Announcements

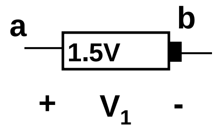
- Website is up:
  http://inst.eecs.berkeley.edu/~ee42
  It includes:
  - Lecture notes and PowerPoint from this semester and Spring 2003 EE 40
  - Homework assignments and solutions from this semester and previous EE 40 semesters
  - Exam information, practice problems and solutions from this semester and previous EE 40 semesters
  - Announcements (on landing page)
  - Contact Info/Office Hours

Circuit Analysis Basics

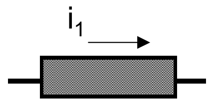
- Fundamental elements
  - Resistor
  - Voltage Source
  - Current Source
  - Air
  - Wire
- Kirchhoff's Voltage and Current Laws
- Resistors in Series
- Voltage Division

Voltage and Current

- Voltage is the difference in electric potential between two points. To express this difference, we label a voltage with a “+” and “-” :
  Here, V_1 is the potential at “a” minus the potential at “b”, which is -1.5 V.



- Current is the flow of positive charge. Current has a value and a direction, expressed by an arrow:
  Here, i_1 is the current that flows right;
  i_1 is negative if current actually flows left.



- These are ways to place a frame of reference in your analysis.

Basic Circuit Elements

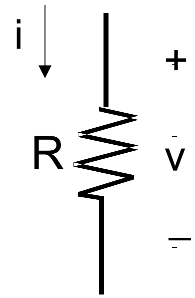
- Resistor
  - Current is proportional to voltage (linear)
- Ideal Voltage Source
  - Voltage is a given quantity, current is unknown
- Wire (Short Circuit)
  - Voltage is zero, current is unknown
- Ideal Current Source
  - Current is a given quantity, voltage is unknown
- Air (Open Circuit)
  - Current is zero, voltage is unknown

Resistor

- The resistor has a current-voltage relationship called Ohm's law:

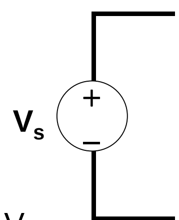
  v = i R

  where R is the resistance in Ω, i is the current in A, and v is the voltage in V, with reference directions **<u>as pictured</u>.**



- If R is given, once you know i, it is easy to find v and vice-versa.
- Since R is never negative, a resistor always absorbs power…

Ideal Voltage Source

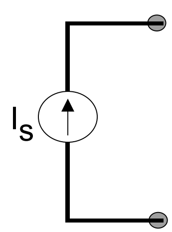


- The ideal voltage source explicitly defines the voltage between its terminals.
  - Constant (DC) voltage source: Vs = 5 V
  - Time-Varying voltage source: Vs = 10 sin(t) V
  - Examples: batteries, wall outlet, function generator, …
- The ideal voltage source does not provide any information about the current flowing through it.
- The current through the voltage source is defined by the rest of the circuit to which the source is attached. Current cannot be determined by the value of the voltage.
- <u>Do not assume that the current is zero!</u>

Wire

- Wire has a very small resistance.
- For simplicity, we will idealize wire in the following way: the potential at all points on a piece of wire is the same, regardless of the current going through it.
  - Wire is a 0 V voltage source
  - Wire is a 0 Ω resistor
- This idealization (and others) can lead to contradictions on paper—and smoke in lab.

Ideal Current Source

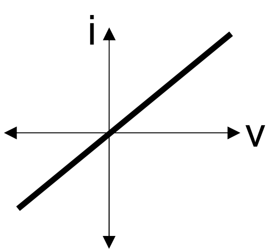


- The ideal current source sets the value of the current running through it.
  - Constant (DC) current source: I_S = 2 A
  - Time-Varying current source: I_S = -3 sin(t) A
  - Examples: few in real life!
- The ideal current source has known current, but unknown voltage.
- The voltage across the voltage source is defined by the rest of the circuit to which the source is attached.
- Voltage cannot be determined by the value of the current.
- <u>Do not assume that the voltage is zero!</u>

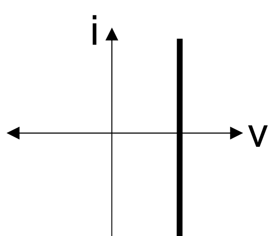
Air

- Many of us at one time, after walking on a carpet in winter, have touched a piece of metal and seen a blue arc of light.
- That arc is current going through the air. So is a bolt of lightning during a thunderstorm.
- However, these events are unusual. Air is usually a good insulator and does not allow current to flow.
- For simplicity, we will idealize air in the following way: current never flows through air (or a hole in a circuit), regardless of the potential difference (voltage) present.
  - Air is a 0 A current source
  - Air is a very very big (infinite) resistor
- <u>There can be nonzero voltage over air or a hole in a circuit!</u>

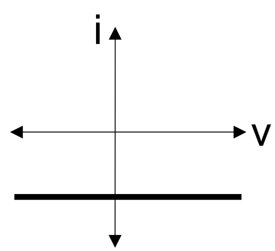
I-V Relationships Graphically



Resistor: Line through origin with slope 1/R



Ideal Voltage Source: Vertical line



Ideal Current Source: Horizontal line

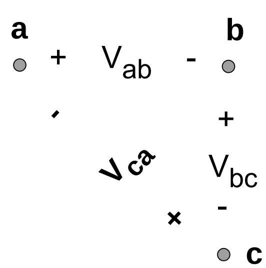
Wire:

Air:

Kirchhoff's Laws

- The I-V relationship for a device tells us how current and voltage are related within that device.
- Kirchhoff's laws tell us how voltages relate to other voltages in a circuit, and how currents relate to other currents in a circuit.
- KVL: The sum of voltage drops around a closed path must equal zero.
- KCL: The sum of currents leaving a closed surface or point must equal zero.

Kirchhoff's Voltage Law (KVL)



- Suppose I add up the potential drops around the closed path, from "a" to "b" to "c" and back to "a".
- Since I end where I began, the total drop in potential I encounter along the path must be zero: $V_{ab} + V_{bc} + V_{ca} = 0$
- It would not make sense to say, for example, "b" is 1 V lower than "a", "c" is 2 V lower than "b", and "a" is 3 V lower than "c". I would then be saying that "a" is 6 V lower than "a", which is nonsense!
- We can use potential rises throughout instead of potential drops; this is an alternative statement of KVL.

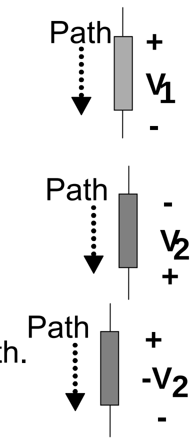
KVL Tricks

- A voltage rise is a negative voltage drop.

Along a path, I might encounter a voltage which is labeled as a voltage drop (in the direction I'm going). The sum of these voltage drops must equal zero.

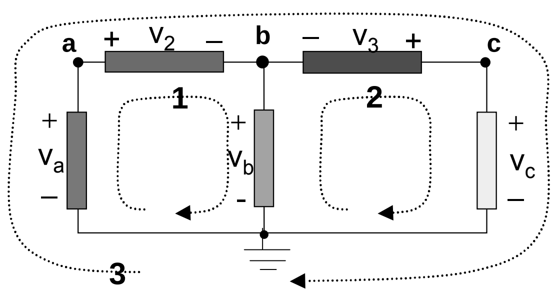
I might encounter a voltage which is labeled as a voltage rise (in the direction I'm going). This rise can be viewed as a "negative drop". Rewrite:

- Look at the first sign you encounter on each element when tracing the closed path. If it is a "-", it is a voltage rise and you will insert a "-" to rewrite as a drop.



Writing KVL Equations

What does KVL say about the voltages along these 3 paths?



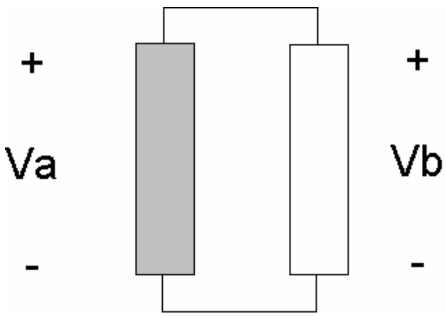
Path 1:

Path 2:

Path 3:

Elements in Parallel

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



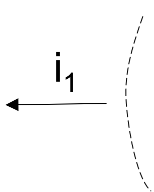
KVL clockwise, start at top:

Vb – Va = 0

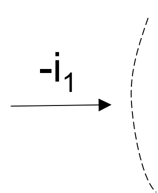
Va = Vb

Kirchhoff's Current Law (KCL)

- Electrons don't just disappear or get trapped (in our analysis).
- Therefore, the sum of all current entering a closed surface or point must equal zero—whatever goes in must come out.
- Remember that current leaving a closed surface can be interpreted as a negative current entering:

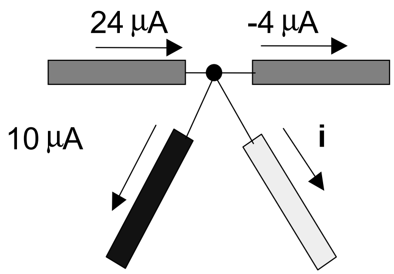


is the same statement as



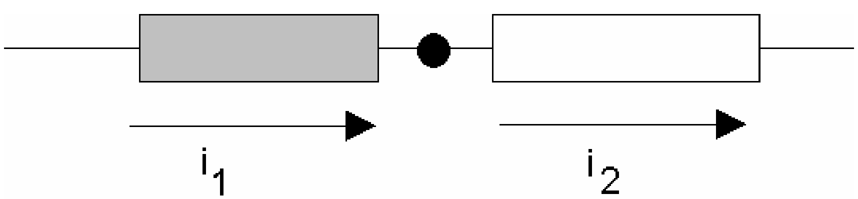
KCL Equations

In order to satisfy KCL, what is the value of i?



Elements in Series

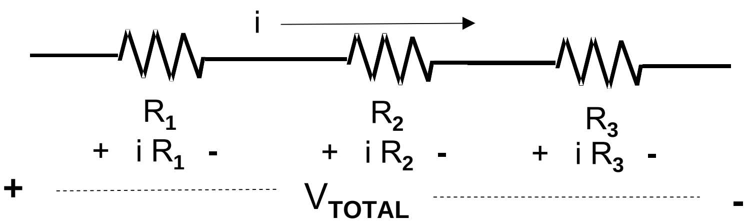
- Suppose two elements are connected with **nothing coming off in between**.
- KCL says that the elements carry the **same current**.
- We say these elements are **in series**.



$i_1 - i_2 = 0$ $\quad$ $i_1 = i_2$

Resistors in Series

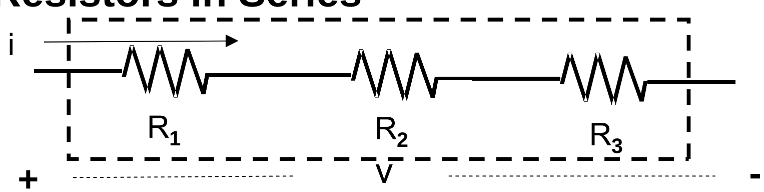
- Consider resistors in series. This means they are attached end-to-end, with nothing coming off in between.



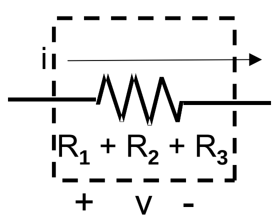
- Each resistor has the same current (labeled i).
- Each resistor has voltage iR, given by Ohm's law.
- The total voltage drop across all 3 resistors is

$V_{TOTAL} = i\,R_1 + i\,R_2 + i\,R_3 = i\,(R_1 + R_2 + R_3)$

Resistors in Series

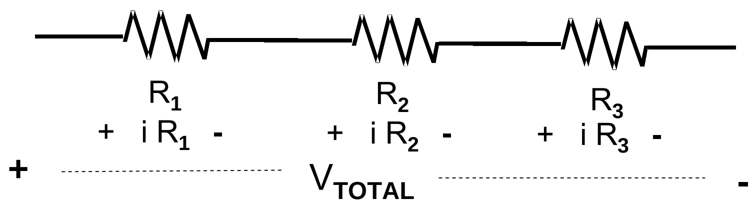


- When we look at all three resistors together as one unit, we see that they have the same I-V relationship as one resistor, whose value is the sum of the resistances:
- So we can treat these resistors as just one **equivalent resistance**, as long as we are not interested in the individual voltages. Their effect on the rest of the circuit is the same, whether lumped together or not.



Voltage Division

- If we know the total voltage over a series of resistors, we can easily find the individual voltages over the individual resistors.



- Since the resistors in series have the same current, the voltage divides up among the resistors in proportion to each individual resistance.

Voltage Division

- For example, we know
  $i = V_{TOTAL} / (R_1 + R_2 + R_3)$
  so the voltage over the **first resistor** is
  $i R_1 = R_1 V_{TOTAL} / (R_1 + R_2 + R_3)$

$$= V_{TOTAL} \frac{R_1}{R_1 + R_2 + R_3}$$

- To find the voltage over an individual resistance in series, take the total series voltage and multiply by the individual resistance over the total resistance.