EE40
Lecture 1
Prof. Chang-Hasnain

8/29/07

Reading: Chap. 1

EE 40 Course Overview

- EECS 40:
  - One of five EECS core courses (with 20, 61A, 61B, and 61C)
    - introduces “hardware” side of EECS
    - prerequisite for EE105, EE130, EE141, EE150
  - Prerequisites: Math 1B, Physics 7B
  - Course involves three hours of lecture, one hour of discussion and three hours of lab work each week.
- Course content:
  - Fundamental circuit concepts and analysis techniques
  - First and second order circuits, impulse and frequency response
  - Op Amps
  - Diode and FET: Device and Circuits
  - Amplification, Logic, Filter
- Text Book
  - Electrical Engineering: Principles and Applications”, Allan R. Hambley, Pearson Prentice Hall, **4th Edition**
  - Supplementary Reader

Instructor

- Prof. Connie Chang-Hasnain
  - Office: 263M Cory Hall
  - Office hour: T 11-12, W 11-12
  - PhD 1987, UC Berkeley; Research on semiconductor lasers, slow and fast light, nanowires and nano-needles, solar cells.
- All emails to me should be forwarded by Ms. Therese George or the Head GSI.
- Head GSI: Chris Chase
- Secretary: Therese George, 253 Cory, therese@eecs.berkeley.edu

Important DATES

- Office hours, Discussion and Lab Sessions will start on week 2
  - Stay with ONE Discussion and Lab session you registered.
- 4 tests and 1 Final:
  - Tests: In Class Monday 9/17, Monday 10/8, Friday 11/2, Friday 11/30
  - Location: 10 Evans
  - Final: 8 – 11 am Tuesday 12/13/2006 (Exam Group 1)
  - Location: to be announced
- Best Final Project Contest
  - 12/10 3-5pm Location TBD
  - Winner projects will be displayed on second floor Cory Hall.

Grading Policy

- Weights:
  - 9%: 10 HW sets - drop one lowest point; hence each is worth 1%
  - 18%: 10 Labs
    - 7 structured experiments (each is worth 1.5%)
    - one 3-week final project (7.5%) with bonus points (2%)
  - 40%: 4 tests – drop one lowest; hence each one is worth 13.33%
  - 33%: Final exam
- No late HW or Lab reports accepted
- No make-up exams.
- Departmental grading policy:
  - A typical GPA for courses in the lower division is 2.7. This GPA would result, for example, from 17% A's, 50% B's, 20% C's, 10% D's, and 3% F's.

Grading Policy (Cont'd)

- Weekly HW:
  - Assignment on the web by 5 pm Wednesdays, starting 8/29/07.
  - Due 5 pm the following Wednesday in HW box, 240 Cory.
  - On the top page, right top corner, write your name (in the form: Last Name, First Name) with discussion session number.
  - Graded homework will be returned one week later in discussion sessions.
- Labs
  - Each lab is graded with 30% on Prelab and 70% on Report.
  - You must complete the prelab section before going to the lab. The prelabs are checked by the GSIs at the beginning of each session. If prelabs are completed during the lab sessions, it is considered late and 50% will be deducted.
  - Lab reports are due exactly one week after your lab is completed.
- It is your responsibility to check with the head GSI from time to time to make sure all grades are entered correctly.

Classroom Rules

- Please come to class on time. There is no web-cast this semester.
- Turn off cell phones, pagers, radio, CD, DVD, etc.
- No food.
- No pets.
- Do not come in and out of classroom.
- Lectures will be recorded and webcasted.

Chapter 1

- Outline
  - Electrical quantities
    - Charge, Current, Voltage, Power
  - Sign conventions
  - The ideal basic circuit element
  - Circuit element I-V characteristics
  - Construction of a circuit model
  - Kirchhoff's Current Law
  - Kirchhoff's Voltage Law

Electric Charge

- Electrical effects are due to
  - separation of charge → electric force (voltage)
  - charges in motion → electric flow (current)
- Macroscopically, most matter is electrically neutral most of the time.
  - Exceptions: clouds in a thunderstorm, people on carpets in dry weather, plates of a charged capacitor, etc.
- Microscopically, matter is full of electric charges
  - Electric charge exists in discrete quantities, integral multiples of the electronic charge -1.6×10^{-19} *Coulomb*

Electric Current

Definition: rate of positive charge flow

Symbol: i

Units: Coulombs per second ≡ Amperes (A)

Note: Current has polarity.

$i = dq/dt$ where

q = charge (Coulombs)

t = time (in seconds)

André-Marie Ampère's

1775-1836

Electric Potential (Voltage)

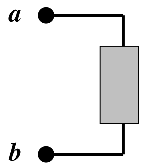
- **Definition:** energy per unit charge
- **Symbol:** v
- **Units:** Joules/Coulomb ≡ Volts (V)

Alessandro Volta (*1745–1827*)

$$v = dw/dq$$

where w = energy (in Joules), q = charge (in Coulombs)

Note: Potential is always referenced to some point.



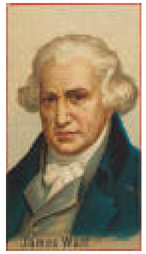
Subscript convention:

v_{ab} means the potential at a minus the potential at b.

$$v_{ab} \equiv v_a - v_b$$

Electric Power

- **Definition:** transfer of energy per unit time
- **Symbol:** p
- **Units:** Joules per second ≡ Watts (W)



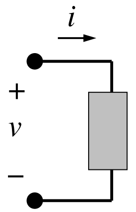
James Watt 1736 - 1819

$$p = dw/dt = (dw/dq)(dq/dt) = vi$$

- **Concept:**

  As a positive charge q moves through a drop in voltage v, it loses energy
  - energy change = qv
  - rate is proportional to # charges/sec

The Ideal Basic Circuit Element



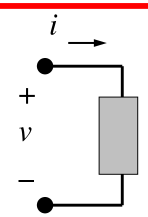
- Polarity reference for voltage can be indicated by plus and minus signs
- Reference direction for the current is indicated by an arrow

Attributes:

- Two terminals (points of connection)
- Mathematically described in terms of current and/or voltage
- Cannot be subdivided into other elements

Passive Sign Convention

$$p = vi$$



- If p > 0, power is being delivered to the box.
  - The element is a passive element.
- If p < 0, power is being generated from the box.
  - The element is an active element.
- How can a circuit element absorb power?
  - By converting electrical energy into heat (resistors in toasters), light (light bulbs), or acoustic energy (speakers); by storing energy (charging a battery).

Circuit Elements

- 5 ideal basic circuit elements:
  - voltage source
  - current source

    } ***active elements***, capable of generating electric energy
  - resistor
  - inductor
  - capacitor

    } ***passive elements***, incapable of generating electric energy
- Many practical systems can be modeled with just sources and resistors
- The basic analytical techniques for solving circuits with inductors and capacitors are similar to those for resistive circuits

Electrical Resistance

- ***Resistance:*** the ratio of voltage drop and current. The circuit element used to model this behavior is the ***resistor***.

Circuit symbol:

Units: Volts per Ampere ≡ ohms (Ω)

- The current flowing in the resistor is proportional to the voltage across the resistor:

Georg Simon Ohm
1789-1854

$v = i R$ (Ohm's Law)

where v = voltage (V), i = current (A), and R = resistance (Ω)

EE40
Lecture 2
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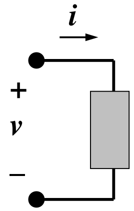
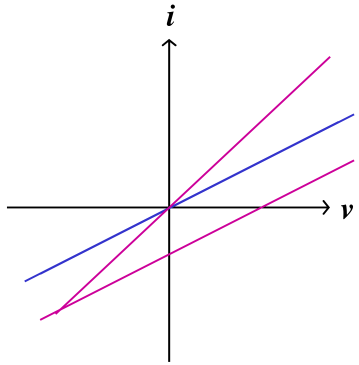
Reading: Chap. 1

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

What is the *I-V* characteristic for an ideal resistor?

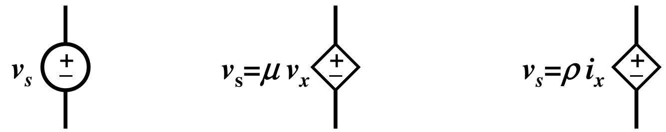




Ideal Voltage Source

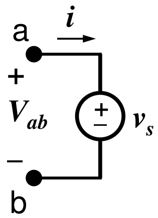
- Circuit element that maintains a prescribed voltage across its terminals, **regardless of the current flowing in those terminals**.
  - Voltage is known, but current is determined by the circuit to which the source is connected.
- The voltage can be either **independent** or **dependent** on a voltage or current elsewhere in the circuit, and can be constant or time-varying.

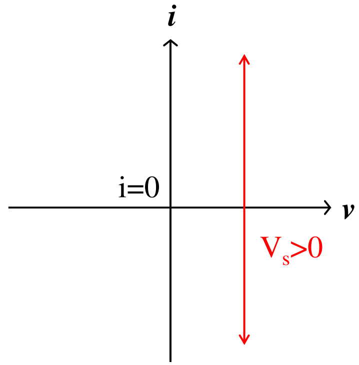
<u>Device symbols</u>:



independent **voltage-controlled** **current-controlled**

I-V Characteristic of Ideal Voltage Source





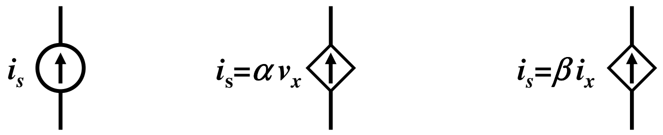
1. **Plot the *I-V* characteristic for $v_s > 0$. For what values of i does the source absorb power? For what values of i does the source release power?**

V_s>0 → i<0 release power; i>0 absorb power

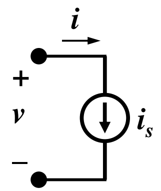
Ideal Current Source

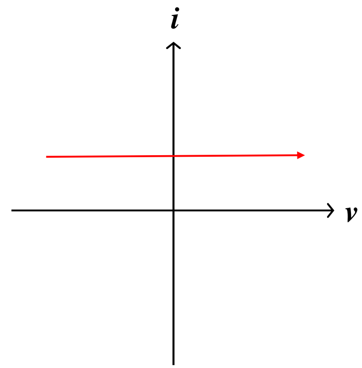
- Circuit element that maintains a prescribed current through its terminals, **regardless of the voltage across those terminals**.
  - Current is known, but voltage is determined by the circuit to which the source is connected.
- The current can be either **independent or dependent** on a voltage or current elsewhere in the circuit, and can be constant or time-varying.

Device symbols:



I-V Characteristic of Ideal Current Source

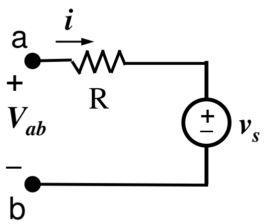




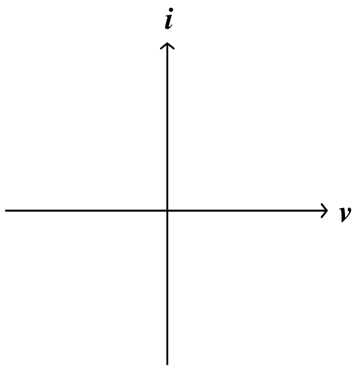
1. **Plot the *I-V* characteristic for $i_s > 0$. For what values of v does the source absorb power? For what values of v does the source release power?**

V>0 absorb power; V<0 release power

I-V Characteristic of Elements



Find the *I-V* characteristic.



Short Circuit and Open Circuit

- Short circuit
  - R = 0 → no voltage difference exists
  - all points on the wire are at the same potential.
  - Current can flow, as determined by the circuit
- Open circuit
  - R = ∞ → no current flows
  - Voltage difference can exist, as determined by the circuit

Short Circuit and Open Circuit

Wire ("short circuit"):

- $R = 0$ → **no voltage difference exists**
  (all points on the wire are at the same potential)
- Current can flow, as determined by the circuit

Air ("open circuit"):

- $R = \infty$ → **no current flows**
- Voltage difference can exist, as determined by the circuit

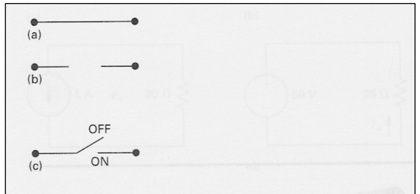


Figure 2.10 Circuit symbols. (a) Short circuit. (b) Open circuit. (c) Switch.

Example: Power Absorbed by a Resistor

$$p = vi = (iR)i = i^2R$$

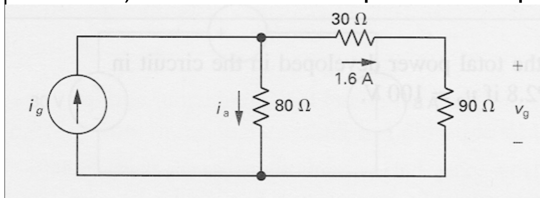
$$p = vi = v(v/R) = v^2/R$$

Note that $p > 0$ always, for a resistor → a resistor dissipates electric energy

Example:

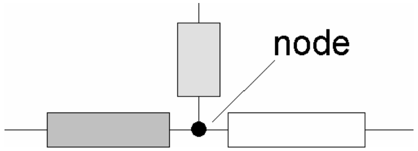
a) Calculate the voltage v_g and current i_a.

b) Determine the power dissipated in the 80Ω resistor.

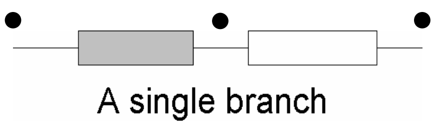


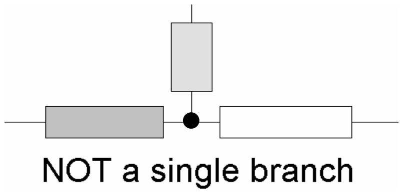
Terminology: Nodes and Branches

Node: A point where two or more circuit elements are connected



Branch: A path that connects two nodes





Circuit Nodes and Loops

- A ***node*** is a point where two or more circuit elements are connected.
- A ***loop*** is formed by tracing a closed path in a circuit through selected basic circuit elements without passing through any intermediate node more than once

Kirchhoff's Laws

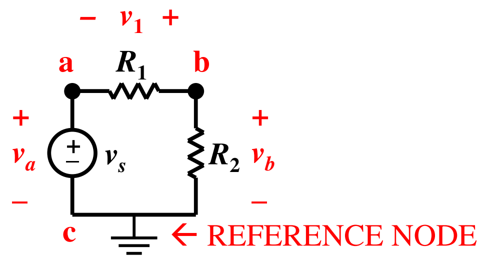
- **<u>Kirchhoff's Current Law (KCL)</u>:**
  - The algebraic sum of all the **currents** entering any **node** in a circuit equals zero.
- **<u>Kirchhoff's Voltage Law (KVL)</u>:**
  - The algebraic sum of all the **voltages** around any **loop** in a circuit equals zero.

Gustav Robert Kirchhoff
1824-1887

Notation: Node and Branch Voltages

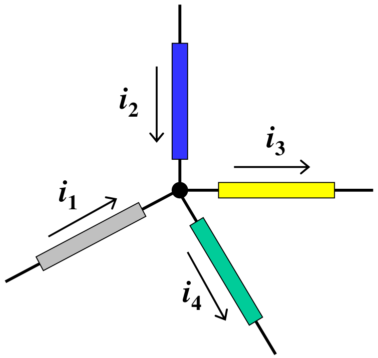
- Use one node as the reference (the "common" or "ground" node) – label it with a symbol
- The voltage drop from node **x** to the reference node is called the **node voltage** $\mathbf{v_x}$.
- The voltage across a circuit element is defined as the difference between the node voltages at its terminals

<u>Example</u>:



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.)

<u>Formulation 1</u>:

Sum of currents entering node
= sum of currents leaving node

<u>Formulation 2</u>:

Algebraic sum of currents entering node = 0

- Currents leaving are included with a minus sign.

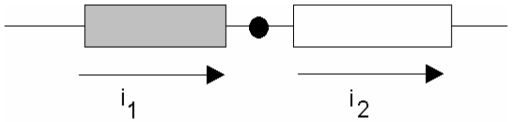
<u>Formulation 3</u>:

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***.



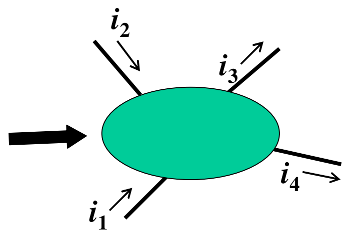
Current entering node = Current leaving node

$$i_1 = i_2$$

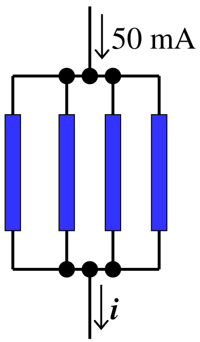
Generalization of KCL

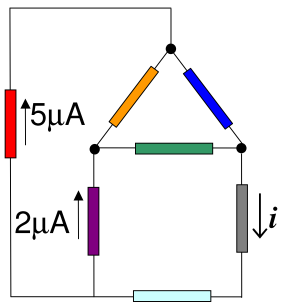
- The sum of currents entering/leaving a **closed surface** is zero. Circuit branches can be inside this surface, *i.e.* the surface can enclose more than one node!

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



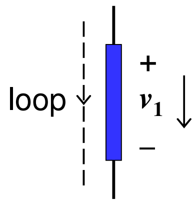
Generalized KCL Examples



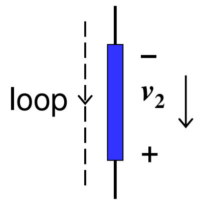


Using Kirchhoff's Voltage Law (KVL)

Consider a branch which forms part of a loop:



Moving from + to -
We add V_1



Moving from - to +
We subtract V_1

- Use **reference polarities** to determine whether a voltage is dropped
- 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.)

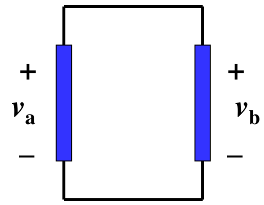
Formulation 3:

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:

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

Summary

- An electrical system can be modeled by an **electric circuit** (***combination of paths***, each containing 1 or more ***circuit elements***)
  - Lumped model
- The ***Current versus voltage characteristics (I-V plot)*** is a universal means of describing a circuit element.
- ***Kirchhoff's current law (KCL)*** states that the algebraic sum of all currents at any node in a circuit equals zero.
  - Comes from conservation of charge
- ***Kirchhoff's voltage law (KVL)*** states that the algebraic sum of all voltages around any closed path in a circuit equals zero.
  - Comes from conservation of potential energy