Announcements

- **Lectures will be in 4 LeConte**
  - beginning Friday 8/29
- **Additional discussion TA**
  - Dennis Chang (Sections 101, 105)
  - Office hours: Mo 2-3 PM; Th 5-6 PM
- **Lab sections begin Tuesday 9/2**
  - Read Experiment #1 online
  - Download Pre-Lab #1 and complete it **before** going to the lab (140 Cory)
- **Discussion sections begin Tuesday 9/2**

Lecture #2

OUTLINE

- Introduction to circuit analysis
- Electrical quantities
  - Charge
  - Current
  - Voltage
  - Power
- The ideal basic circuit element
- Sign conventions

Reading

Chapter 1

Electrical System Design Process

1. **Identify system performance requirements**
   → design specifications
2. **Conceive of approach**
   → design concept
3. **Develop an electric circuit model**
   (mathematical model that approximates the behavior of an actual electrical system)
   … using ideal circuit components
   (mathematical models of actual electrical components)
4. **Build and test a physical prototype**

Circuit Analysis

- **Circuit analysis is used to predict the behavior of the electric circuit, and plays a key role in the design process.**
  – Comparison between desired behavior (design specifications) and predicted behavior (from circuit analysis) leads to refinements in design
- **In order to analyze an electric circuit, we need to know the behavior of each ideal circuit element (in terms of its voltage and current) and the constraints imposed by interconnecting the various elements.**

Electric Charge

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 x 10^{-19} coulombs**

- **Electrical effects are due to**
  - **separation of charge** → electric force (***voltage***)
  - **charges in motion** → electric flow (***current***)

Classification of Materials

Solids in which all electrons are tightly bound to atoms are ***insulators***.

Solids in which the outermost atomic electrons are free to move around are ***metals***.

Metals typically have ~1 "free electron" per atom (~5 ×10^{22} free electrons per cubic cm)

Electrons in ***semiconductors*** are not tightly bound and can be easily "promoted" to a free state.

insulators	semiconductors	metals
Quartz, SiO_2	**Si, GaAs**	**Al, Cu**
dielectric materials		excellent conductors

Electric Current

Definition: rate of positive charge flow
Symbol: i
Units: Coulombs per second ≡ Amperes (A)

$$i = dq/dt$$

where q = charge (in Coulombs), t = time (in seconds)

Note: Current has polarity.

Electric Current Examples

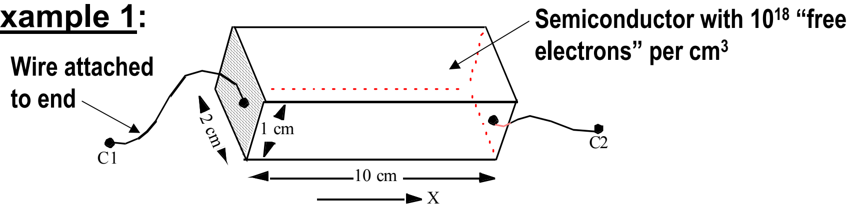
1. 10^5 positively charged particles (each with charge 1.6×10^{-19} C) flow to the right ($+x$ direction) every nanosecond

2. 10^5 electrons flow to the right ($+x$ direction) every microsecond

Current Density

Definition: rate of positive charge flow per unit area
Symbol: J
Units: A / cm²

Example 1:



Suppose we force a current of 1 A to flow from C1 to C2:

- Electron flow is in $-x$ direction:

$$\frac{1C/\sec}{-1.6\times10^{-19}C/electron} = -6.25\times10^{18}\frac{electrons}{\sec}$$

Current Density Example (cont'd)

The current density in the semiconductor is

Example 2:

Typical dimensions of integrated circuit components are in the range of 1 μm. What is the current density in a wire with 1 μm² area carrying 5 mA?

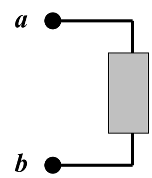
Electric Potential (Voltage)

- **<u>Definition</u>:** energy per unit charge
- **<u>Symbol</u>:** v
- **<u>Units</u>:** Volts (V)

$$v = dw/dq$$

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

Note: Potential is always referenced to some point.



<u>Subscript convention</u>:

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

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

Electric Power

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

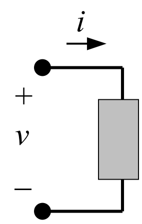
$$p = dw/dt = (dw/dq)(dq/dt) = vi$$

- **<u>Concept</u>:**

  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



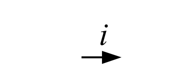
- Polarity reference for voltage can be indicated by plus and minus signs
- Reference direction for the current is indicated by an arrow

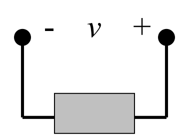
Attributes:

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

A Note about Reference Directions

A problem like "Find the current" or "Find the voltage" is always accompanied by a definition of the direction:



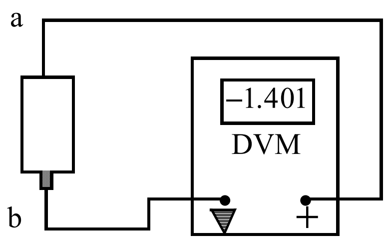


In this case, if the current turns out to be 1 mA flowing to the left, we would say i = -1 mA.

In order to perform circuit analysis to determine the voltages and currents in an electric circuit, you need to specify reference directions. There is no need to guess the reference direction so that the answers come out positive, however.

Sign Convention Example

Suppose you have an unlabelled battery and you measure its voltage with a digital voltmeter (DVM). It will tell you the **magnitude and sign** of the voltage.



With this circuit, you are measuring v_{ab}.

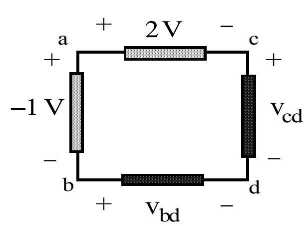
The DVM indicates –1.401, so v_a is lower than v_b by 1.401 V.

Which is the positive battery terminal?

Note that we have used the "ground" symbol (▼) for the reference node on the DVM. Often it is labeled "C" for "common."

Another Example

Find v_{ab}, v_{ca}, v_{cb}

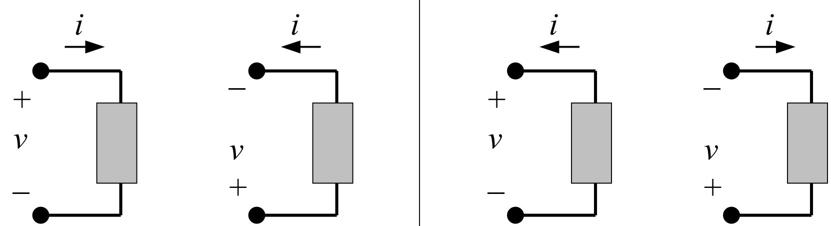


Note that the labeling convention has nothing to do with whether or not v is positive or negative.

Sign Convention for Power

Passive sign convention

$p = vi$ $\qquad$ $p = -vi$



- **If p > 0, power is being delivered to the box.**
- **If p < 0, power is being extracted from the box.**

Summary

- ***Current*** = rate of charge flow
- ***Voltage*** = energy per unit charge created by charge separation
- ***Power*** = energy per unit time
- ***Ideal Basic Circuit Element***
  - 2-terminal component that cannot be sub-divided
  - described mathematically in terms of its terminal voltage and current
- ***Passive sign convention***
  - Reference direction for current through the element is in the direction of the reference voltage drop across the element