EE292: Fundamentals of ECE

Fall 2012
TTh 10:00-11:15 SEB 1242

Lecture 2
120830

http://www.ee.unlv.edu/~b1morris/ee292/

Outline

- Review
- Power/Energy
- KCL
- KVL
- Circuit Elements

Fluid Flow Analogy

- Fluid = electric charge
  - What is moving around
- Pipes = wires
  - The medium of transport
- Valve = switch
  - Start/stop flow
- Pump = battery
  - Provides the force to move charge
- Pipe blockage = resistor
  - Prevents smooth flow

Electric Charge

- A conductor is a material where charge is free to flow
- Even at rest, charge carriers are in rapid motion due to thermal energy
  - Think back to physics
- Typical charge carriers are electrons (negative) and ions or holes (positive) charge

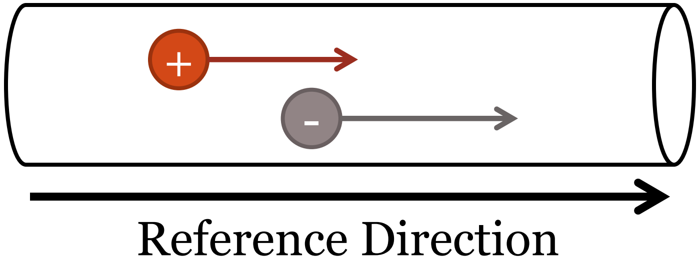
- Electron charge (Coulombs)
  - $q = -1.602 \times 10^{-19}\,C$

Current

- Current is charge in motion
- It is defined as the amount of charge passing through a surface in a small time interval
- $i(t) = \frac{dq(t)}{dt}$
  - $q(t)$ is the charge crossing a surface over time
  - Units are [C/s], also known as an amp

Current Reference Directions

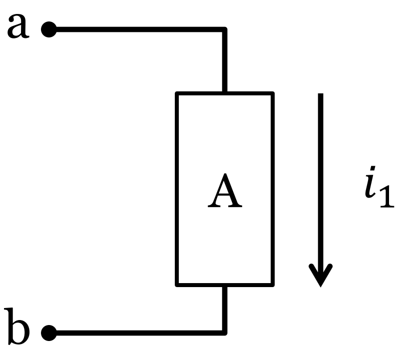
- In order to define a current, a reference direction must be defined
- The reference direction indicates which direction positive charge is moving



  - Positive charge carriers in reference direction → positive current
  - Negative charge carriers in reference direction → negative current

Determining Current Direction

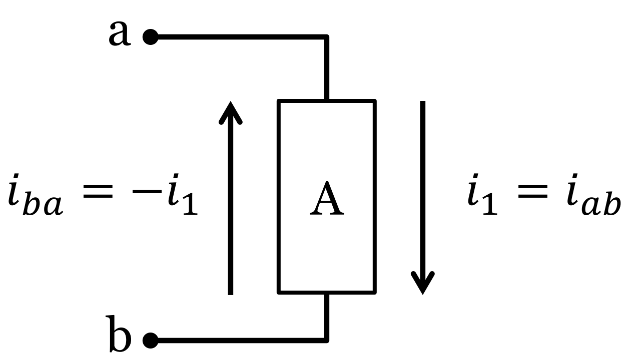
- When analyzing a circuit the direction of current flow is unknown
- Arbitrarily define a current reference direction
  - This may not match actual current flow
  - If the current value turns out to be negative, it means current flows opposite your reference direction
  - $i_1 = -2\text{ mA}$
    - Current flows from b to a



Double Subscript Notation

- Alternative to arrows for denoting reference direction
- Current is defined from a start node to an end node

- $i_1 = i_{ab}$
  - Current flow from a to b
- $i_1 = i_{ab} = -i_{ba}$



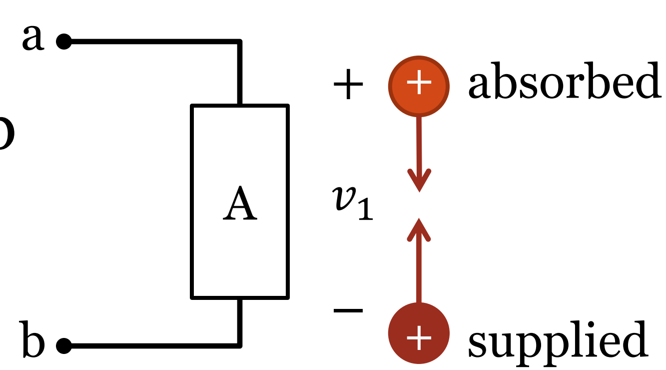
Voltage

- A measure of the energy transferred per unit charge from one point to another in a circuit
- The potential difference between two nodes

- Units are Volts [V = J/C]

Voltage Reference Polarities

- Like with currents, must assign arbitrary reference
- Set the polarity on either side of circuit element
  - a is positive polarity
  - b is negative polarity
  - Assume a has higher voltage than b

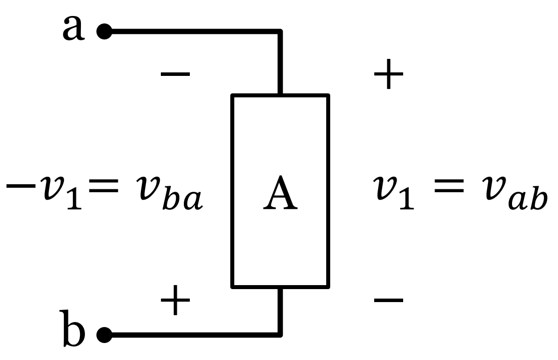


- Positive charge flowing into the positive terminal → energy is absorbed by element A
- Positive charge flowing into the negative terminal → energy supplied by element A

Double Subscript Notation

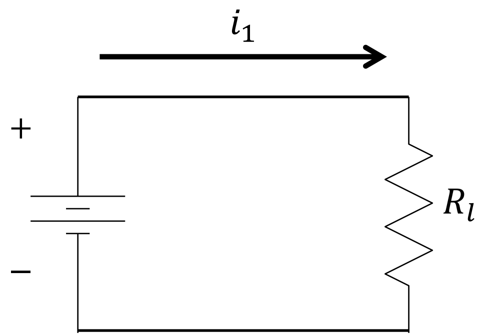
- Voltage is defined based on polarities
  - Voltage from the positive to the negative polarity

- $v_1 = v_{ab}$
  - Voltage from node a to node b
  - Implicitly assume that a is at higher voltage than b
- $v_1 = v_{ab} = -v_{ba}$



Battery Example

- Imagine a battery and a light bulb

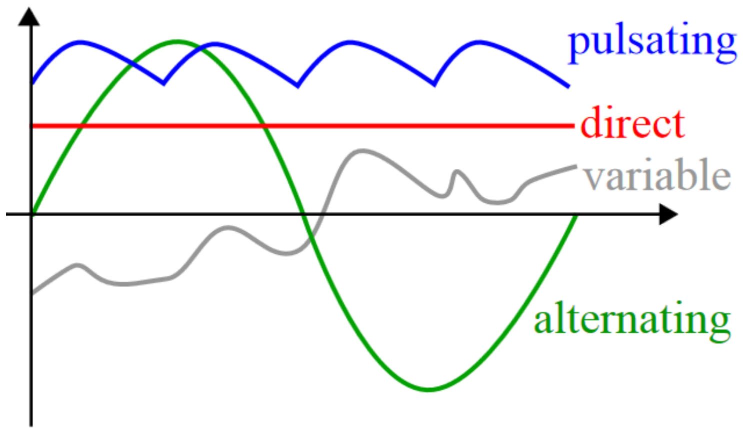


- $i_1 > 0$ current leaves the battery → energy is supplied to the light
- $i_1 < 0$ current enters the battery → energy is absorbed (charging)

DC and AC

- Terms apply to both current and voltage
  - Originally come from current

- Direct current (DC) – constant in time
  - E.g. 9V battery – always outputs 9V
- Alternating current (AC) – time-varying and sign/direction changes
  - E.g. 120V 60 Hz wall outlet



Source: Wikipedia

Power

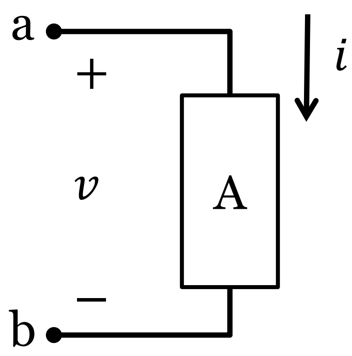
- Rate of energy transfer

- $p = vi$
  - Voltage v is J/C (energy/charge)
  - Current i is C/s (charge/second)

- Units are watts [W = (J/C)(C/s) = J/s]

Passive Reference Configuration

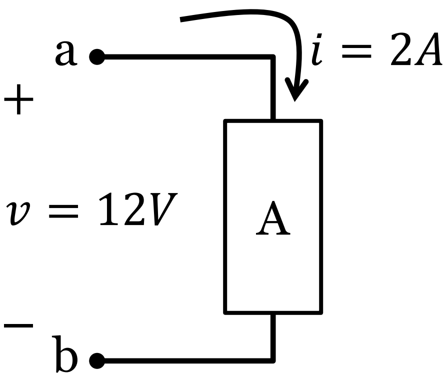
- Current flows into the positive polarity terminal



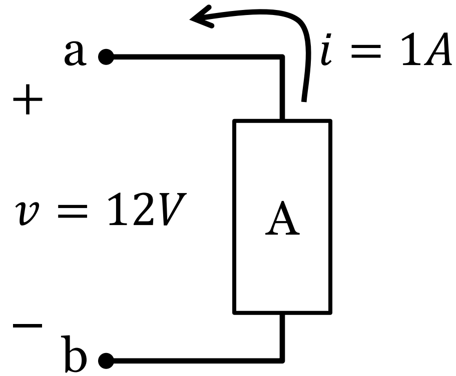
  - $p > 0$ → energy absorbed by element
  - $p < 0$ → energy supplied by element

- If current is defined into the negative terminal
  - $p = -vi$

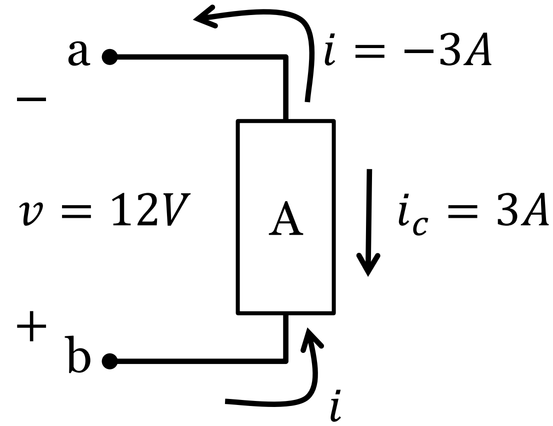
Example



$p = vi = 24$ W
A absorbs energy



$p = -vi = -12$ W
A supplies energy



$p = vi = (12)(-3)$
$= -vi_c = -(12)(3)$
$= -36$ W
A supplies energy

Energy

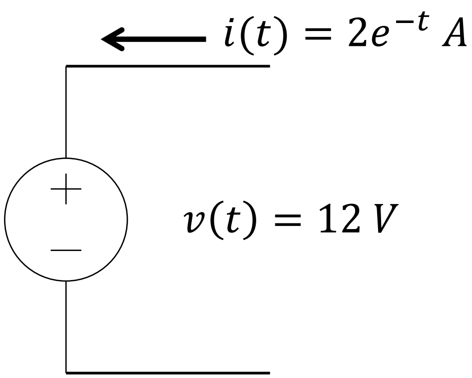
- The amount of power delivered in a time interval

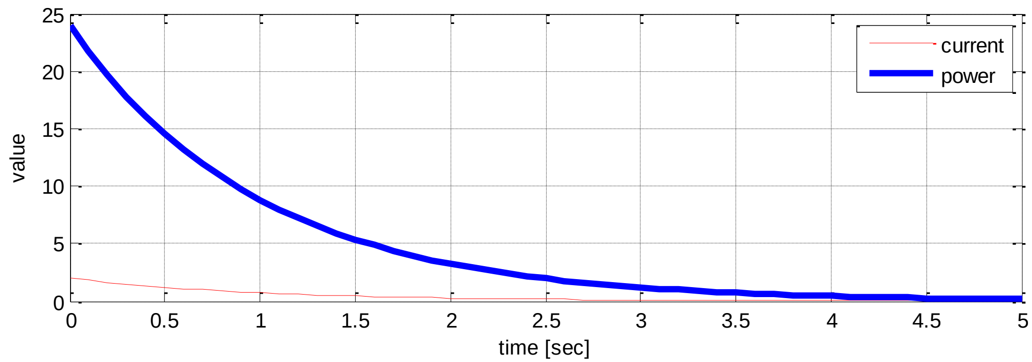
$$w = \int_{t_1}^{t_2} p(t)dt$$

- Power p is a function of time

Example

$$p(t) = v(t)i(t) = 12 \cdot 2e^{-t} = 24e^{-t}$$





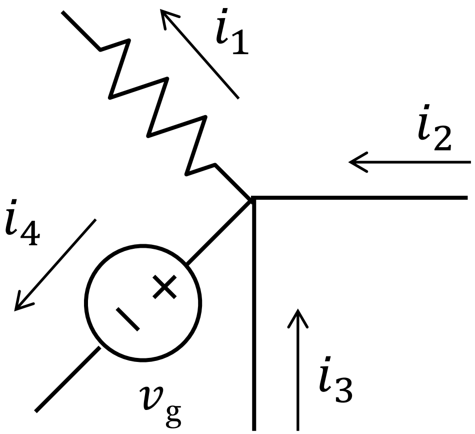
$$w = \int_0^\infty p(t)dt = \int_0^\infty 24e^{-t}dt$$
$$= 24\left[-e^{-t}\right]_0^\infty = 24[1-0] = 24 \quad J$$

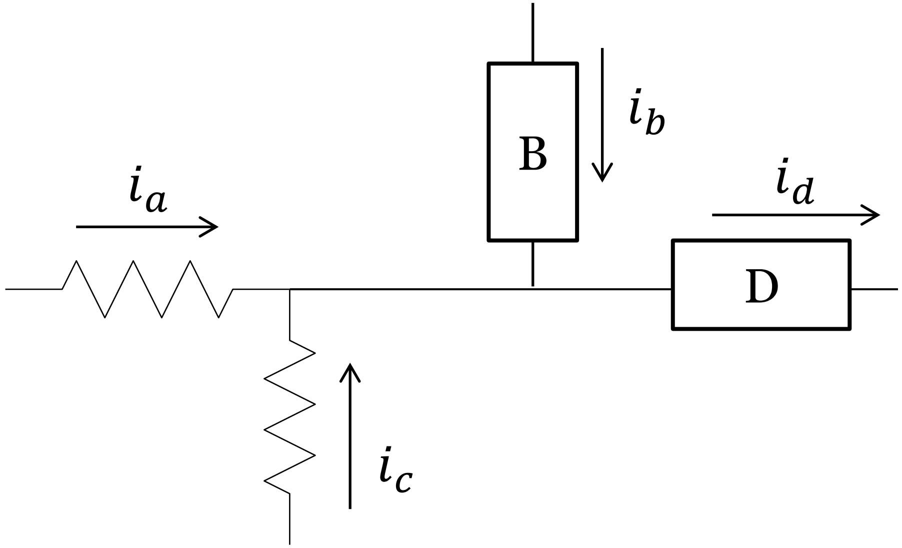
- Positive power/energy → absorbed by voltage source

Kirchhoff's Current Law (KCL)

- KCL states the net current entering a node is zero
  - Sum of currents into a node is equal to sum of currents leaving the node
- This is a consequence of conservation of charge
  - Cannot have accumulation of charge
  - Think of:
    - pipes and fluid flow → water in must go out

KCL Examples



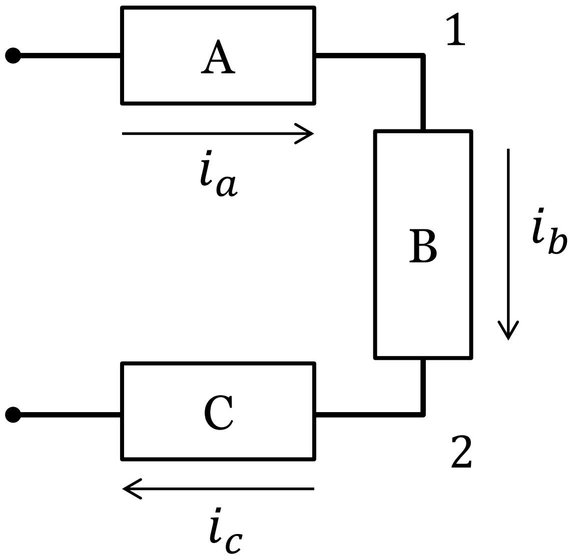


$$i_2 + i_3 = i_1 + i_4$$

$$i_2 + i_3 - i_1 - i_4 = 0$$

$$i_a + i_c + i_b = i_d$$

Series Example



by KCL

1. $i_a = i_b$
2. $i_b = i_c$

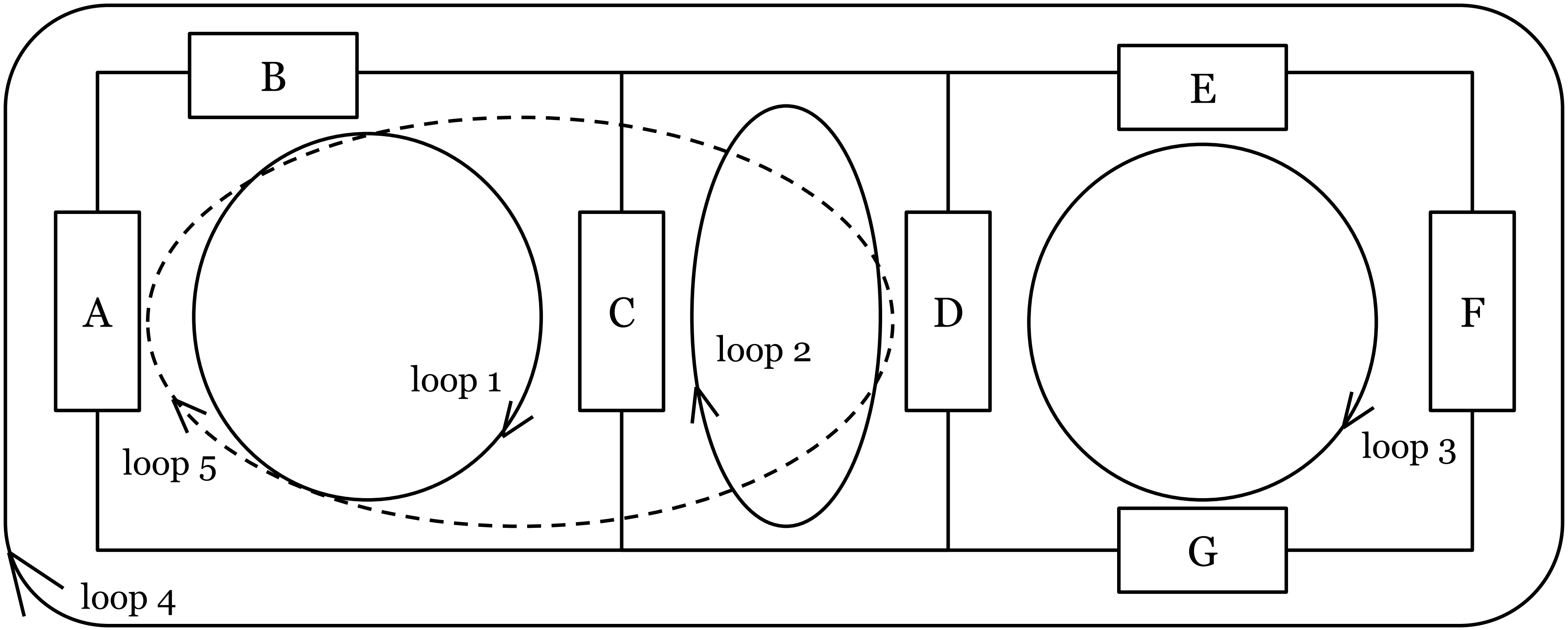
$$i_a = i_b = i_c$$

- These elements are connected in series → same current flows through all of them

Kirchhoff's Voltage Law (KVL)

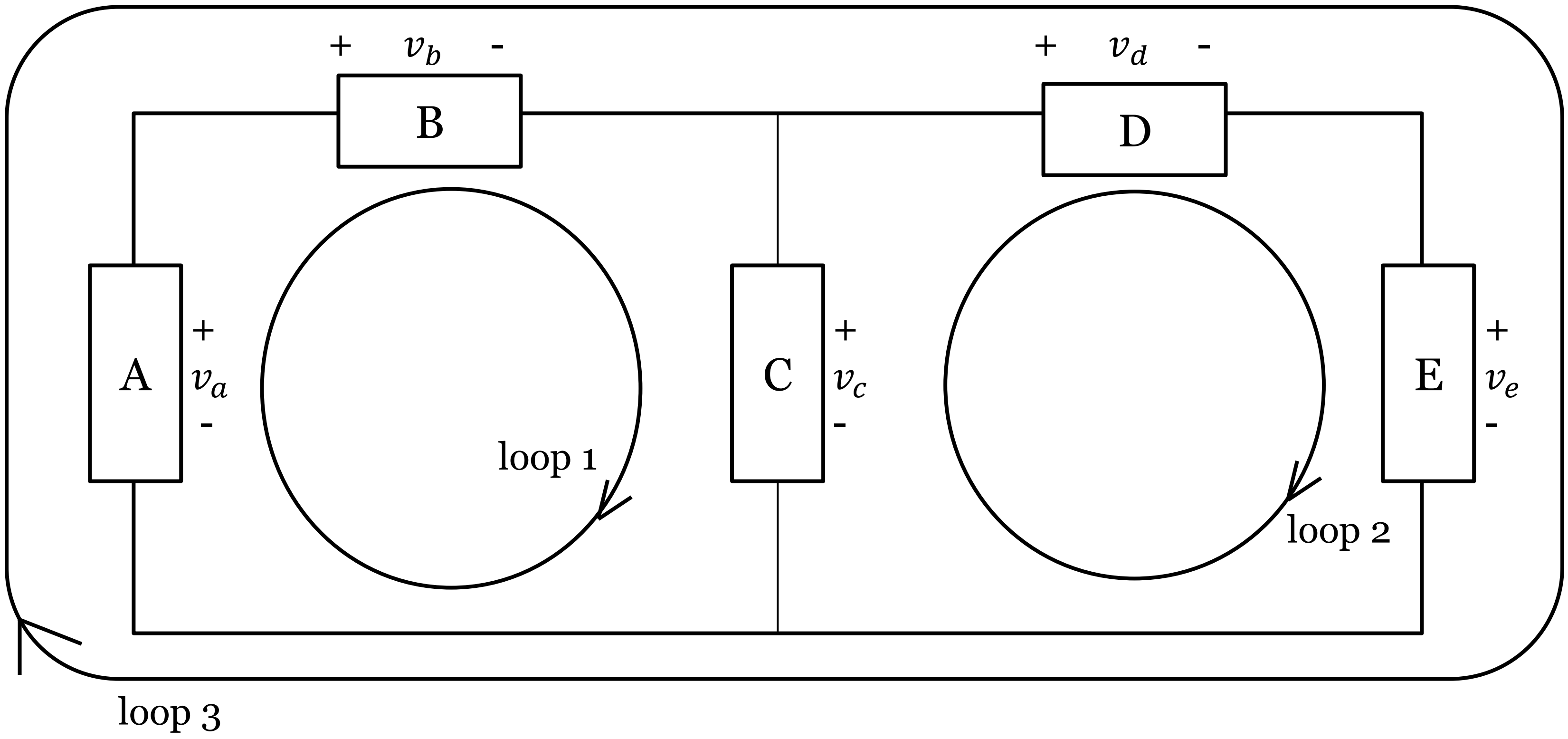
- KVL states the algebraic sum of voltages for any closed path (loop) is zero
- This is a consequence of conservation of energy
  - Cannot have more energy absorbed than supplied
  - Think of:
    - potential energy in going up a hill → energy gained going up is lost going back down

Example Loop



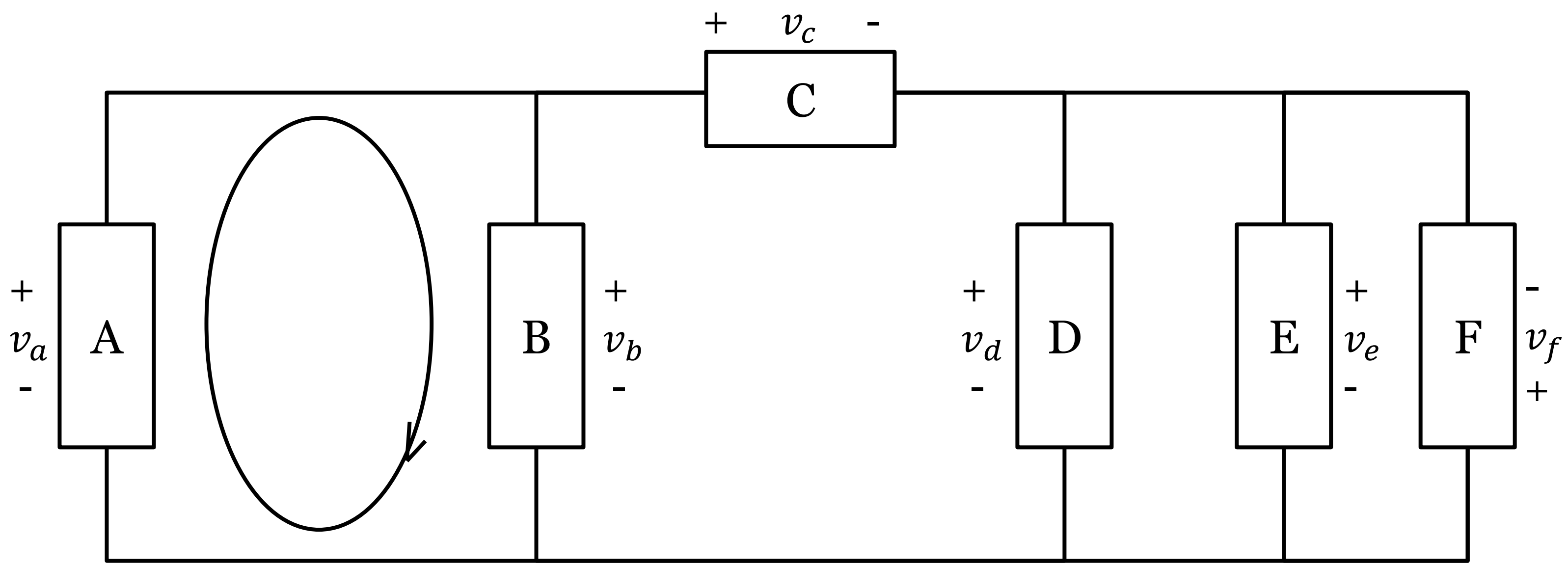
A loop is a closed path along circuit from a start node back to itself

Example



- Loop 1 $v_a - v_b - v_c = 0$
- Loop 2 $v_c - v_d - v_e = 0$
- Loop 3 $v_a - v_b - v_d - v_e = 0$

Parallel Example



- Using KVL
  - $v_a - v_b = 0 \rightarrow v_a = v_b$
  - $v_a = v_b$ the ends are the same wire
  - $v_d = v_e = -v_f$

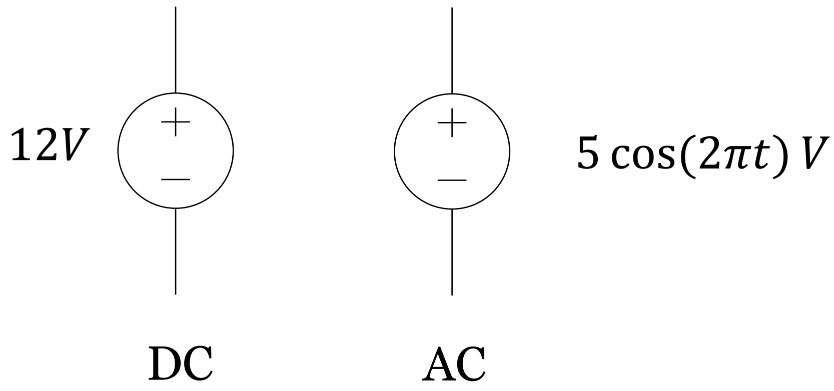
Conductors

- Charge carrying material
- Ideal conductors – voltage drop between ends is zero regardless of current flow
  - Think a direct connection
  - Represented by solid lines in a circuit
- “Short Circuit” – two circuit points connected by an ideal conductor
  - The points are “shorted” together
- “Open circuit” – no conducting path between two elements
  - No current flow between points

Independent Voltage Sources

- Maintains a specified voltage across its terminals independent of any other circuit elements

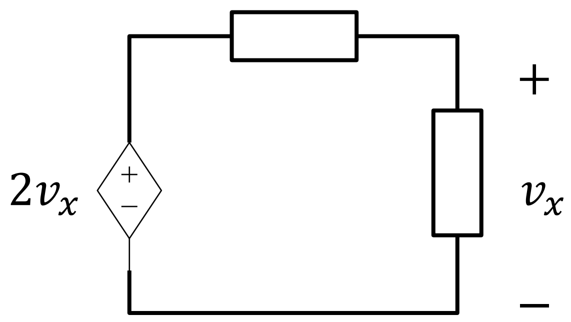
- Ideal sources

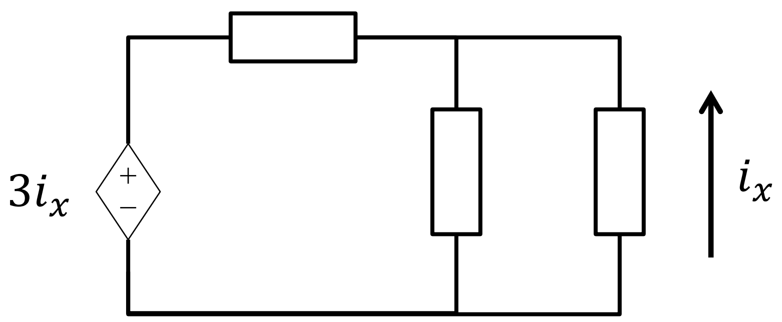


- Non-ideal source
  - Voltage not constant with current
  - Modeled as a series resistance (more later)
  - What happens if you were to put a screwdriver across the terminals of a car battery?

Dependent (Controlled) Voltage Sources

- Source voltage is a function of other voltages or currents





Voltage-controlled voltage source

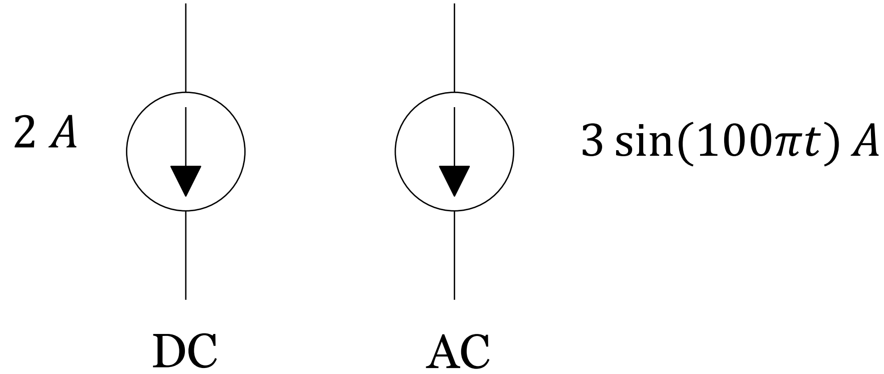
$\text{gain} = 2\ \frac{V}{V}$

Current-controlled voltage source

$\text{gain} = 3\ \frac{V}{A}$

Independent Current Sources

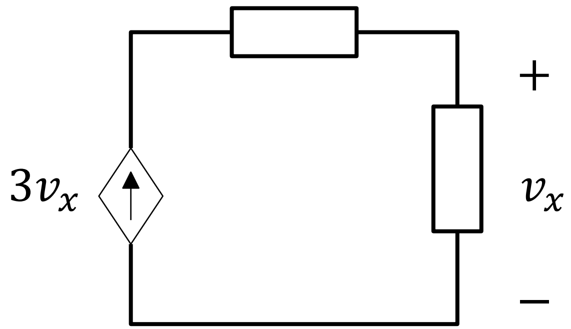
- Maintains a fixed current through it
- Ideal sources

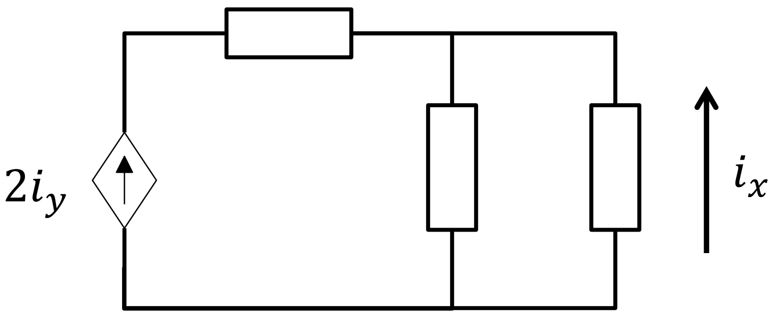


- Non-ideal source
  - Current not constant
  - Modeled as a parallel resistance (more later)

Dependent (Controlled) Current Sources

- Source current is a function of other voltages or currents





Voltage-controlled current source

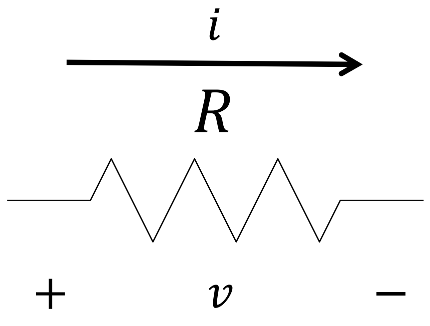
gain $= 2\ \frac{A}{V}$

Current-controlled current source

gain $= 2\ \frac{A}{A}$

Resistor

- Circuit element that impedes current flow



- Ohm's Law
  - $v = iR$
- Resistance – prevents current flow
  - $R = \frac{v}{i}$ Units Ohms [Ω= V/A]
- Conductance – allows current flow
  - $G = \frac{1}{R}$ Units [Ω^{-1}]

Power with Resistors

$$
\begin{aligned}
p &= vi \\
&= i^2 R \\
&= \frac{V^2}{R} = GV^2
\end{aligned}
\qquad\qquad v = iR
$$

- Power in a resistor is always positive → energy is absorbed
  - A result of squared term