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

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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

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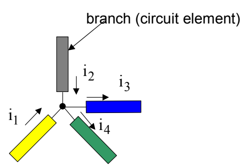
BRANCHES AND NODES

Circuit with several branches connected at a node:



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

(Sum of currents entering node) – (Sum of currents leaving 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.

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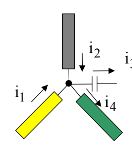
Capacitor at a Node

Circuit with several branches, including a capacitor



(Sum of currents entering node) – (Sum of currents leaving node) = 0

q = charge stored at node is zero. If charge *is* stored, for example 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.

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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!

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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

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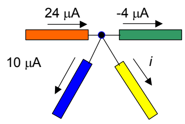
KIRCHHOFF'S CURRENT LAW EXAMPLE



Currents entering the node: 24 μA

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

} 24 = 10 + (–4) + i
i = 18 μA

Three statements of KCL

$$\sum_{IN} i_{in} = \sum_{OUT} i_{out} \qquad 24 = -4 + 10 + i \quad \Rightarrow \quad i = 18\ \mu A$$

$$\sum_{ALL} i_{in} = 0 \qquad 24 - (-4) - 10 - i = 0 \quad \Rightarrow \quad i = 18\ \mu A$$

$$\sum_{ALL} i_{out} = 0 \qquad -24 - 4 + 10 + i = 0 \quad \Rightarrow \quad i = 18\ \mu A$$

} EQUIVALENT

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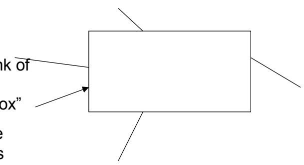
GENERALIZATION OF KCL TO SURFACES

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.

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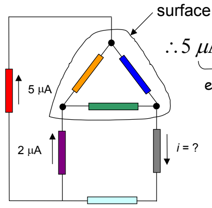
KIRCHHOFF'S CURRENT LAW USING SURFACES

Example

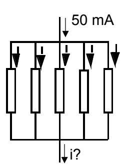


$\therefore 5\ \mu A + 2\ \mu A = i$

entering leaving

i=7μA

Another example



i must be 50 mA

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Example of the use of KCL

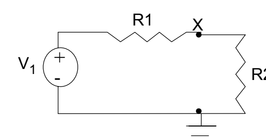
At node X:

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)

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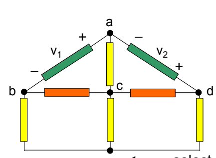
BRANCH AND NODE VOLTAGES

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.

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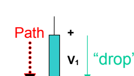
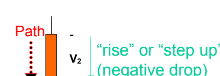
KIRCHHOFF'S VOLTAGE LAW (KVL)

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

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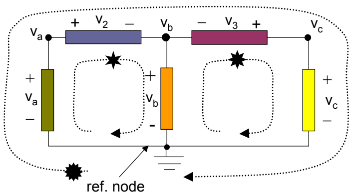
KVL EXAMPLE

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

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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)

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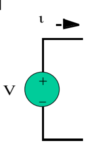
DEFINITION OF IDEAL VOLTAGE SOURCE

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*

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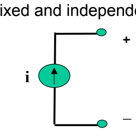
IDEAL CURRENT SOURCE

"Complement" or "dual" 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)

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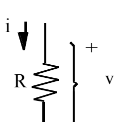
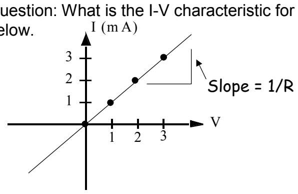
RESISTOR



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 ⇒ I = 0

V = 1V ⇒ I = 1 mA

V = 2V ⇒ I = 2 mA

etc

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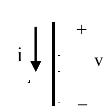
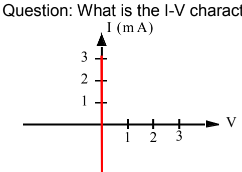
IDEAL WIRE



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.

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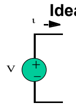
CURRENT-VOLTAGE CHARACTERISTICS OF VOLTAGE & CURRENT SOURCES

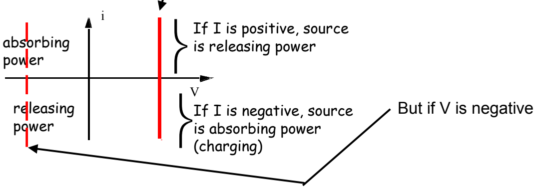
Describe a two-terminal circuit element by plotting current vs. voltage

Ideal voltage source



Assume **un**associated signs

If V is positive



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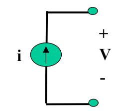
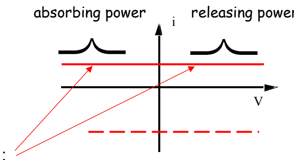
CURRENT-VOLTAGE CHARACTERISTICS OF VOLTAGE & CURRENT SOURCES (con't)





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.

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