (KCL):**
  - The algebraic sum of all the **currents** entering any **node** in a circuit equals zero.
- **Kirchhoff's Voltage Law (KVL):**
  - The algebraic sum of all the **voltages** around any **loop** in a circuit equals zero.

KCL:

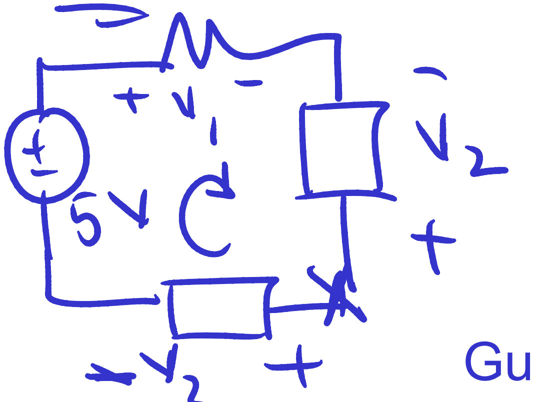


$5 = 3 + 2$

or

$5 - 3 - 2 = 0$

KVL:



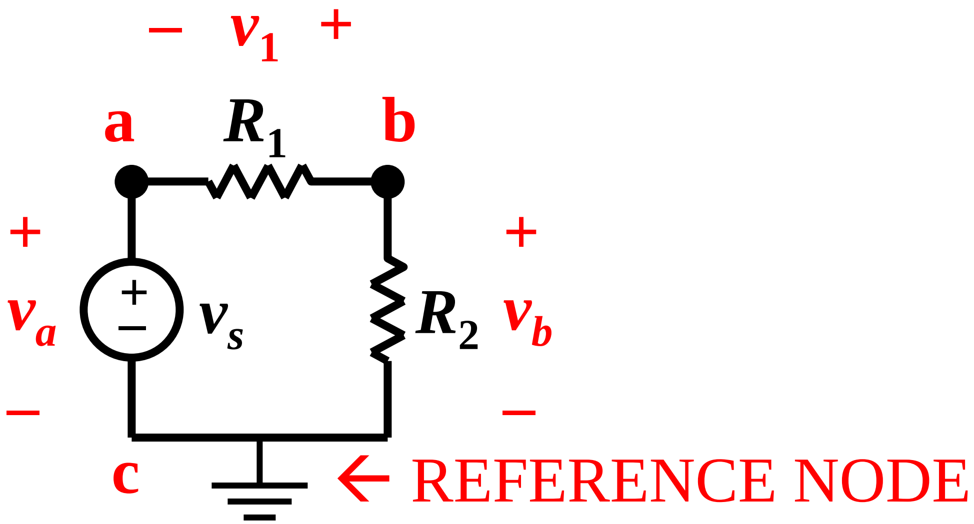
$-v_3 + 5 - v_1 + v_2 = 0$

Gustav Robert Kirchhoff
1824-1887

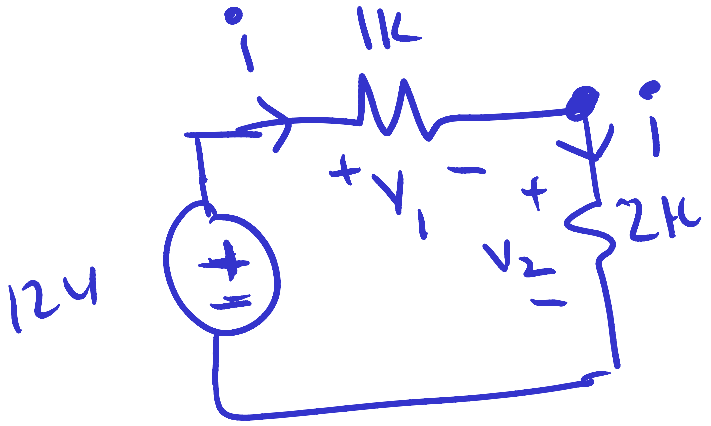
Notation: Node and Branch Voltages

- Use one node as the reference (the “common” or “ground” node) – label it with a symbol
- The voltage drop from node **x** to the reference node is called the **node voltage v_x**.
- The voltage across a circuit element is defined as the difference between the node voltages at its terminals

Example:



Concrete example



Ohm's law: $V_1 = (i)(1k)$

$V_2 = (i)(2k)$

KVL: $12 = V_1 + V_2$

$= (i)(1k) + (i)(2k)$

$\Rightarrow 12 = (i)(3k)$

$\Rightarrow i = \frac{12}{3k} = 4\times10^{-3}\,A$

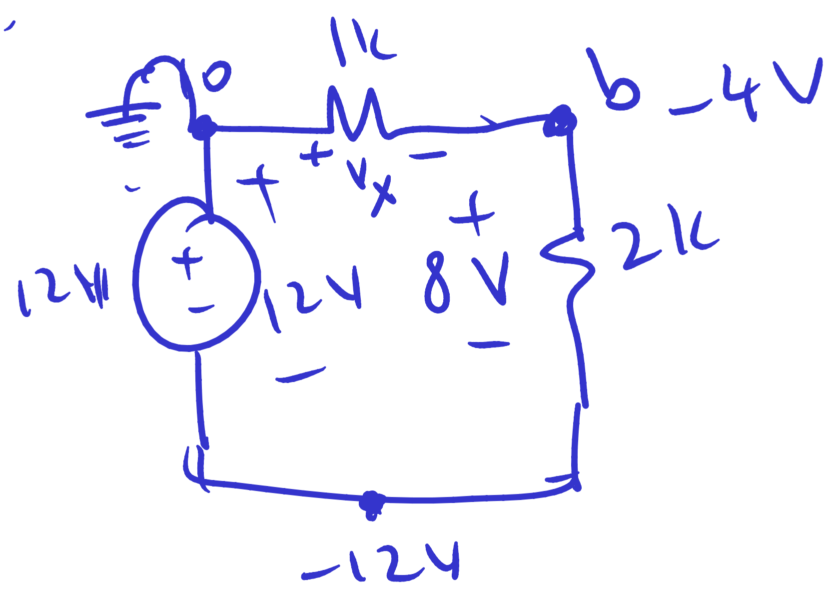
$= 4\,\underline{m}A$

$\therefore V_1 = (1k)(i) = 4\,V$

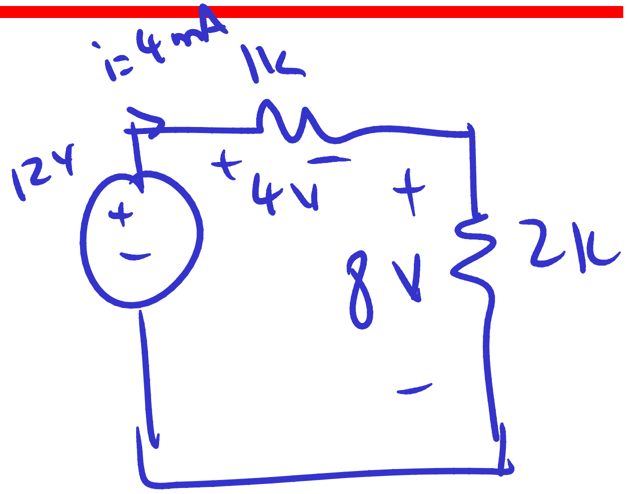
$V_2 = (2k)(i) = 8\,V$

Concept of reference node

Suppose:



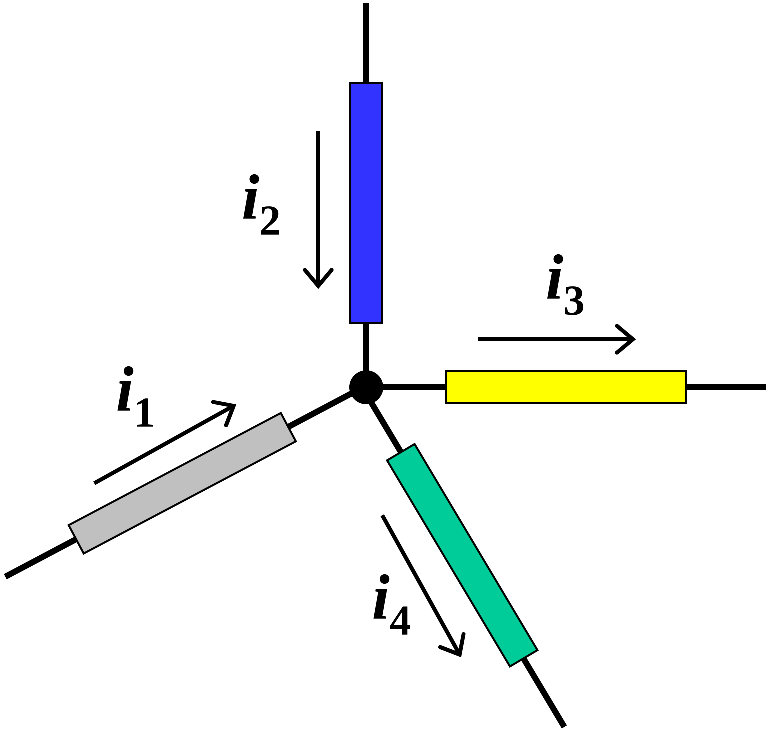
$$V_x = 0-(-4) = \underline{\underline{4\ V}}$$



Notice: potential drops (voltage) across elements is same!

Using Kirchhoff's Current Law (KCL)

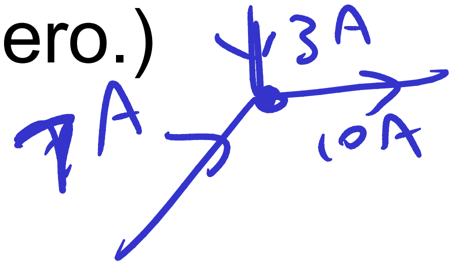
Consider a node connecting several branches:



- Use **reference directions** to determine whether currents are "entering" or "leaving" the node – with no concern about actual current directions

Formulations of Kirchhoff's Current Law

(Charge stored **in node** is zero.)



Formulation 1:

Sum of currents entering node

= sum of currents leaving node

7+3=10

Formulation 2:

Algebraic sum of currents entering node = 0

- Currents leaving are included with a minus sign.

7+3-10=0

Formulation 3:

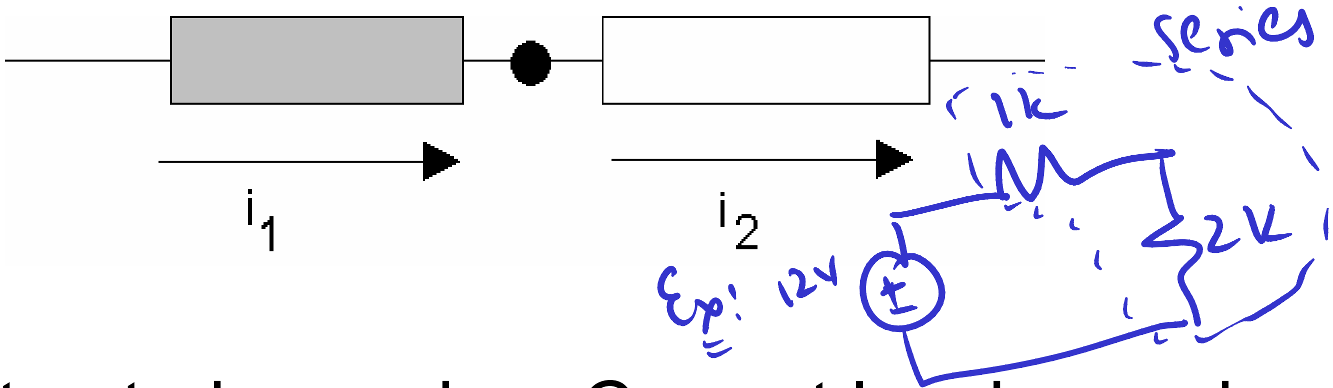
Algebraic sum of currents leaving node = 0

10-7-3=0

- Currents entering are included with a minus sign.

A Major Implication of KCL

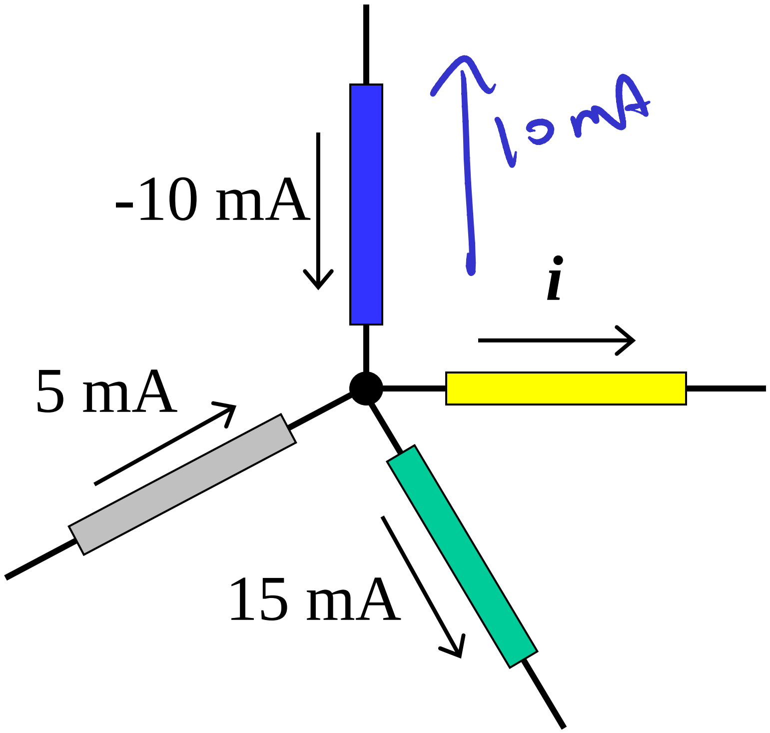
- KCL tells us that **all of the elements in a single branch carry the same current**.
- We say these elements are connected ***in series***.



Current entering node = Current leaving node

$$i_1 = i_2$$

KCL Example



Currents entering the node:

5 mA

Currents leaving the node:

i, 10mA, 15mA

<u>3 formulations of KCL</u>:

1.

2.

3.

Do this urself ☺