EECS 42 Introduction to Electronics for Computer Science
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Lecture #3
- Kirchhoff's Laws
- Ideal independent sources
- Resistors

http://inst.EECS.Berkeley.EDU/~ee42/

Game Plan 01/22/03

Monday 01/27/03

- ☐ Electrical Quantities
  Schwarz and Oldham: 1.3-1.4

Today 01/29/03

- ☐ Kirchhoff Laws
  Schwarz and Oldham: 2.1-2.2

Next (3rd) Week

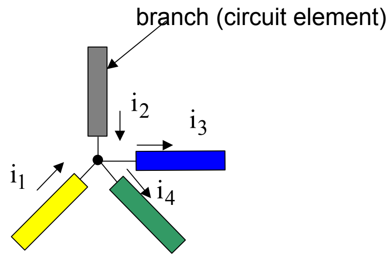
- ☐ Capacitors, inductors, I vs. V
  Schwarz and Oldham: 5.1, 2.2, 3.1
- ☐ Power and Energy
  Schwarz and Oldham: 5.1, 2.2, 3.1

Problem Set #2 – Out 1/27/03 - Due 2/5/03 2:30 in box in 240 Cory

2.1 Flow; 2.2 KCL; 2.3 KVL; 2.4 resistor circuit; 2.5 Power

BRANCHES AND NODES

Circuit with several branches connected at a node:



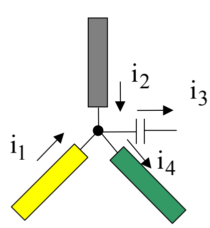
KIRCHOFF's CURRENT LAW "KCL":
(see Text 1.2 and 1.3)

(Sum of currents <u>entering</u> node) – (Sum of currents <u>leaving</u> node) = 0

q = charge stored at node is zero. If charge *is* stored, for example in a capacitor, then the capacitor is a branch and the charge is stored there NOT at the node.

Capacitor at a Node

Circuit with several branches, including a capacitor



(Sum of currents <u>entering</u> node) – (Sum of currents <u>leaving</u> node) = 0

q = charge stored at node is zero. If charge *is* stored, for example in the capacitor shown as branch 3, the charge is accounted for as the time-integral of i_3. Thus the charge is not over at the node; it is on the capacitor.

WHAT IF THE NET CURRENT WERE NOT ZERO?

Suppose imbalance in currents is 1μA = 1 μC/s (net current entering node)

Assuming that q = 0 at t = 0, the charge increase is 10^{-6} C each second

or $10^{-6}/1.6\times10^{-19} = 6\times10^{12}$ charge carriers each second

But by definition, the capacitance of a node to ground is ZERO because we show any capacitance as an explicit circuit element (branch). Thus, the voltage would be infinite (Q = CV).

Something has to give! In the limit of zero capacitance the accumulation of charge would result in infinite electric fields … there would be a spark as the air around the node broke down.

Charge is transported around the circuit branches (even stored in some branches), but it doesn't pile up at the nodes!

SIGN CONVENTIONS FOR SUMMING CURRENTS

Kirchhoff's Current Law (KCL)

Sum of currents *entering* node = sum of currents *leaving* node

Use reference directions to determine "entering" and "leaving" currents … **no concern** about actual polarities

☞ KCL yields one equation per node

Alternative statements of KCL

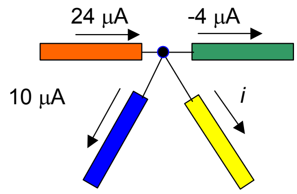
1 "Algebraic sum" of currents *entering* node = 0

where "algebraic sum" means currents leaving are included with a minus sign

2 "Algebraic sum" of currents leaving node = 0

where currents entering are included with a minus sign

KIRCHHOFF'S CURRENT LAW EXAMPLE



Currents entering the node: 24 μA

Currents leaving the node: –4 μA + 10 μA + i

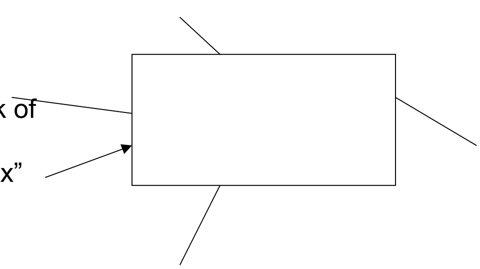
$$\boxed{\begin{array}{c} 24 = 10 + (-4) + i \\ i = 18\ \mu A \end{array}}$$

Three statements of KCL

$$\left.\begin{array}{lll} \sum_{IN} i_{in} = \sum_{OUT} i_{out} & 24 = -4 + 10 + i & \Rightarrow \quad i = 18\ \mu\text{A} \\ \sum_{ALL} i_{in} = 0 & 24 - (-4) - 10 - i = 0 & \Rightarrow \quad i = 18\ \mu\text{A} \\ \sum_{ALL} i_{out} = 0 & -24 - 4 + 10 + i = 0 & \Rightarrow \quad i = 18\ \mu\text{A} \end{array}\right\} \text{EQUIVALENT}$$

GENERALIZATION OF KCL TO SURFACES

Sum of currents entering and leaving any "black box" is zero

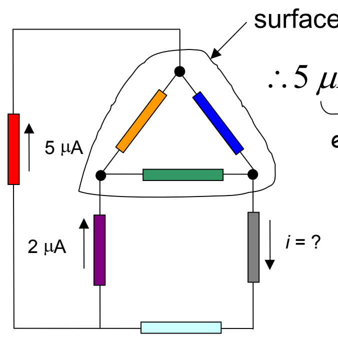


Could be a big chunk of circuit in here, e.g., could be a "Black Box"

In other words there can be lots of nodes and branches inside the box.

KIRCHHOFF'S CURRENT LAW USING SURFACES

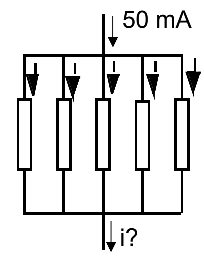
Example



$$\therefore \underbrace{5\ \mu\text{A} + 2\ \mu\text{A}}_{\text{entering}} = \underbrace{\text{i}}_{\text{leaving}}$$

i=7µA

Another example



i must be 50 mA

Example of the use of KCL

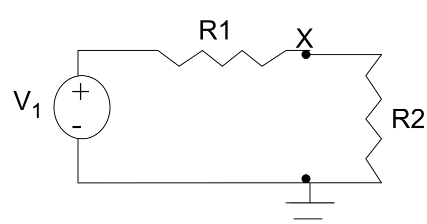
At node X:

Current into X from the left:

$(V_1 - v_X)/R1$

Current out of X to the right:

$v_X/R2$



KCL: $(V_1 - v_X)/R1 = v_X/R2$

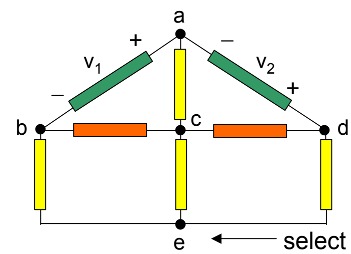
Given V_1, This equation can be solved for v_X

$v_X = V_1\ R2 /(R1 + R2)$

Of course we just get the same result as we obtained from our series resistor formulation. (Find the current and multiply by R2)

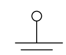
BRANCH AND NODE VOLTAGES

The voltage across a circuit element is defined as the difference between the node voltages at its terminals



$v_2 = v_d - v_a$

$v_e \equiv 0$ (since it's the reference)

select as ref. ⇒  "ground"

Specifying node voltages: Use one node as the implicit reference (the "common" node … attach special symbol to label it)

Now single subscripts can label voltages:

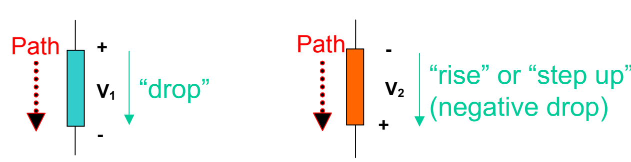
e.g., v_b means $v_b - v_e$, v_a means $v_a - v_e$, etc.

KIRCHHOFF'S VOLTAGE LAW (KVL)

The algebraic sum of the "voltage drops" around any "closed loop" is zero.

Why? We must return to the same potential (conservation of energy).

Voltage drop → defined as the branch voltage if the + sign is encountered first; it is (-) the branch voltage if the – sign is encountered first … important bookkeeping

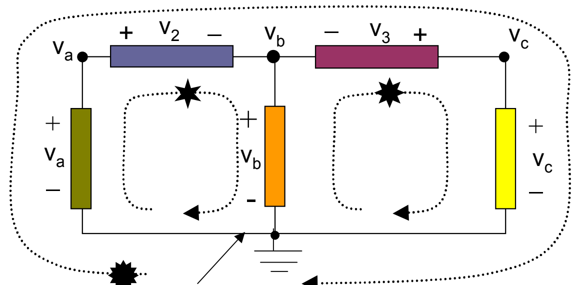


Closed loop: Path beginning and ending on the same node

KVL EXAMPLE

Examples of
Three closed paths:

✶, ✷, ✹



Note that:

$v_2 = v_a - v_b$

$v_3 = v_c - v_b$

Path 1:

$-v_a + v_2 + v_b = 0$

↑

$v_a - v_b$

YEP!

Path 2:

$-v_b - v_3 + v_c = 0$

Path 3:

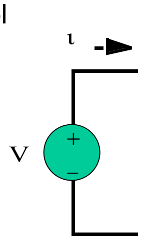
$-v_a + v_2 - v_3 + v_c = 0$

BASIC CIRCUIT ELEMENTS

- Voltage Source (always supplies some constant given voltage - like ideal battery)
- Current Source (always supplies some constant given current)
- Resistor (Ohm's law)
- Wire ("short" – no voltage drop)
- Capacitor (capacitor law – based on energy storage in electric field of a dielectric S&O 5.1)
- Inductor (inductor law – based on energy storage in magnetic field in space S&O 5.1)

DEFINITION OF IDEAL VOLTAGE SOURCE

Symbol



Note: The current and voltage are unassociated here.

Examples:

1) $V = 3V$

2) $v = v(t) = 160 \cos 377t$

☞Special cases:

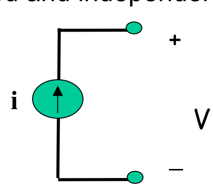
upper case V → constant voltage … called "DC"

lower case v → general voltage, may vary with time

Current through voltage source can take on *any* value (positive or negative) *but not infinite*

IDEAL CURRENT SOURCE

"Complement" or "<u>dual</u>" of the voltage source: Current though branch is fixed and independent of the voltage across the branch



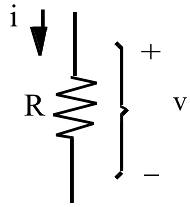
note **un**associated direction

Actual current source examples – hard to find except in electronics (transistors, etc.), as we will see

upper-case I → DC (constant) value

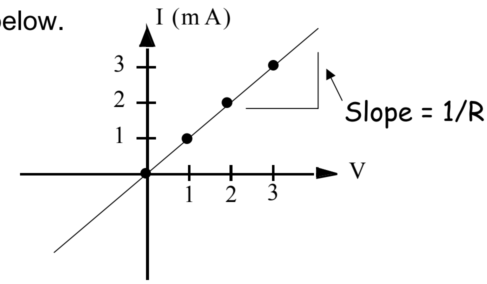
lower-case implies current could be time-varying i(t)

RESISTOR



We use associated current and voltage (i.e., i is defined as into + terminal), then $v = iR$ (Ohm's law).

Question: What is the I-V characteristic for a 1KΩ resistor? Draw on axis below.



☞Answer: $V = 0 \Rightarrow I = 0$

$V = 1V \Rightarrow I = 1$ mA
$V = 2V \Rightarrow I = 2$ mA

etc

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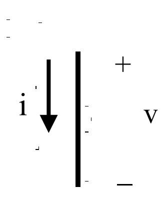
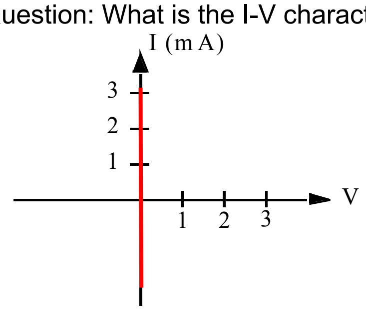
Version Date 01/30/03

IDEAL WIRE



Think of a resistor with zero resistance. Clearly V is identically zero, for any current.

Question: What is the I-V characteristic?



☞Answer: V = 0 for all I

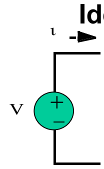
see red line

Note that all real wires and circuit connections have resistance, but we will most often approximate it to be zero, that is assume an ideal wire.

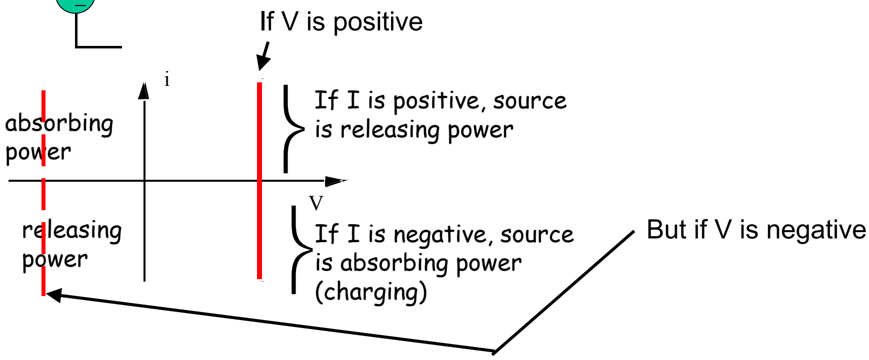
CURRENT-VOLTAGE CHARACTERISTICS OF VOLTAGE & CURRENT SOURCES

Describe a two-terminal circuit element by plotting current vs. voltage

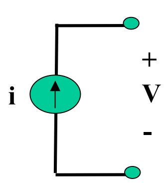
Ideal voltage source

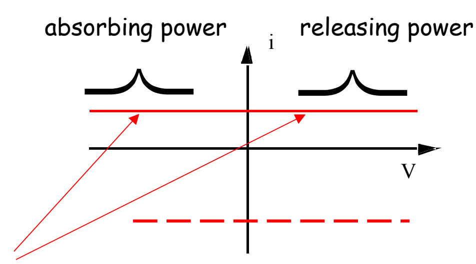


Assume **un**associated signs



CURRENT-VOLTAGE CHARACTERISTICS OF VOLTAGE & CURRENT SOURCES (con't)





If i is positive then we are confined to quadrants 4 and 1:

Remember the voltage across the current source can be *any* finite value (not just zero)

And do not forget i can be positive or negative. Thus we can be in any quadrant.