## Announcements

- **Visit the class website to see updated TA section assignments**

  http://www-inst.eecs.berkeley.edu/~ee40

- **Lab section 13 (Mondays 6-9PM) is cancelled**

- **Prof. King's Office Hour tomorrow (Thu. 9/4) will be held from 8:30AM-9:30AM**

- **HW assignments will NOT be accepted in class. Turn in your assignments BEFORE class on Friday in 240 Cory.**



## Lecture #4

**OUTLINE**

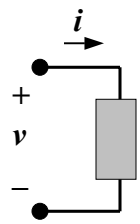
- Circuit element *I-V* characteristics
- Construction of a circuit model
- Kirchhoff's laws – a closer look

**Reading**

(Finish Chapter 2)

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

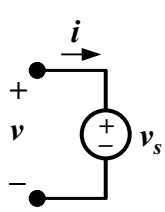
- Voltage sources, current sources, and resistors can be described by plotting the current ($i$) as a function of the voltage ($v$)

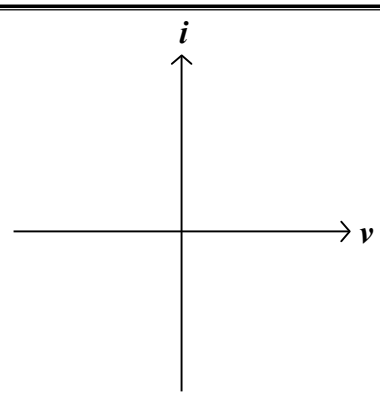



- Later, we will see that the *I-V* characteristic of any circuit consisting only of sources and resistors is a straight line.



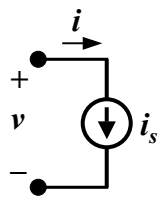
## *I-V* Characteristic of Ideal Voltage Source

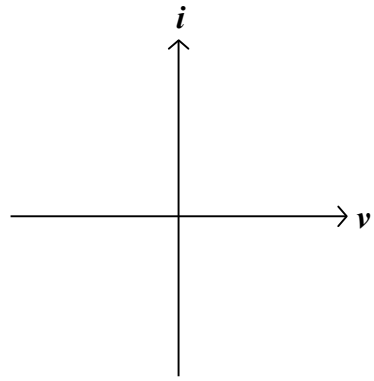



1. **Plot the *I-V* characteristic for $v_s > 0$. For what values of $i$ does the source absorb power? For what values of $i$ does the source release power?**
2. **Repeat (1) for $v_s < 0$.**
3. **What is the *I-V* characteristic for an ideal wire?**

## *I-V* Characteristic of Ideal Current Source

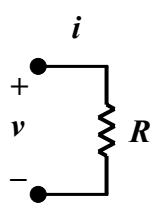


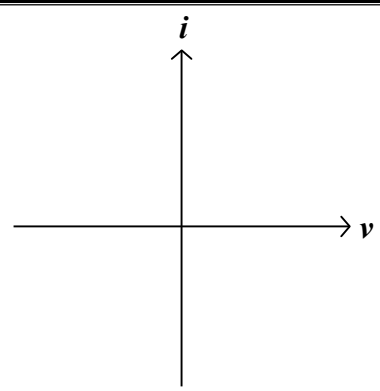




1. Plot the *I-V* characteristic for $i_s > 0$. For what values of $v$ does the source absorb power? For what values of $v$ does the source release power?
2. Repeat (1) for $i_s < 0$.
3. What is the *I-V* characteristic for an open circuit?



## *I-V* Characteristic of Ideal Resistor




1. Plot the *I-V* characteristic for $R$ = 1 kΩ. What is the slope?

## "Lumped Element" Circuit Modeling

(Model = representation of a real system which simplifies analysis)

- In circuit analysis, important characteristics are grouped together in "lumps" (separate circuit elements) connected by perfect conductors ("**wires**")
- An electrical system can be modeled by an **electric circuit** (combination of paths, each containing 1 or more **circuit elements**) if

$$\lambda = c/f >> \text{physical dimensions of system}$$

Distance travelled by a particle travelling at the speed of light in one period

<u>Example</u>: f = 60 Hz

$$\lambda = 3 \times 10^8 \text{ m/s} / 60 = 5 \times 10^6 \text{ m}$$

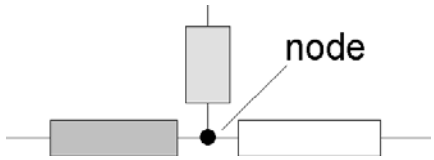


## Construction of a Circuit Model

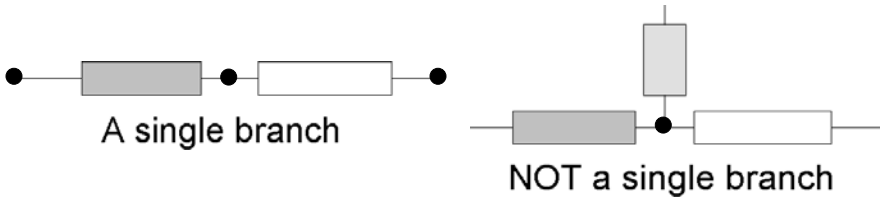
- The electrical behavior of each physical component is of primary interest.
- We need to account for undesired as well as desired electrical effects.
- Simplifying assumptions should be made wherever reasonable.

## Terminology: Nodes and Branches

***Node***: A point where two or more circuit elements are connected – entire wire




***Branch***: A path that connects two nodes

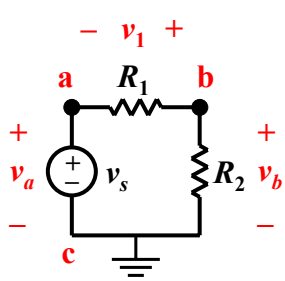





## Notation: Node and Branch Voltages

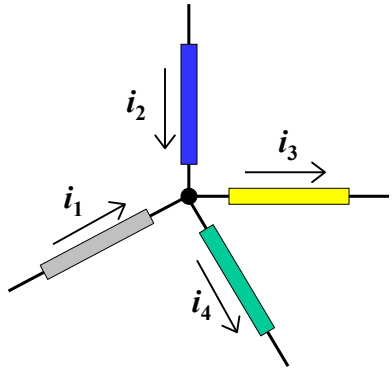
- Use one node as the reference (the "common" or "ground" node) – label it with a symbol
- The voltage drop from node **x** to the reference node is called the **node voltage $v_x$**.
- The voltage across a circuit element is defined as the difference between the node voltages at its terminals

Example:



## 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

**Formulation 2:**

Algebraic sum of currents entering node = 0

- Currents leaving are included with a minus sign.

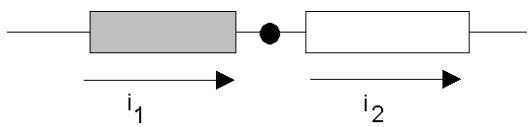
**Formulation 3:**

Algebraic sum of currents leaving node = 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***.

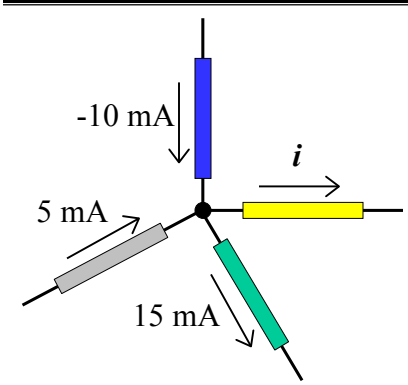



Current entering node = Current leaving node

$$i_1 = i_2$$



# KCL Example




**Currents entering the node:**

**Currents leaving the node:**

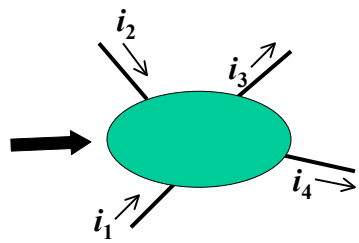
**<u>3 formulations of KCL</u>:**

1.
2.
3.

# Generalization of KCL

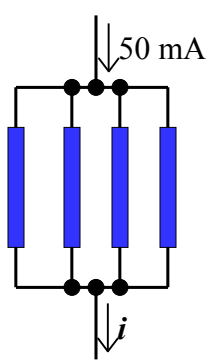
- The sum of currents entering/leaving a **closed surface** is zero. Circuit branches can be inside this surface, *i.e.* the surface can enclose more than one node!

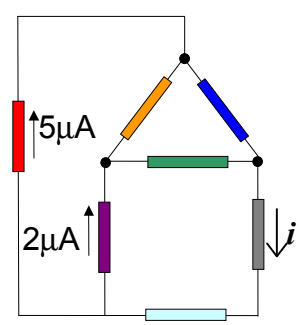
This could be a big chunk of a circuit, *e.g.* a "black box"





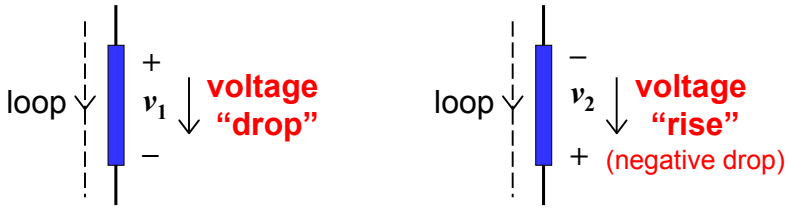

# Generalized KCL Examples



## Using Kirchhoff's Voltage Law (KVL)

Consider a branch which forms part of a loop:




- Use **reference polarities** to determine whether a voltage is dropped – with no concern about actual voltage polarities



## Formulations of Kirchhoff's Voltage Law

(Conservation of energy)

**Formulation 1:**

Sum of voltage drops around loop
= sum of voltage rises around loop

**Formulation 2:**

Algebraic sum of voltage drops around loop = 0

- Voltage rises are included with a minus sign.

**(Handy trick: Look at the first sign you encounter on each element when tracing the loop.)**

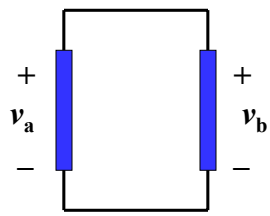
**Formulation 3:**

Algebraic sum of voltage rises around loop = 0

- Voltage drops are included with a minus sign.

# A Major Implication of KVL

- KVL tells us that **any set of elements which are connected at both ends carry the same voltage**.
- We say these elements are connected **in parallel**.



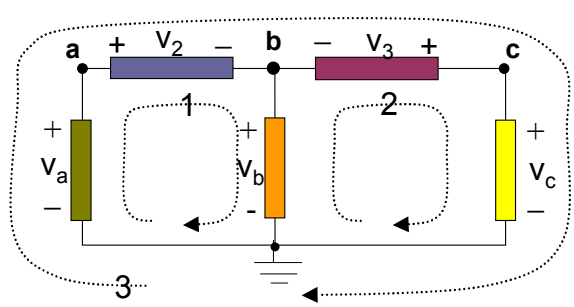

Applying KVL in the clockwise direction, starting at the top:

$$v_b - v_a = 0 \;\Rightarrow\; v_b = v_a$$



# KVL Example

**Three closed paths:**




**<u>Path 1</u>:**

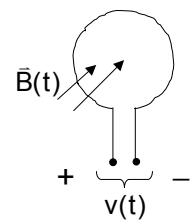
**<u>Path 2</u>:**

**<u>Path 3</u>:**

## An Underlying Assumption of KVL

- No time-varying magnetic flux through the loop
  Otherwise, there would be an induced voltage (Faraday's Law)

- Note: Antennas are designed to "pick up" electromagnetic waves; "regular circuits" often do so undesirably.




Avoid these loops!

*How do we deal with antennas (EECS 117A)?*

Include a voltage source as the circuit representation of the induced voltage or "noise".

(Use a lumped model rather than a distributed (wave) model.)



## Summary

- 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:

$$v = iR \quad \text{(Ohm's law)}$$

- ***Kirchhoff's current law*** states that the algebraic sum of all currents at any node in a circuit equals zero.
- ***Kirchhoff's voltage law*** states that the algebraic sum of all voltages around any closed path in a circuit equals zero.