Electric Circuits

Lecture 0 - Introduction

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Spring 2018

Welcome!

- Lectures
  - Monday, 10:15AM – 11:55AM
  - Wednesday, 10:15AM – 11:55AM (Even week only!)
- Office hours
  - Monday, 1:00pm – 2:00pm, SIST 2-202.F
  - Or by appointment
- Labs:
  - 2 students per group! Find your partner by 7th March.

Outline

- Basic course information

You will learn various analysis methods in lectures to analyze the behavior of electric circuits.

- Why should you study this course?

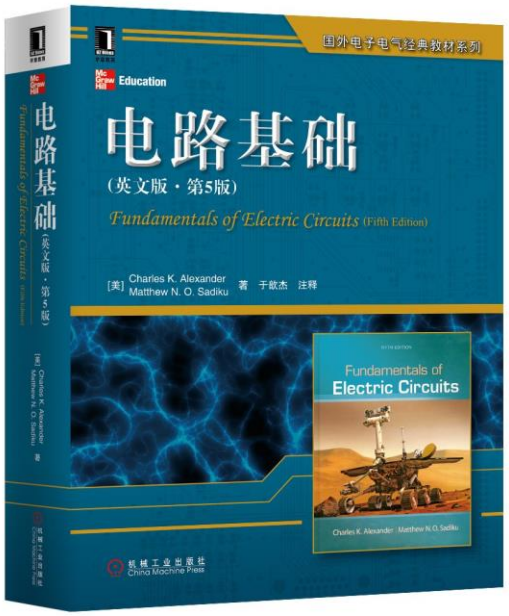
- What will we study in this course?

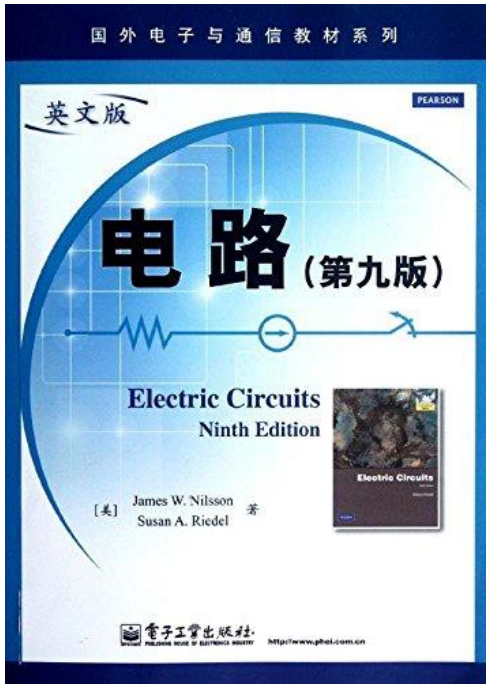
Workload/Grading Policy

- 10 homework assignments: 20%
- 8 lab assignments: 25%
  - No late HW or Lab reports accepted!
- 2 midterms (15% x 2) + 1 final exam (20%)
  - Midterm 1: week 6 (tentative)
  - Midterm 2: week 11 (tentative)
  - Notify the instructor immediately if you miss an exam due to an unforeseeable event, and submit a note from your physician in case of illness.
  - NO make-up exams!
- Quizzes (5%)
  - Quizzes are held in classes and will not be announced in advance.
  - Again no make-up quizzes.

References

- Charles K. Alexander and Matthew N. O. Sadiku, *Fundamentals of Electric Circuits*, 5th edition, McGraw Hill, 2012.
- James W. Nilsson and Susan Riedel, *Electric Circuits*, 9th edition, Prentice Hall, 2010.



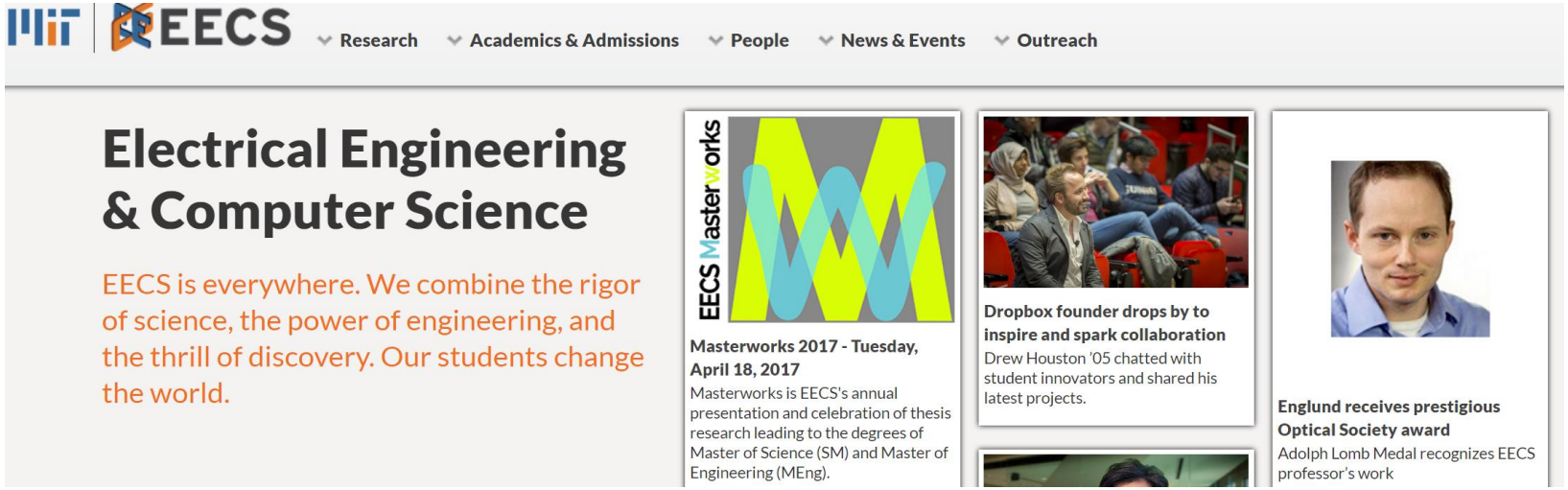


请务必遵守学术道德规范！

- 单次作业或者实验抄袭
  - 抄袭与被抄袭者该次作业/实验均计零分，课程总成绩打九折。
- 累计两次作业或者实验抄袭
  - 抄袭与被抄袭者相应作业/实验计零，课程总成绩均打七折。
- 累计三次作业或实验抄袭者，或者考试作弊者
  - 课程总成绩计零，同时上报信息学院学术委员会公开处理。

Why should you study this course?

Any reason for EECS?



Why should you study this course?

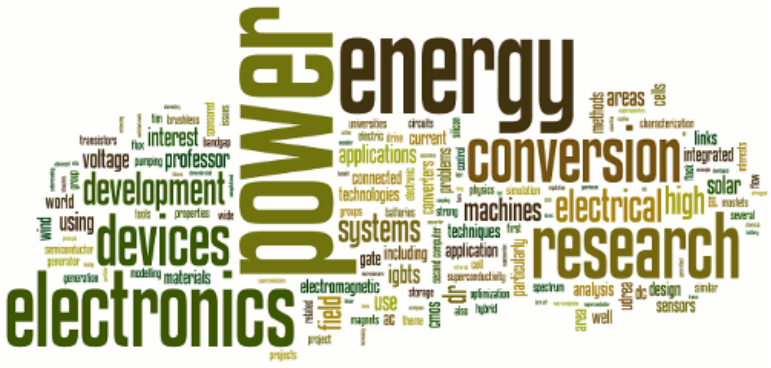
What is Electrical Engineering (EE)?

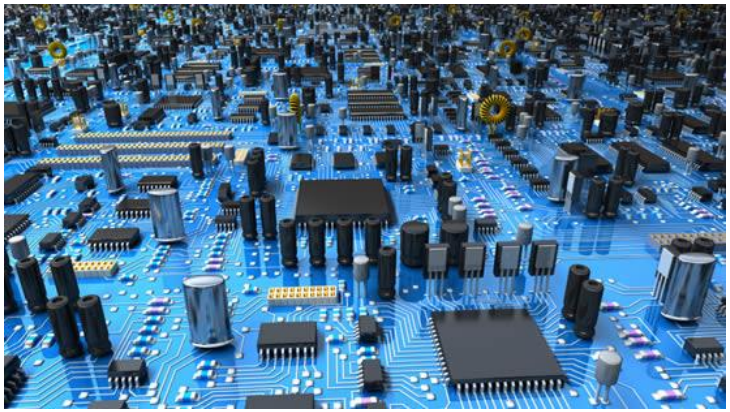
- "EE is the profession concerned with *systems* that produce, transmit, and measure *electric* signals. Electrical engineering combines the *physicist's models of natural phenomena* with the *mathematician's tools* for manipulating those models to produce systems that meet practical needs."
  - James W. Nilsson and Susan Riedel, *Electric Circuits*, 10th edition, Prentice Hall, 2014.
- "Electrical engineers design *systems* that have two main objectives:
  1. To gather, store, process, transport, and present *information*.
  2. To distribute, store, and convert *energy* between various forms."
  - Allan R. Hambley, *Electrical Engineering – Principles and Applications*, 5th edition, Prentice Hall, 2011.

Major Areas of Electrical Engineering (EE)

Electronics

- Study and application of materials, devices and circuits used in *amplifying* and *switching* electrical signals.





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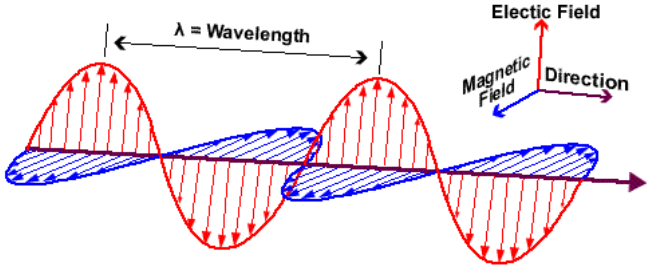
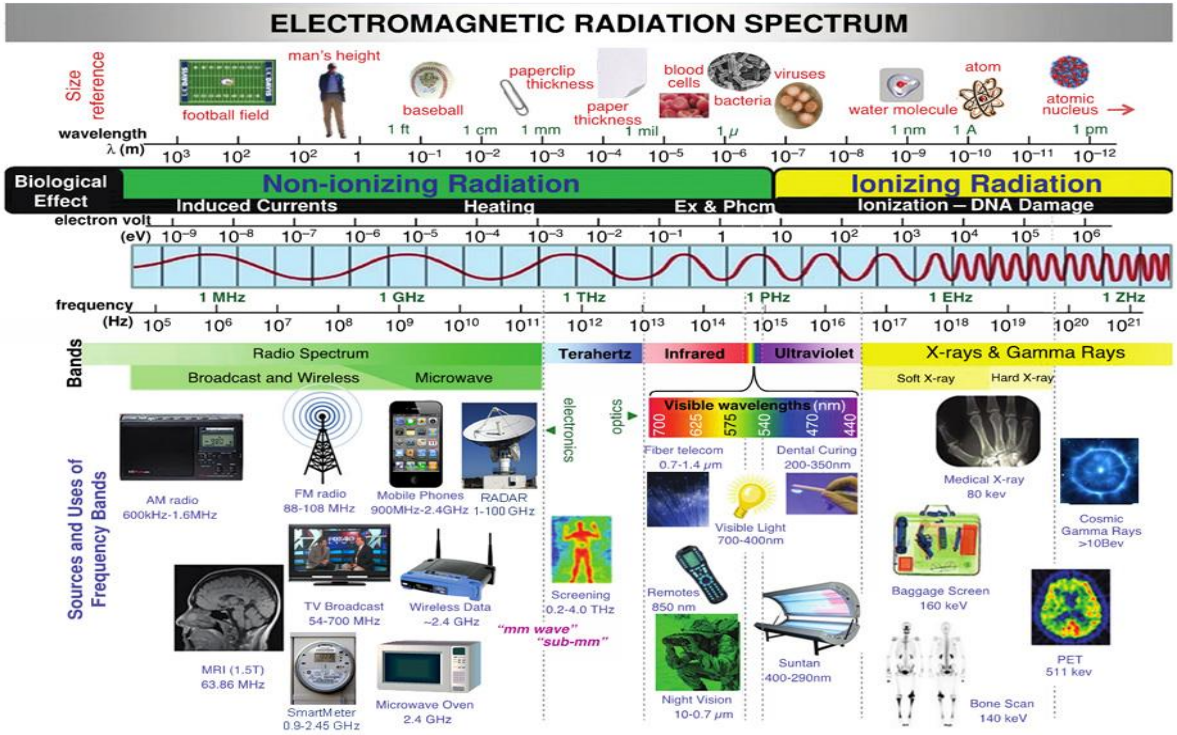
Electromagnetics

- Study and application of electric and magnetic fields.





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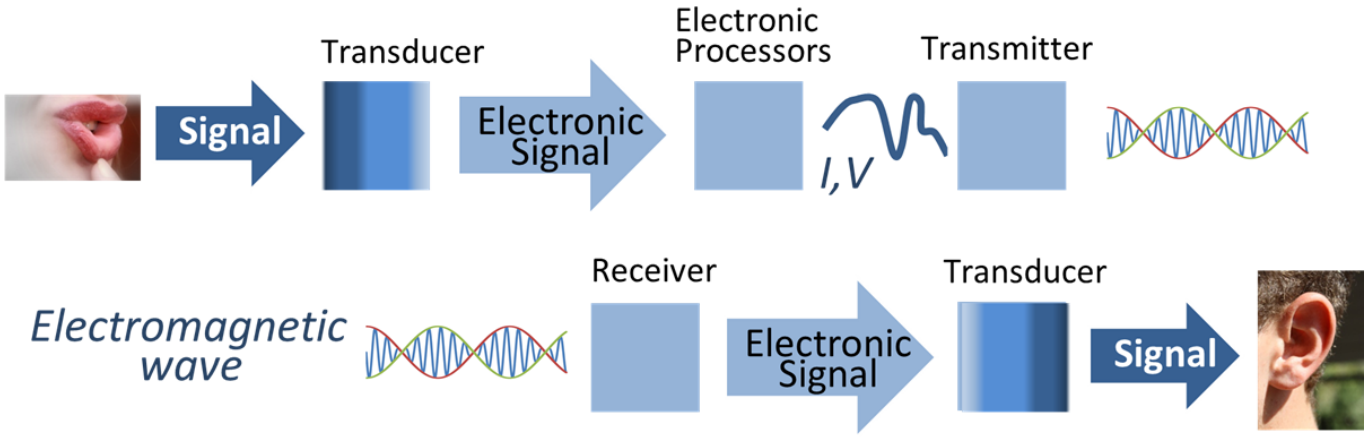
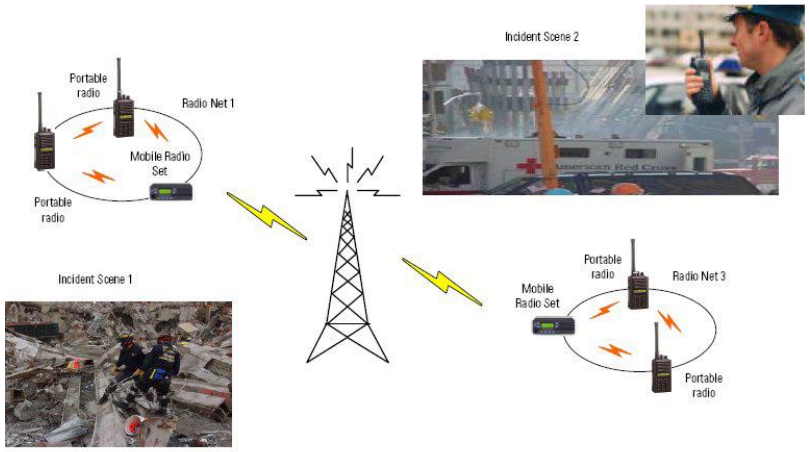
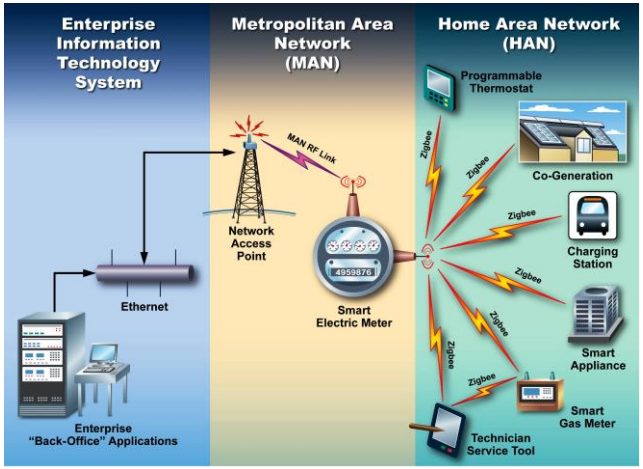
Communication Systems

- *Transport* information in electrical form.







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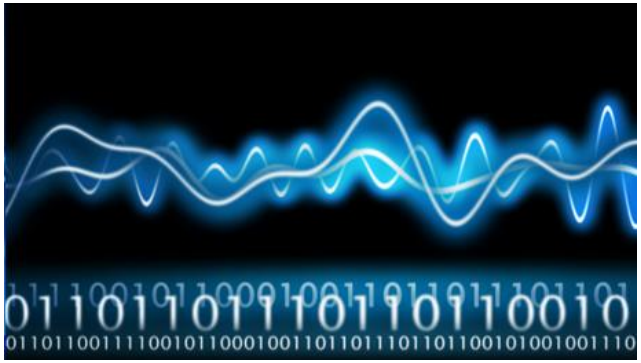
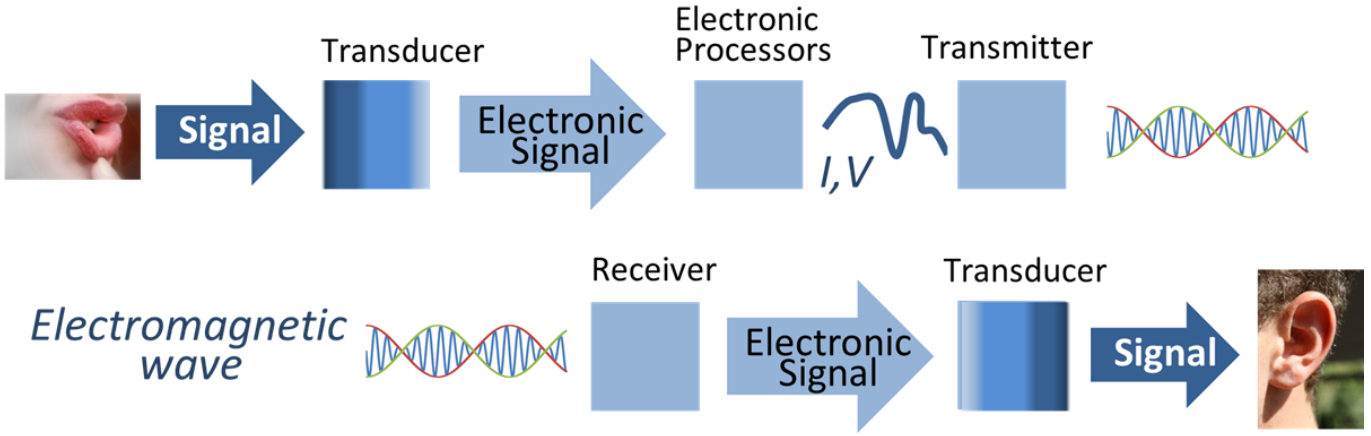
Signal Processing

- Concerned with information-bearing electrical signals
  - Objective: extract useful information from electrical signals derived from sensors.





[Source: Google Image]

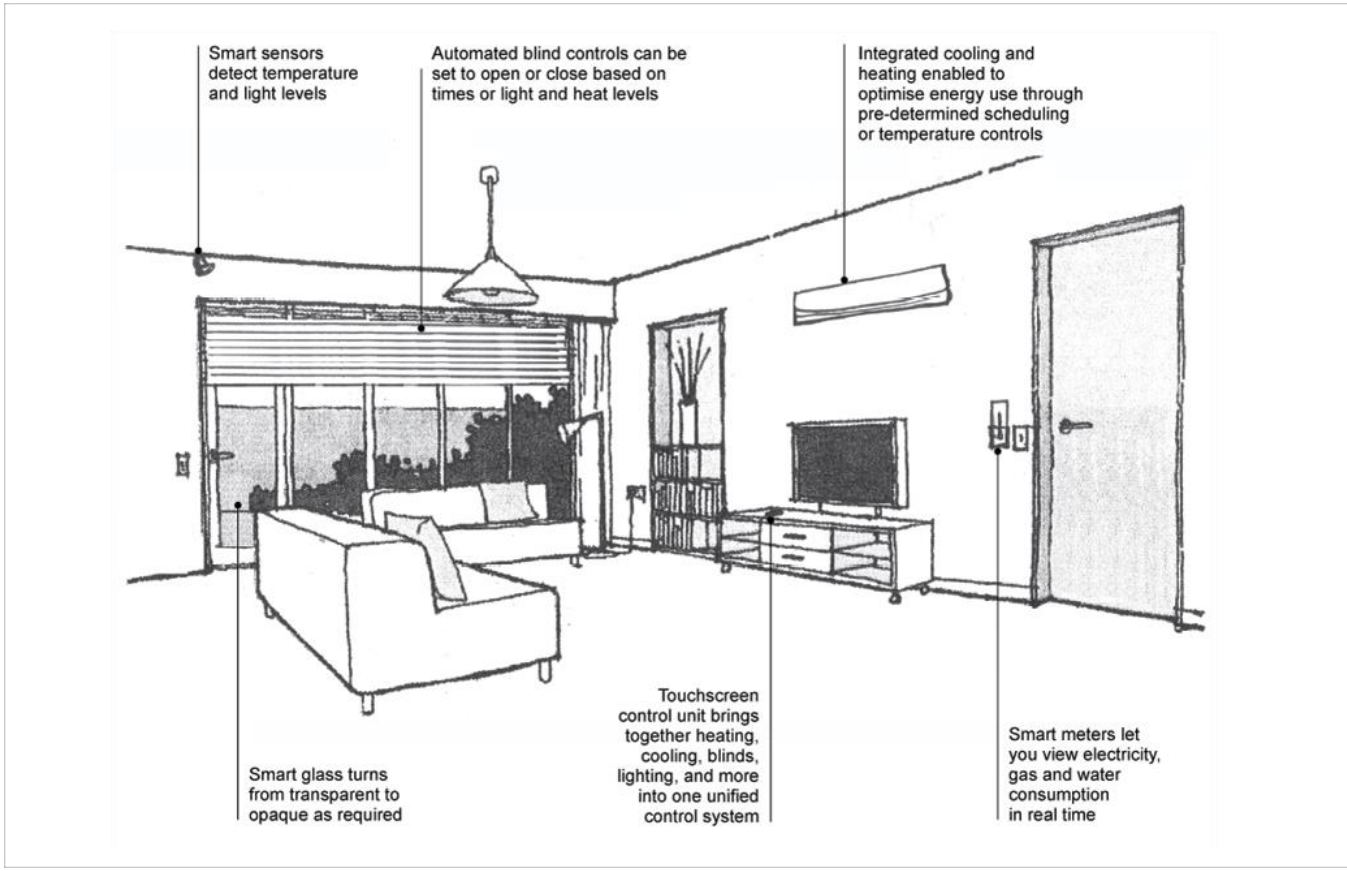
Computer Systems

- *Process and store* information using electrical signals.

[Source: Google Image]

Control Systems

- Use electric signals to *regulate* processes.



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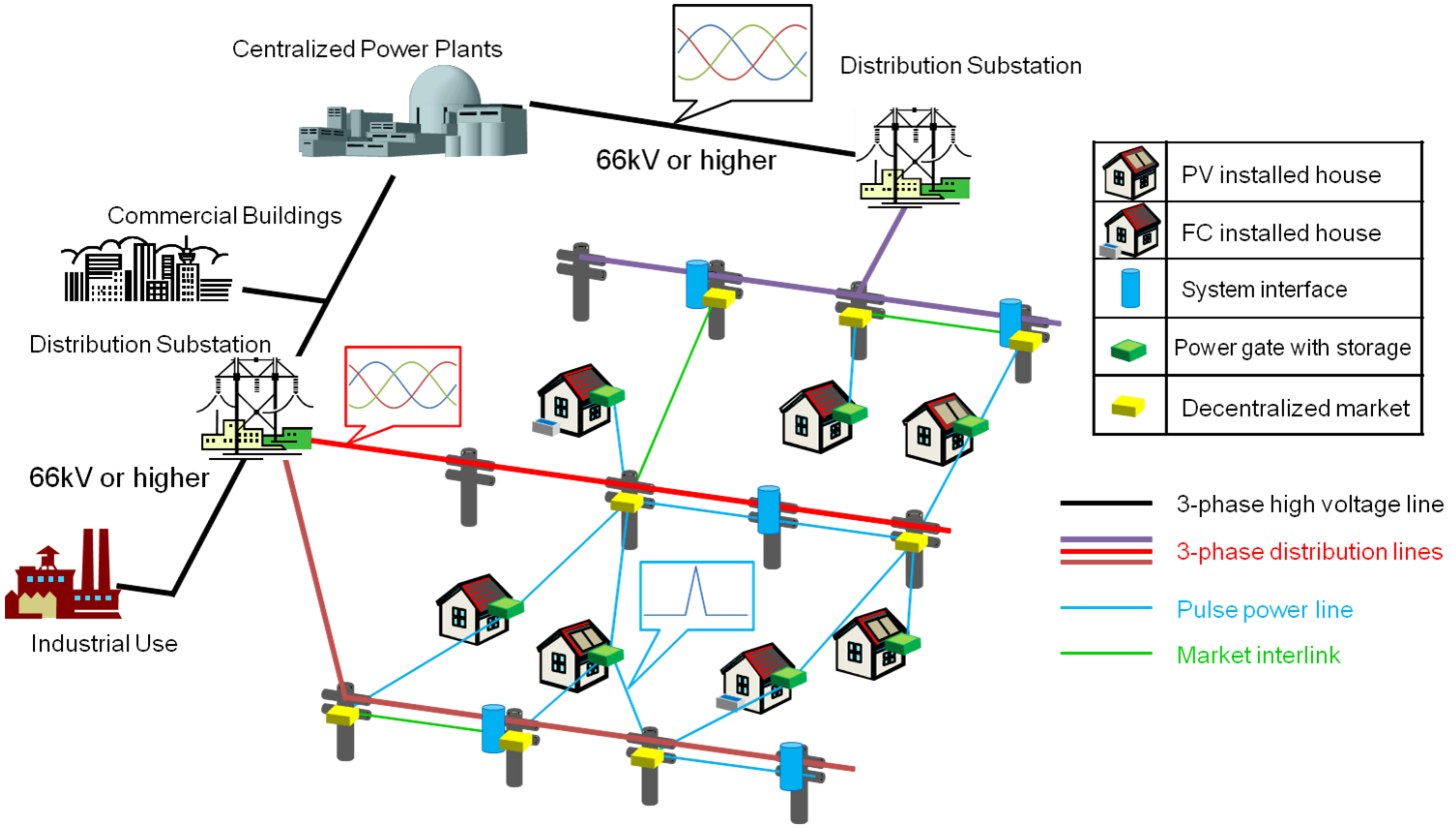
Power Systems

- *Convert* energy to and from electrical form and *transmit* energy over long distances.



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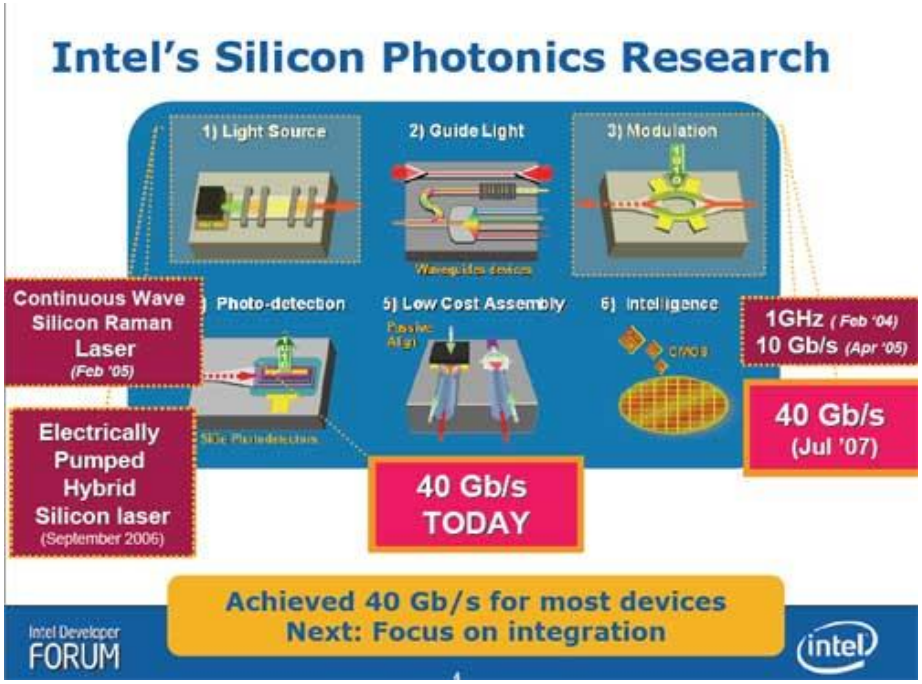
Photonics

- An exciting new field that manipulates *photon*s, instead of manipulating *electron*s in conventional computing, signal processing, sensing and communication.



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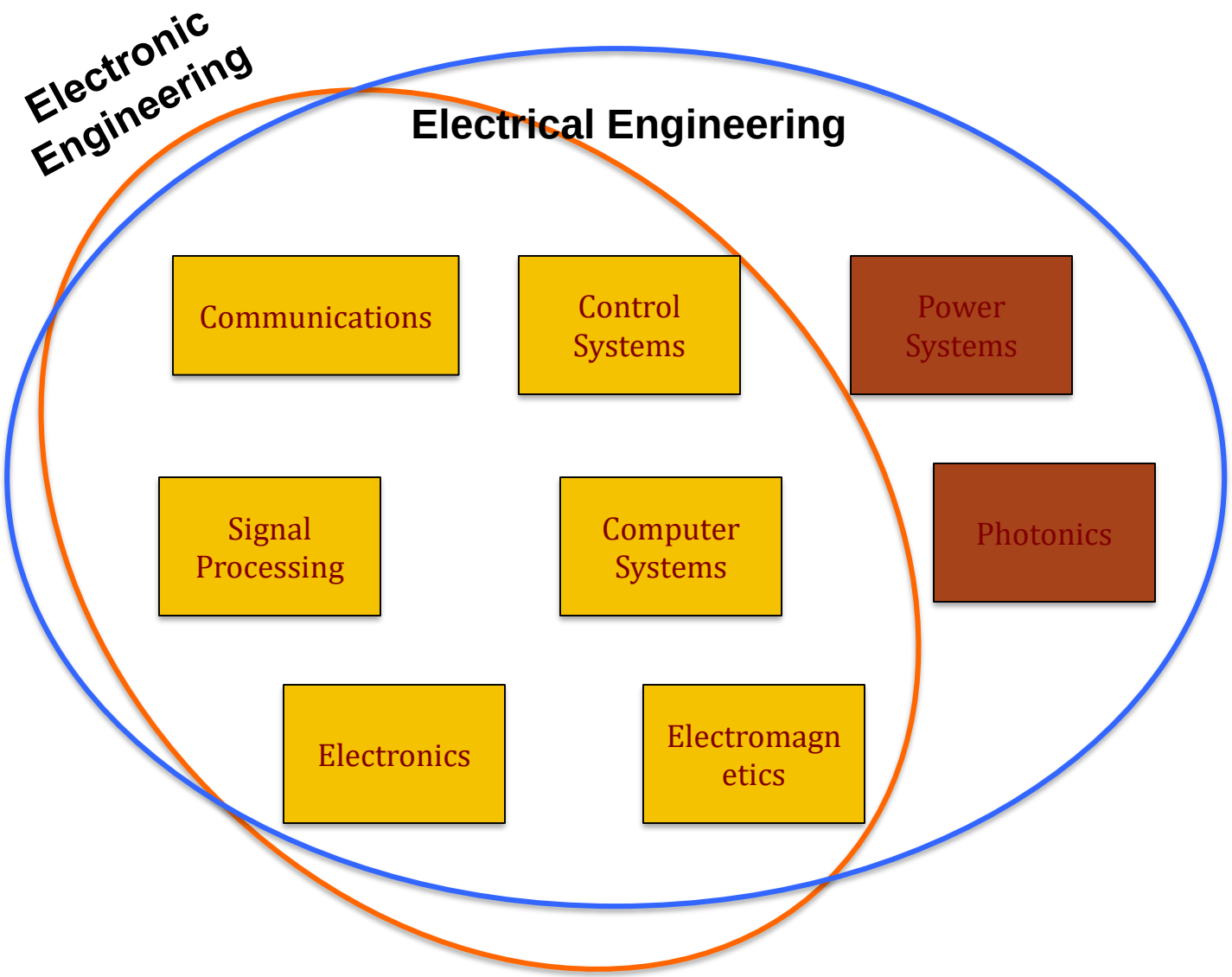

Electronic Engineering
Electrical Engineering
Communications
Control Systems
Power Systems
Signal Processing
Computer Systems
Photonics
Electronics
Electromagnetics

EE Trichotomy

- Devices
  - You can “touch and feel” devices
  - Semiconductors are materials of choice
  - Information is ultimately represented by electrons (and ‘holes’) and/or photons
- Circuits
  - Interconnection of devices that performs a useful function
  - Digital circuits, analog circuits, “RF” and microwave
- Systems
  - The theory behind EE systems.
  - A model for the system that includes noise, non-linearity, feedback and dynamics.

[Source: Berkeley]

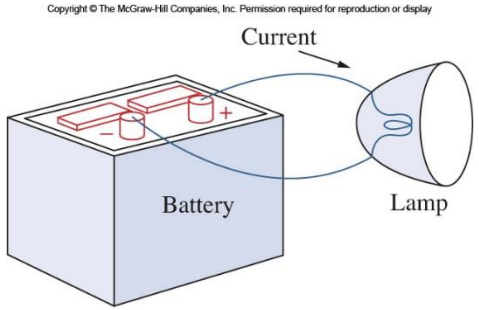
In a field as diverse as electrical engineering, does all its branches have anything in common?

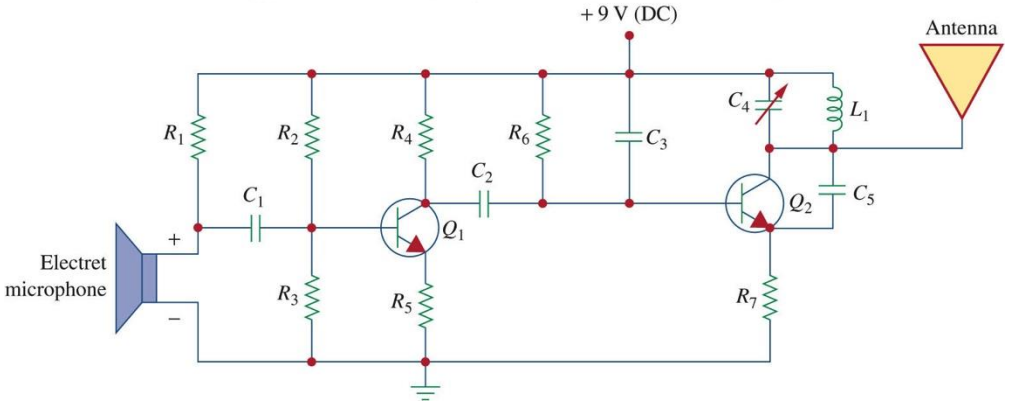
Electric Circuit!

- an actual electrical system, as well as the *model* that represents it.

What will You Learn from "Electric Circuits"?

- An *electric circuit* is an interconnection of electrical elements.





- Theory: You will learn various *analysis* methods in <u>lectures</u> to analyze the behavior of such electric circuits.
  - How does the circuit respond to a given input?
  - How do the elements in the circuit interact?
- Practice: You will also learn how to *build and test* basic electric circuits through <u>labs</u>!

Topics to be Covered in This Course

- Introduction to circuits: currents, voltages; power and energy; circuit elements
- DC circuits
- Basic circuit laws: Ohm's law; Kirchhoff's laws; voltage and current divisions; Wye-Delta transformations
- Techniques of circuit analysis: nodal analysis and mesh analysis
- Circuit theorems: Thevenin and Norton equivalent circuits; Superposition
- Operational amplifiers: ideal operational amplifiers; inverting and non-inverting amplifiers; summing amplifier; difference amplifier
- Inductance, capacitance and mutual inductance
- Laplace transform and Fourier transform
- First-order and second-order circuits
- AC circuits
- Sinusoidal steady-state analysis and power calculations
- Three-phase circuits; magnetically coupled circuits
- Frequency response: transfer function; resonance; passive filters; active filters

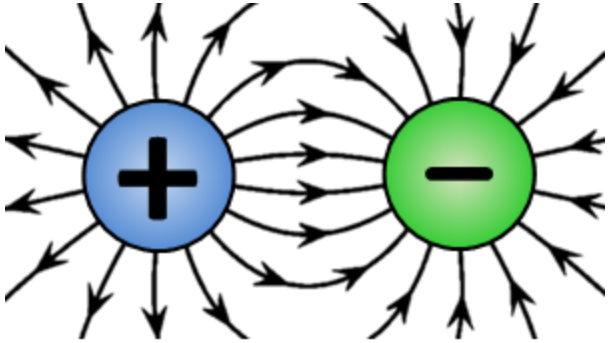
Lecture 1
Circuit Terminology

Outline

- Circuit Terminology
  - Charge, Current, Voltage, Power and Energy
- Ideal basic circuit elements
  - Sign conventions
  - I-V characteristics

Electric Charge

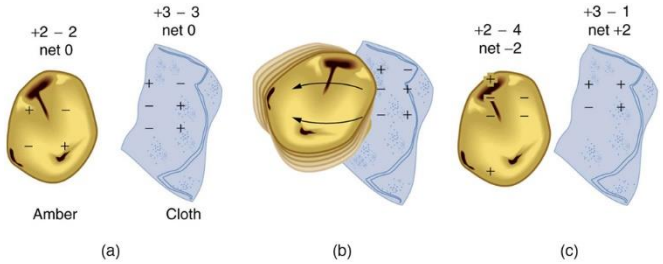
Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C)



- Microscopically, matter is full of electric charges
  - Electric charge exists in discrete quantities, integral multiples of the electronic charge $-1.602*10^{-19}$ *Coulomb*.
- Electrical effects are due to
  - Separation of charge -> electric force
- Charge can neither be created nor destroyed.
- Macroscopically, most *matter* is electrically neutral most of the time
  - Exceptions: clouds in a thunderstorm, plates of a charged capacitor, etc.

[Source: Berkeley]

Etymology

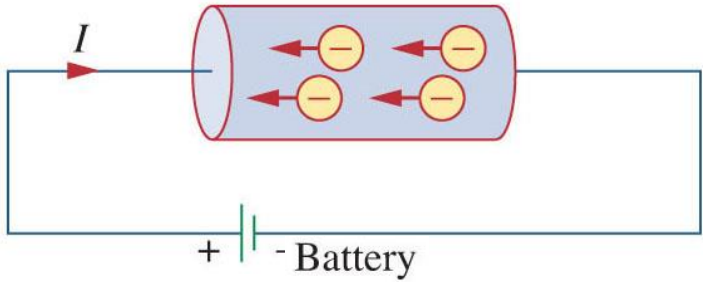


- The word electric is derived from the Greek elektron (Latin electrum) denoting amber.
- It was discovered in ancient times that when amber is rubbed, it attracts feathers, dried leaves, etc.
  - Because amber becoming charged (discovered much later).
- These are the roots of our subject.

[Source: Berkeley]

Electric Current

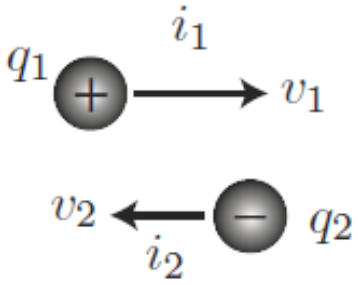
- Charges in motion -> electric flow (current)



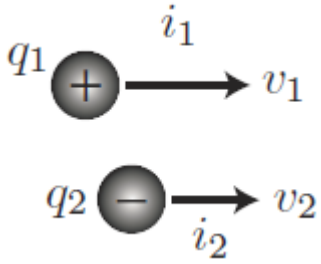
- The current flowing through a surface can be defined as

$$I = \frac{dq}{dt}$$

- Conventional to take the current flow as the movement of positive charges

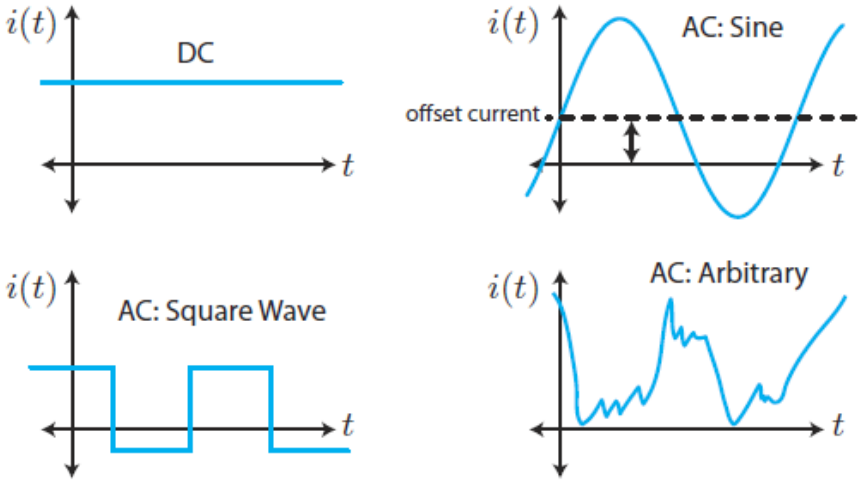


Net current
=



Net current
=

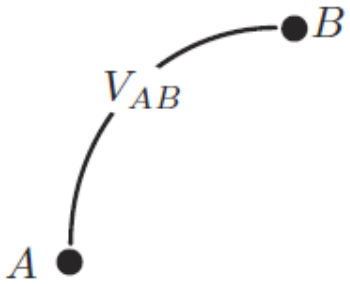
DC versus (vs.) AC



- A constant current is called a “Direct Current" (DC). Otherwise it’s AC (alternating current).
  - Some AC typical waveforms are shown above. Sine waves are the waveforms coming out of an electric outlet. A square wave is the clock signal in a digital circuit.
  - Any time-varying current is known as an AC. Note that the sign of the current does not necessarily have to change (the current does not have to alter direction), as the name implies.

Voltage (= potential difference)

- The voltage difference V_{AB} between *A* and *B* is the amount of energy needed to move a unit of charge from A to B.

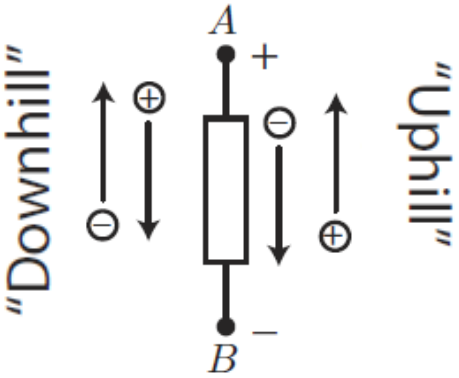


$$v = \frac{d\mathrm{E}}{dq}$$

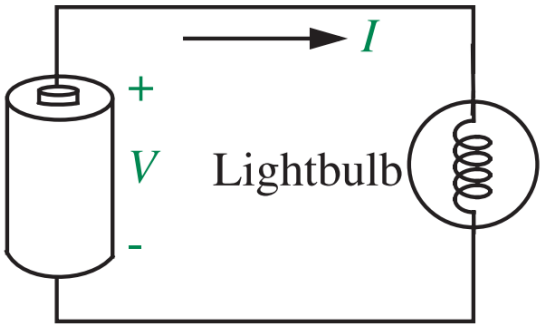
- If a total charge of Δq is moved from $A \rightarrow B$, the energy required is

$$E = \Delta q \cdot V_{AB}, \qquad V_{AB} \equiv V_A - V_B$$

  - If the energy is positive, then energy is lost by the charges. Why?



Voltage across a Component

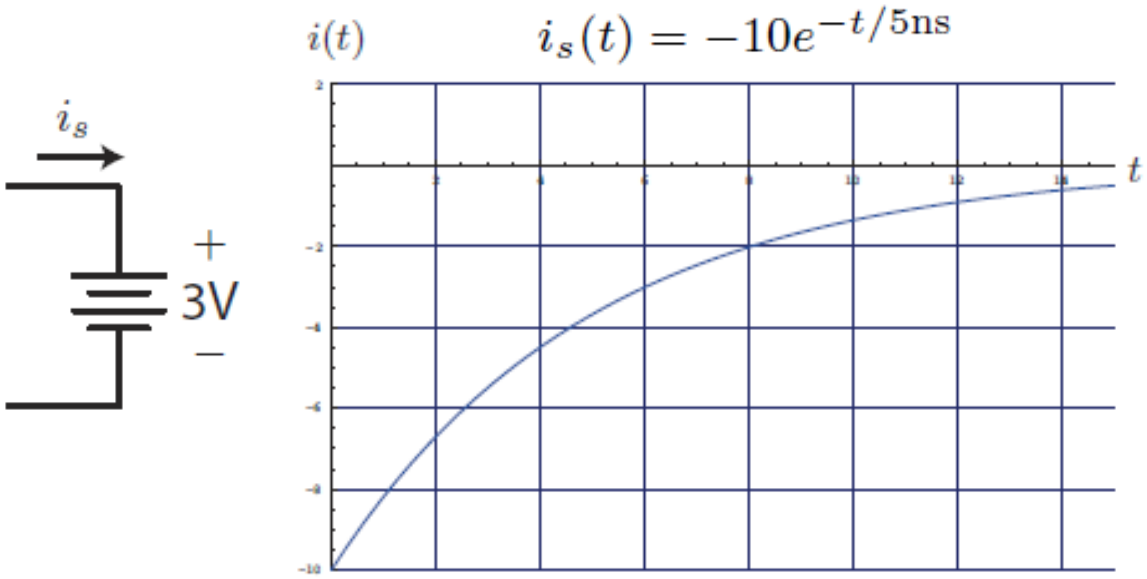


- In electrical circuits, the path of motion is well defined by wires/circuit components (also known as elements).
- We usually label the terminals of a component as *positive* and *negative* to denote the voltage drop across the component.
- Voltage is a relative quantity. An absolute voltage is meaningless and usually is implicitly referenced to a known point in the circuit (ground) or in some cases a point at infinity.

Power and Energy

- Definition: transfer of energy per unit time.

$$p \triangleq \frac{d\mathrm{E}}{dt}$$



Power = ?

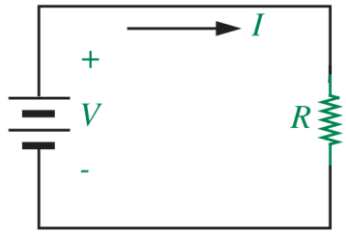
Net energy supplied by the source = ?

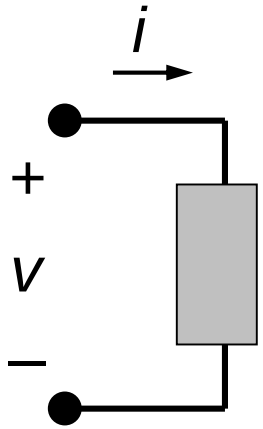
[Source: Berkeley]

Outline

- Circuit Terminology
  - Charge, Current, Voltage, Power and Energy
- Ideal basic circuit elements
  - Sign conventions
  - I-V characteristics

The Ideal Basic Circuit Element





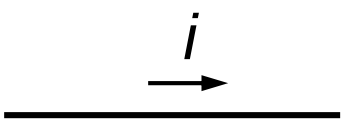
- Polarity reference for voltage can be indicated by plus and minus signs.
- Reference direction for the current is indicated by an arrow.

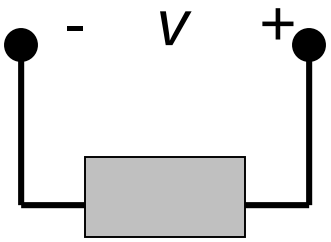
Attributes:

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

Sign Convention

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



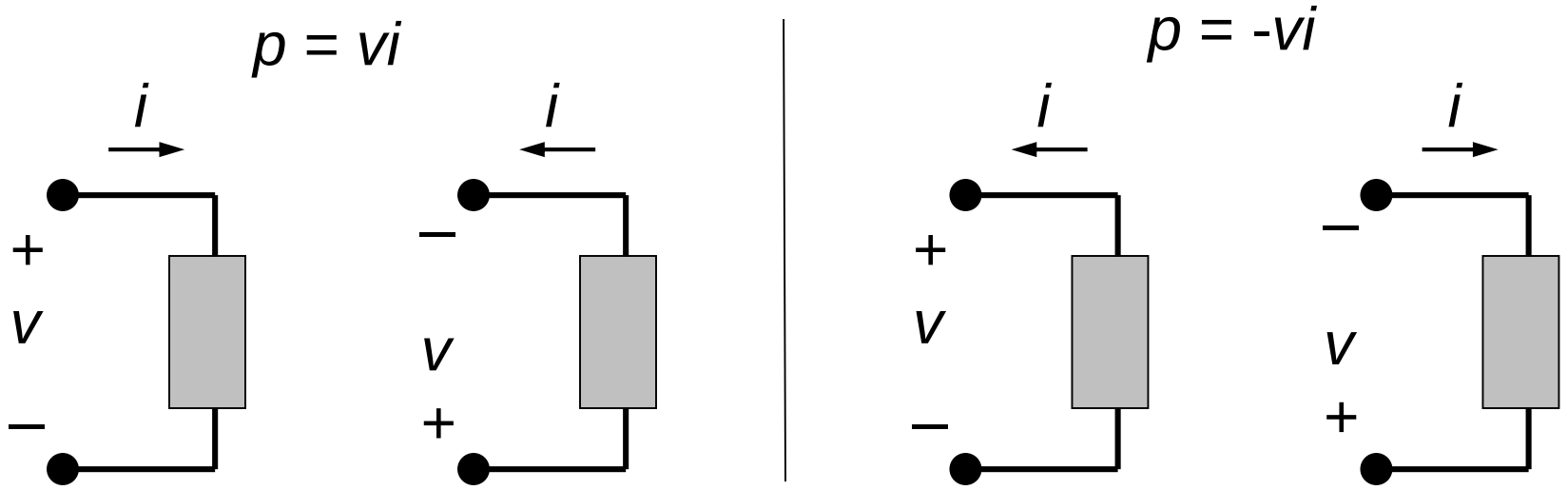


- In this case, if the current turns out to be 1 mA flowing to the left, we would say i = ?.
- In order to perform circuit analysis to determine the voltages and currents in an electric circuit, you need to specify reference directions.
- By convention, when current flows into the positive terminal of a component, we say the current is positive. Otherwise the current is negative.

[Source: Berkeley]

Passive Sign Convention (for Power)

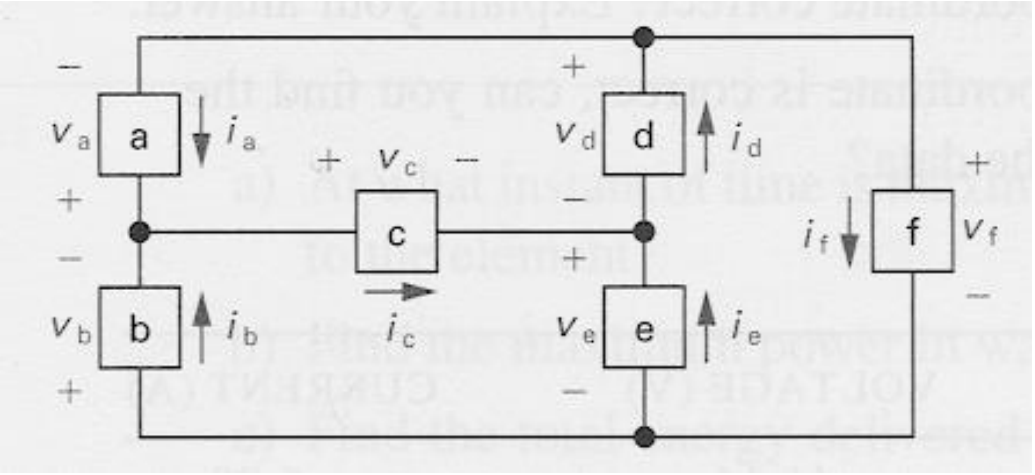
Whenever the reference direction for the current in an element is in the direction of the reference voltage drop across the element, use positive sign in any expression that relates the voltage to the current. Otherwise, use a negative sign.



- If $p > 0$, power is absorbed by the element.
  - electrical energy into heat (resistors in toasters), light (light bulbs), or acoustic energy (speakers); by storing energy (charging a battery).
- If $p < 0$, power is extracted from the element.

Power Calculation Exercise

Find the power absorbed by each element:



ELEMENT	VOLTAGE (V)	CURRENT (A)
a	−18	−51
b	−18	45
c	2	−6
d	20	−20
e	16	−14
f	36	31

Conservation of energy:
Does total power delivered equal total power absorbed?

[Source: Berkeley]

Circuit Elements

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

  } ***active elements***, capable of generating electric energy

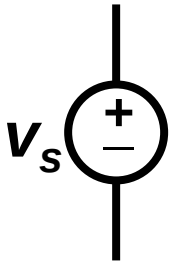
  - resistor
  - inductor
  - capacitor

  } ***passive elements***, incapable of generating electric energy

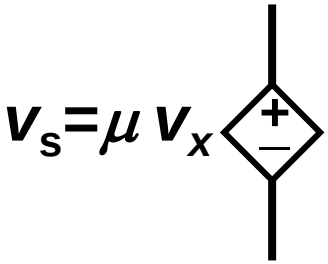
Ideal Voltage Source

- 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.

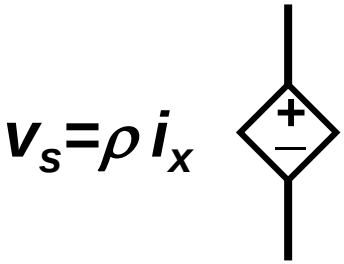
Device symbols:



independent



voltage-controlled



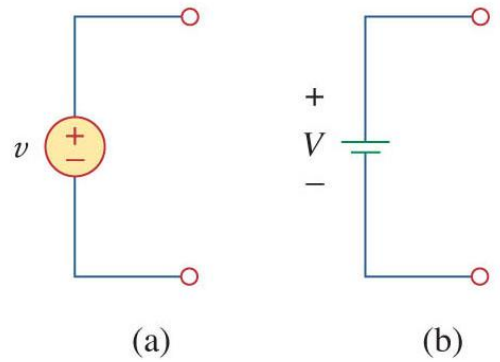
current-controlled

Electrical Sources

- An ***electrical source*** is a device that is capable of converting non-electric energy to electric energy and *vice versa*.

Examples:

- battery: chemical ⟷ electric



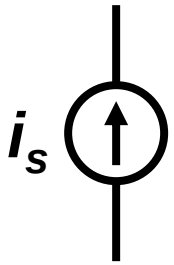
- dynamo (generator/motor): mechanical ⟷ electric
  (Ex. gasoline-powered generator, Bonneville dam)

- Electrical sources can either deliver or absorb power.

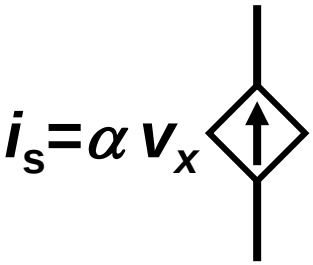
Ideal Current Source

- 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.

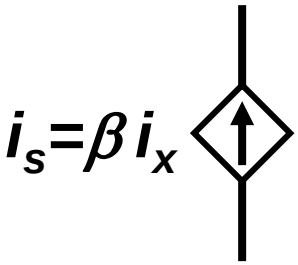
Device symbols:



independent



voltage-controlled



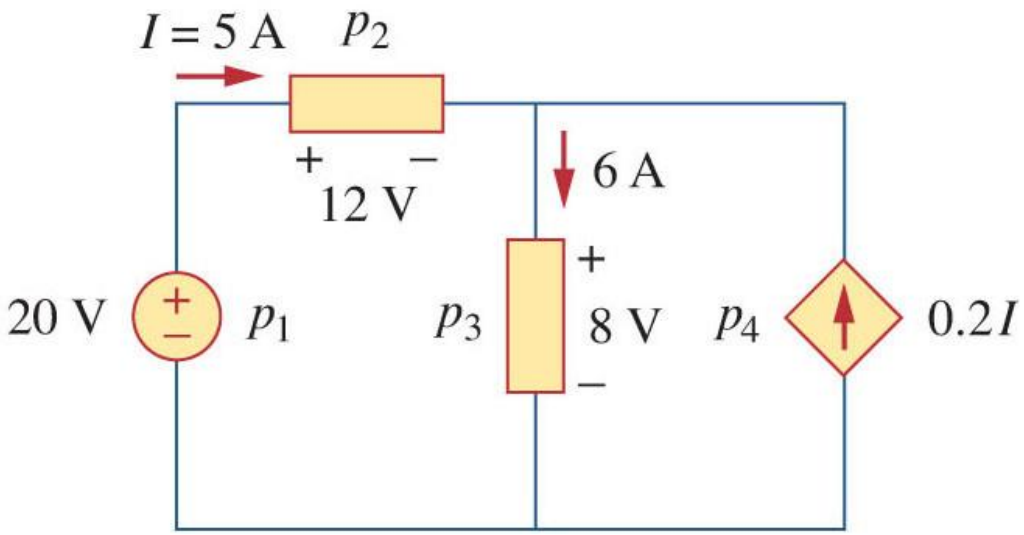
current-controlled

Ideal Sources

- Both the voltage and current source ideally can generate infinite power.
- They are also capable of absorbing power from the circuit.
- It is important to remember that these sources do have limits in reality:
  - Voltage sources have an upper current limit.
  - Current sources have an upper voltage limit.

Exercise

- Calculate the power supplied or absorbed by each element in the following figure.



Electrical Resistance/Conductance

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

Circuit symbol: 

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

$$v = iR$$ (Ohm's Law)

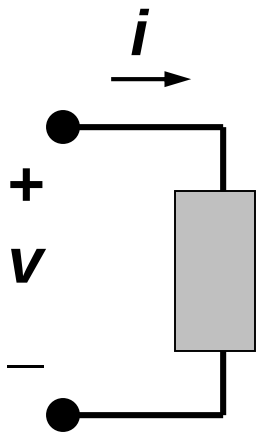
- **Conductance** is the reciprocal of resistance

$$G = \frac{1}{R} = \frac{i}{v}$$

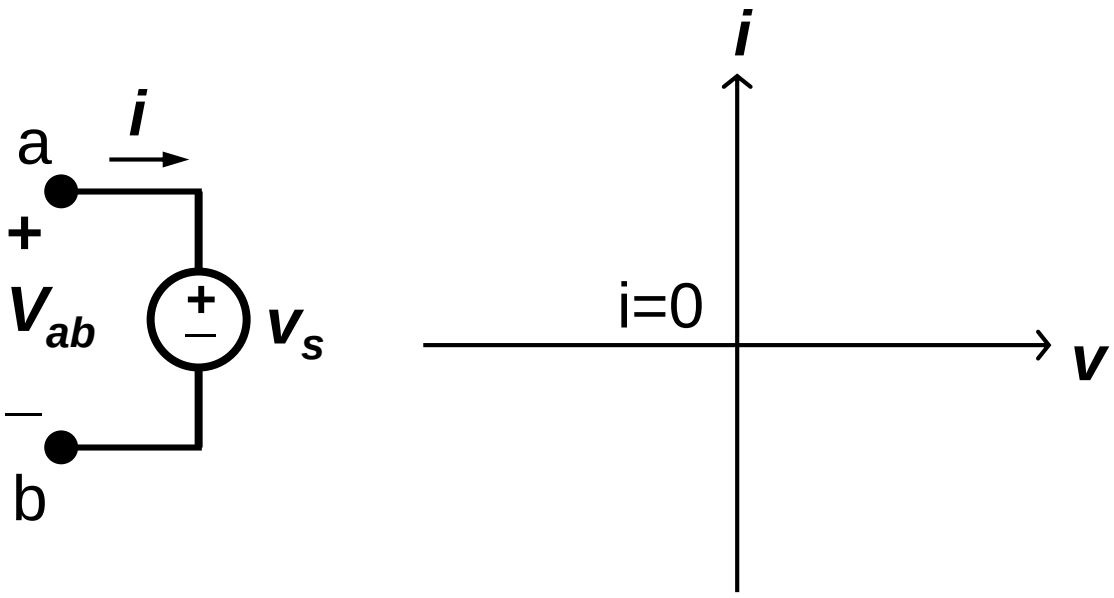
Werner von Siemens
1816-1892

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

- Voltage sources, current sources, and resistors can be described by plotting the current (***i***) as a function of the voltage (***v***).



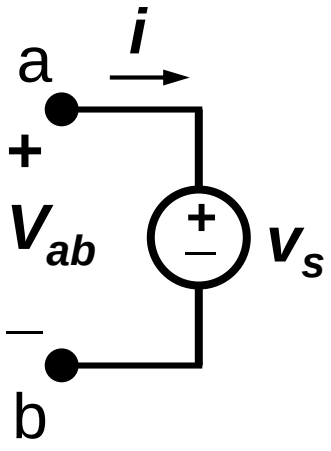
I-V Characteristic of Ideal Voltage Source

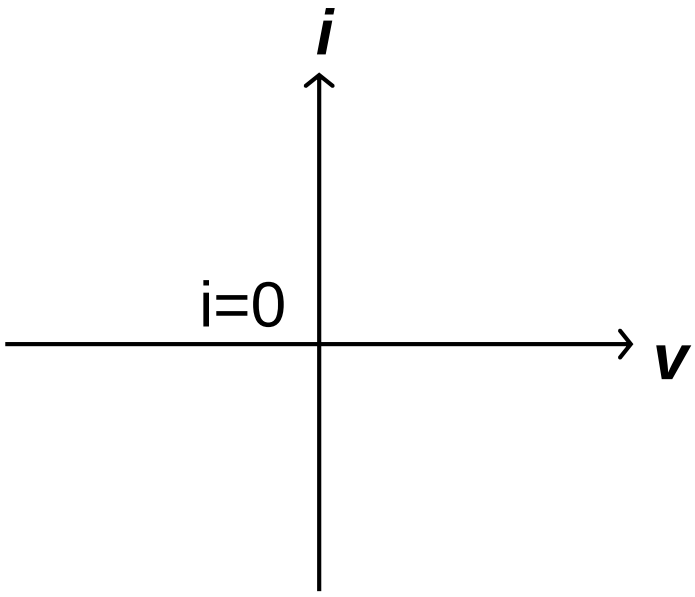


Plot the *I-V* characteristic for $v_s > 0$. For what values of *i* does the source absorb power? For what values of *i* does the source release power?

[Source: Berkeley]

I-V Characteristic of Ideal Voltage Source

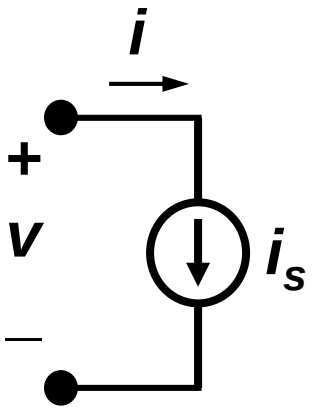


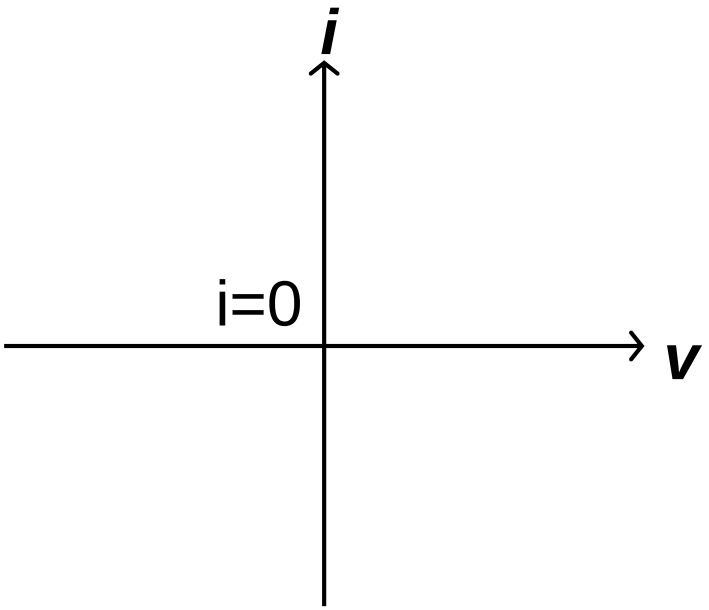


Plot the *I-V* characteristic for $v_s < 0$. For what values of *I* does the source absorb power? For what values of *i* does the source release power?

[Source: Berkeley]

I-V Characteristic of Ideal Current Source

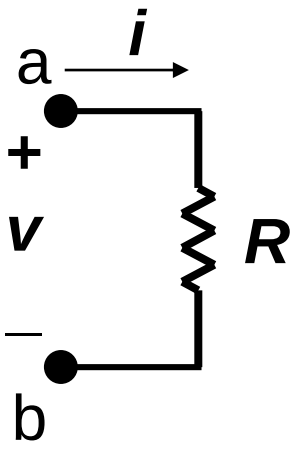


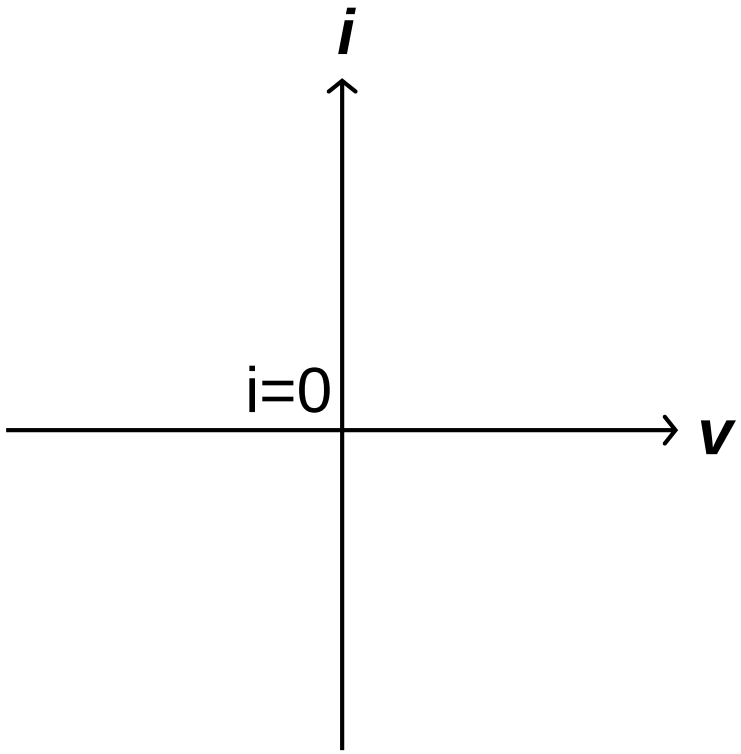


Plot the *I-V* characteristic for $i_s > 0$. For what values of *v* does the source absorb power? For what values of *v* does the source release power?

[Source: Berkeley]

I-V Characteristic of Ideal Resistor





Plot the *I-V* characteristic for $R = 1$ kW. What is the slope?

[Source: Berkeley]

Summary

- ***Current*** = rate of charge flow, $i = dq/dt$
- ***Voltage*** = energy per unit charge created by charge separation
- ***Power*** = energy per unit time
- ***Ideal Basic Circuit Elements***
  - two-terminal component that cannot be sub-divided
  - described mathematically in terms of its terminal voltage/current
  - An ***ideal voltage source*** maintains a prescribed voltage regardless of the current in the device.
  - An ***ideal current source*** maintains a prescribed current regardless of the voltage across the device.
  - A ***resistor*** constrains its voltage and current to be proportional to each other: $\boldsymbol{v = iR}$ (Ohm's law)