Electric Circuits

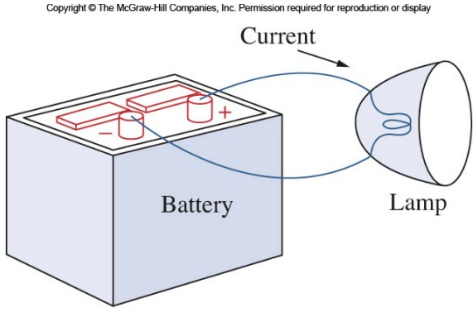
Lecture 0 – Course Introduction

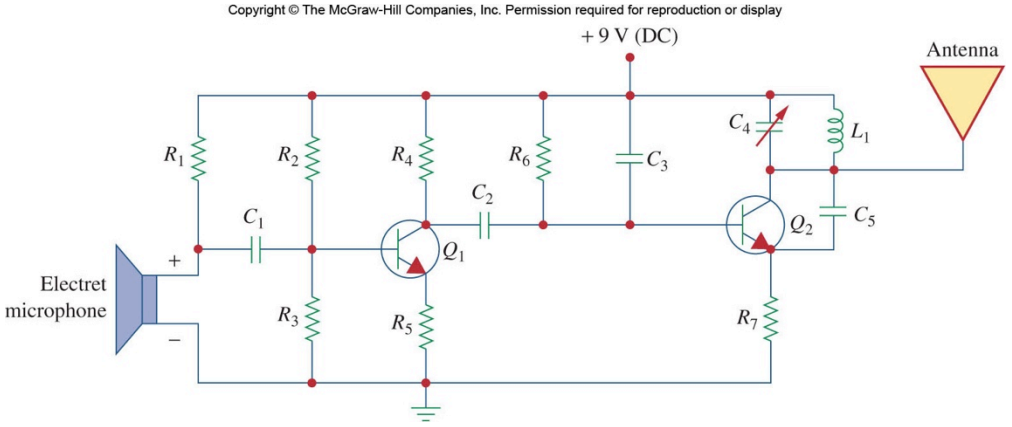
Spring 2022

Welcome!

What will You Learn from "Electric Circuits"?

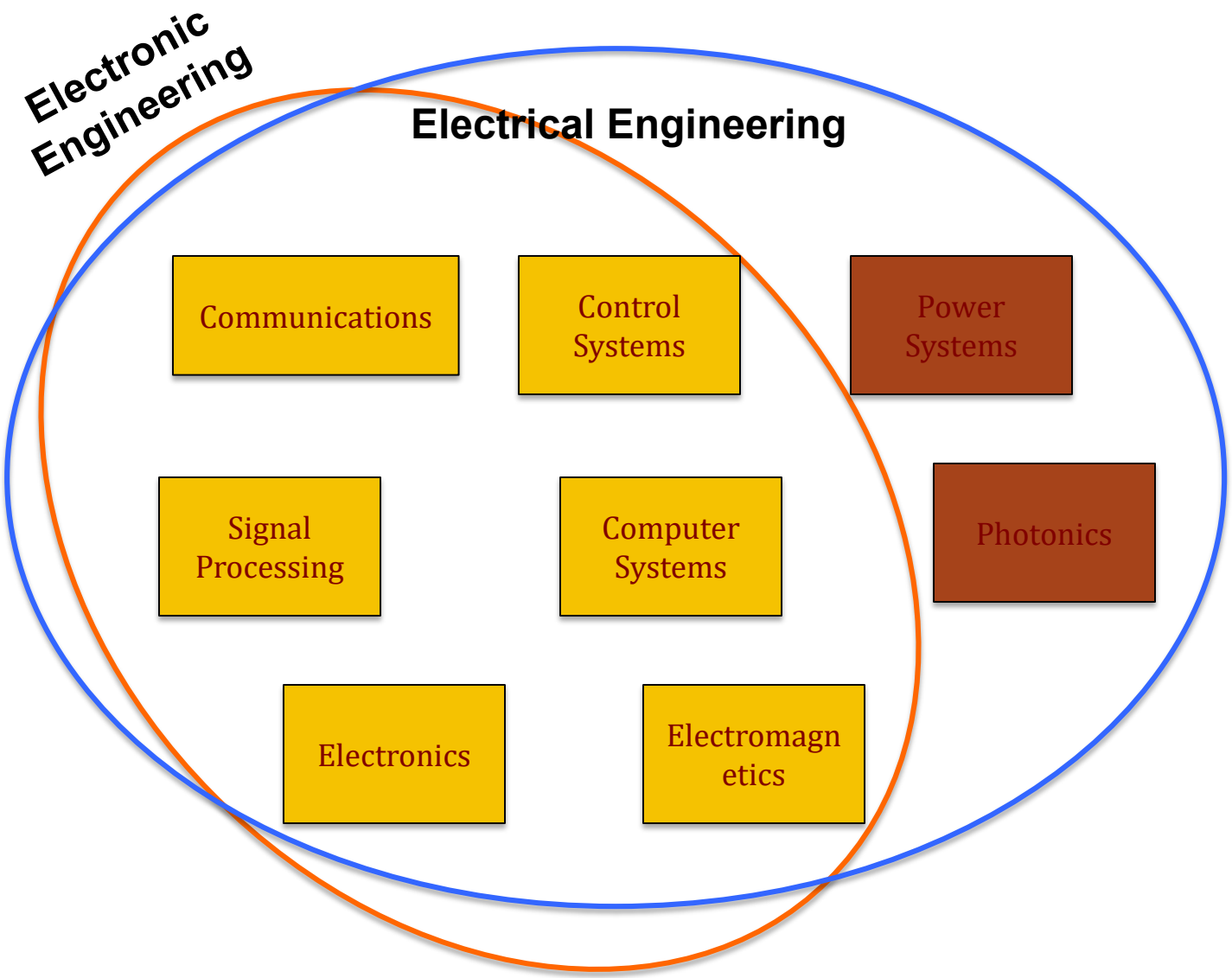
- An *electric circuit* is an interconnection of electrical elements.





- 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 learn how to *build and test* basic electric circuits through <u>labs</u>!


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

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."

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."

– *J.W. Nilsson and S. Riedel, Electric Circuits, 10th edition, Prentice Hall, 2014.*

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

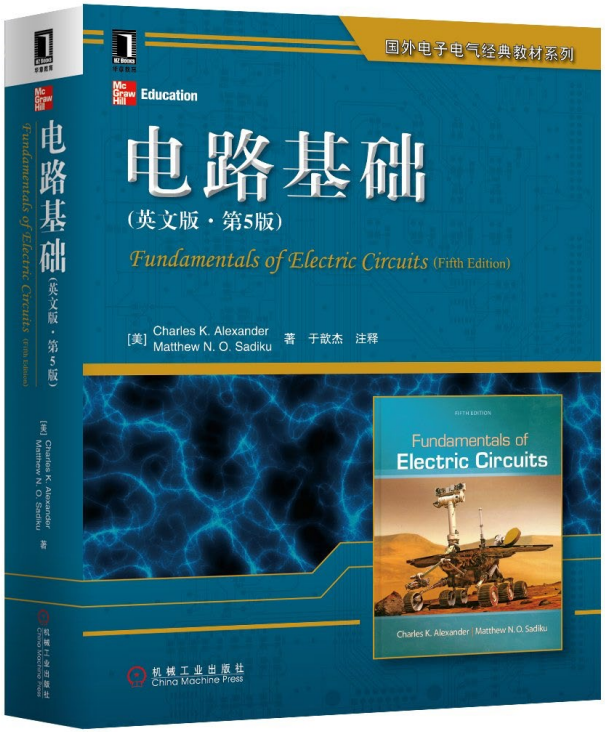
Electric Circuit!

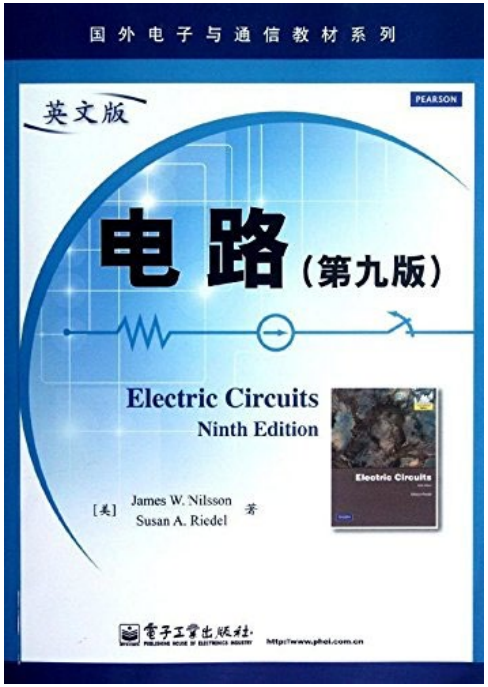
- an actual electrical system, as well as the *model* that represents it.

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

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.





Topics to be Covered in This Course

- Basics: currents, voltages; power/energy; circuit elements
- DC circuits
  - Basic circuit laws (Ohm, Kirchhoff, Wye-Delta etc.)
  - Circuit analysis: nodal analysis and mesh analysis
  - Circuit theorems: Thevenin, Norton, Superposition
  - Operational amplifiers: ideal, inverting/non-inverting, summing and difference)
- Transient circuits
  - Inductance, capacitance and mutual inductance
  - 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; filters
- Laplace transform

Score

- Performance (30%)
  - Home work, attendance/quizzes and discussion etc.
  - Quizzes are held in classes and will not be announced
    There won't be any makeup quizzes
    No late HW reports accepted
- Midterm exam (30%)
- Final exam (40%)
  - NO make-up exams!
  - Write HW and exam paper in English

请务必遵守学术道德规范！

- 单次作业抄袭
  - 抄袭与被抄袭者该次作业均计零分，课程总成绩打九折。
- 累计两次作业抄袭
  - 抄袭与被抄袭者相应作业计零，课程总成绩均打七折。
- 累计三次作业抄袭者，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。

Office Hour

- Monday 07:00-09:00pm or on appointment
- SIST 1D302E
- Contact:
  - yechf@shanghaitech.edu.cn
  - 021-20685366

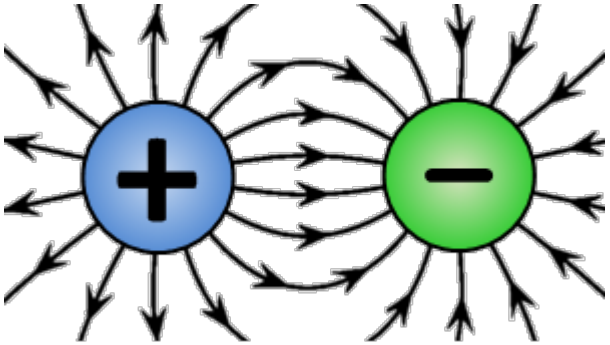
Lecture 1
Circuit Terminology

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)

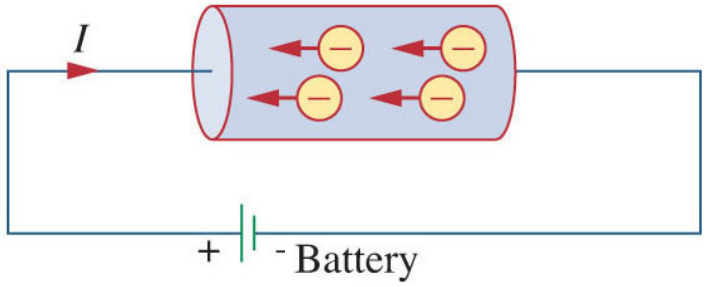


- Microscopically, matter is full of electric charges
  - Electric charge exists in discrete quantities, integral multiples of the electronic charge -1.602*10^{-19} *Coulomb*.
- Electrical effects are due to
  - Separation of charge -> electric force ->electric field
- Charge can neither be created nor destroyed

[Source: Berkeley]

Electric Current

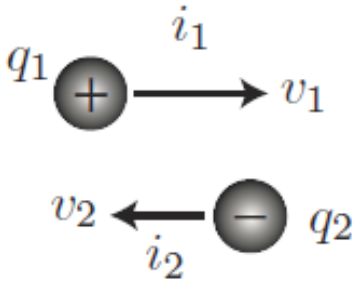
- Charges in motion -> electric flow (current)



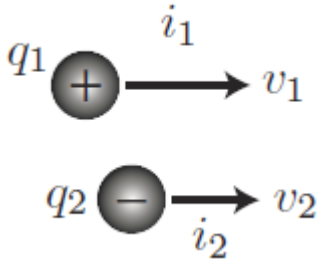
- The current flowing through a surface can be defined as

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

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

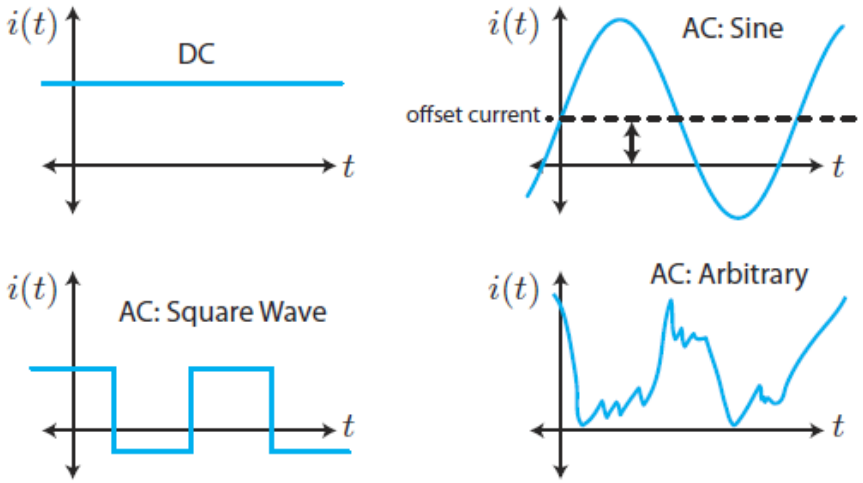


Net current =



Net current =

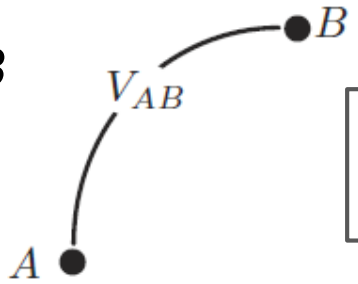
DC versus (vs.) AC



- 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 difference

- The voltage difference V_{AB} between *A* and *B* is the amount of potential energy difference, when moving a unit of (positive) charge from A to B.



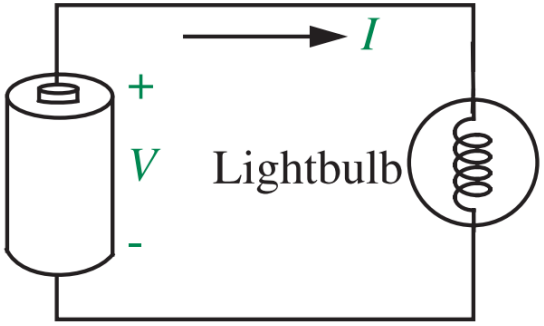
$$V_{AB} = \frac{d\mathrm{E}}{dq}$$

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

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

If the **energy difference** is positive, then energy is lost by the charges as they move “downhill *(in terms of energy level)* ".

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 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.

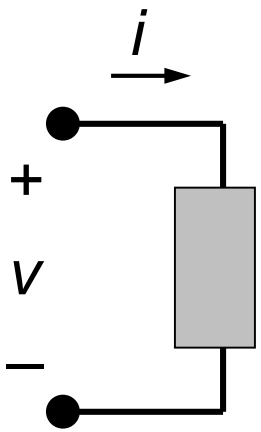
$$p \triangleq \frac{d\mathrm{E}}{dt}$$

Outline

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

Reference directions

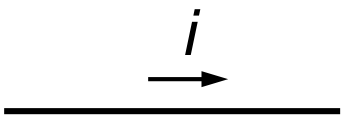
- In order to perform circuit analysis to determine the voltages and currents in an electric circuit, you need to specify reference directions.

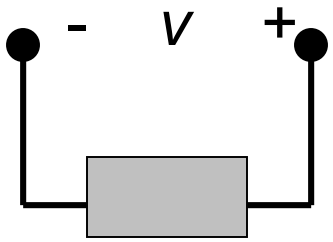


- Polarity reference for voltage can be indicated by plus and minus signs.
- Reference direction for the current is indicated by an arrow.

Sign Convention

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

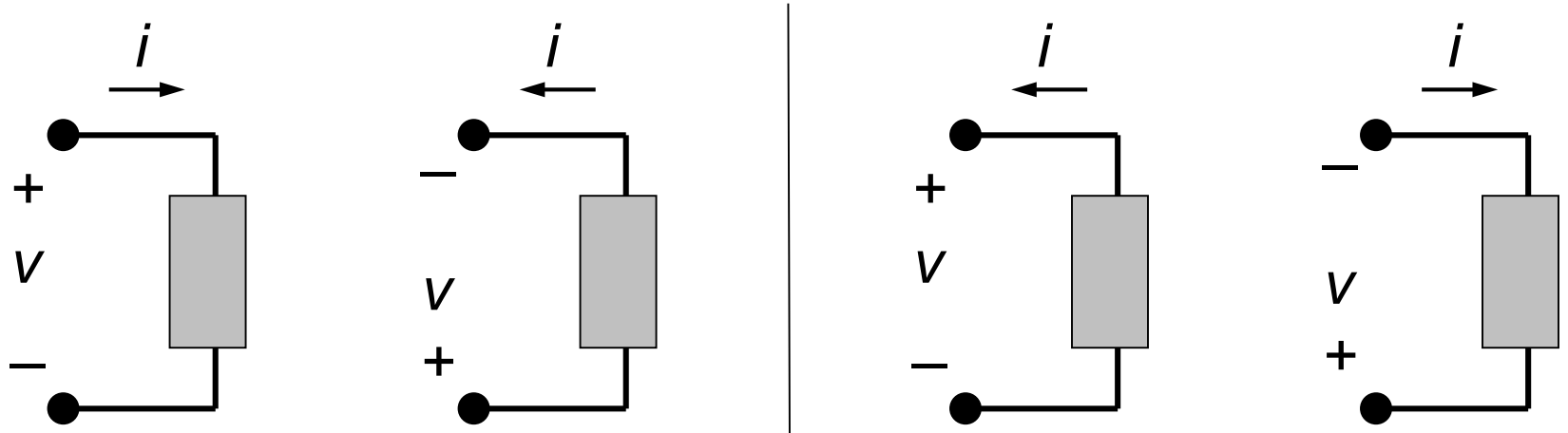




- In this case, if the current turns out to be 1 mA flowing to the left, we would say i = ?.

[Source: Berkeley]

Passive Sign Convention

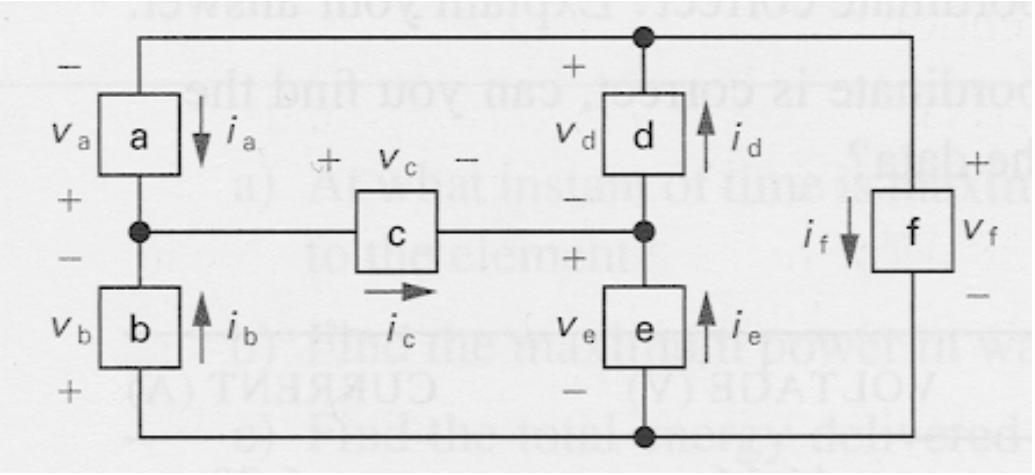


$p = vi$ $p = -vi$

- 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:

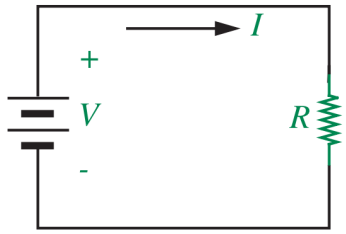


ELEMENT	VOLTAGE (V)	CURRENT (A)
a	−18	−51
b	−18	45
c	2	−6
d	20	−20
e	16	−14
f	36	31

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

[Source: Berkeley]

The Ideal Basic Circuit Element



Attributes:

- Mathematically described in terms of current and/or voltage
- Cannot (not necessary) be subdivided into other elements

Circuit Elements

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

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

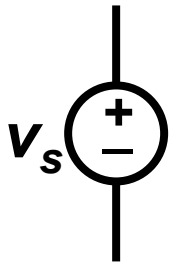
  - resistor
  - inductor
  - capacitor

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

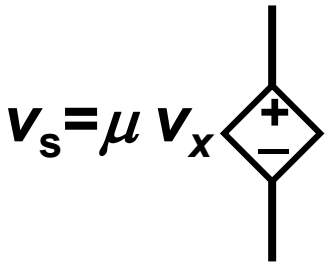
Ideal Voltage Source

- 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.

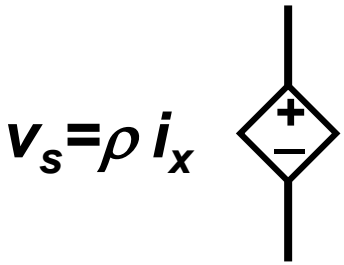
Device symbols:



independent



voltage-controlled

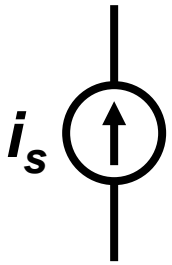


current-controlled

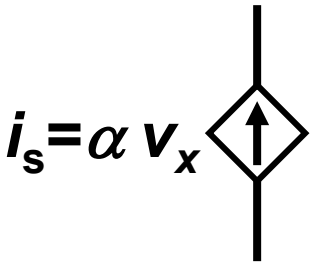
Ideal Current Source

- 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.

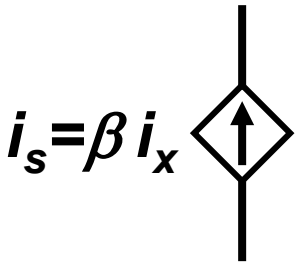
Device symbols:



independent



voltage-controlled



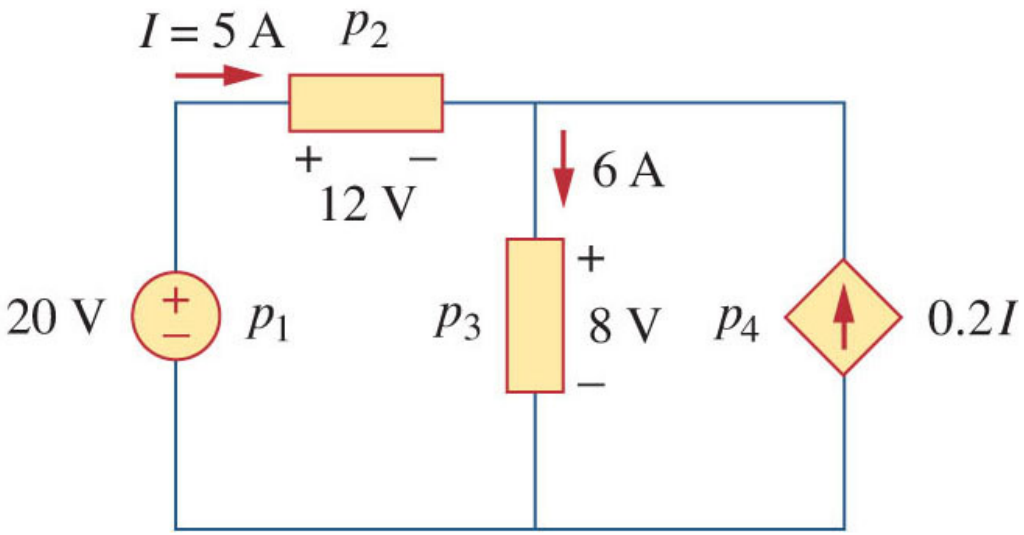
current-controlled

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)

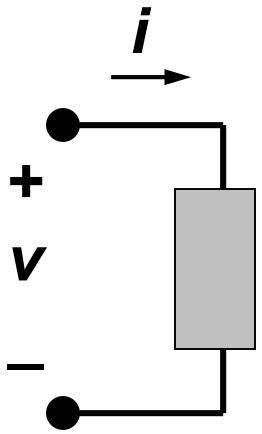
- **Conductance** is the reciprocal of resistance

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

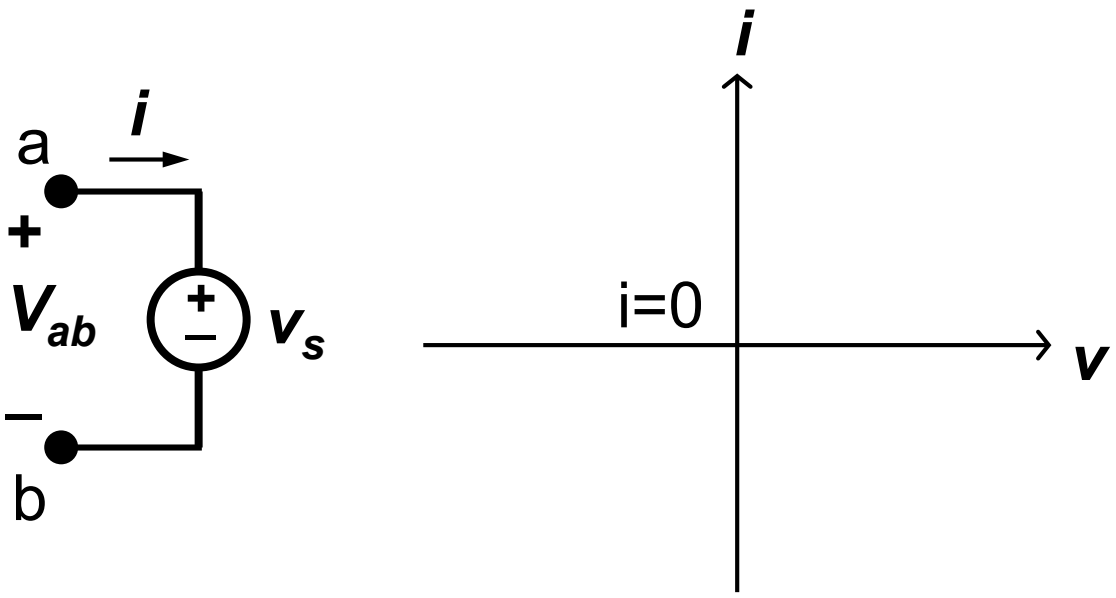
Werner von Siemens
1816-1892

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).



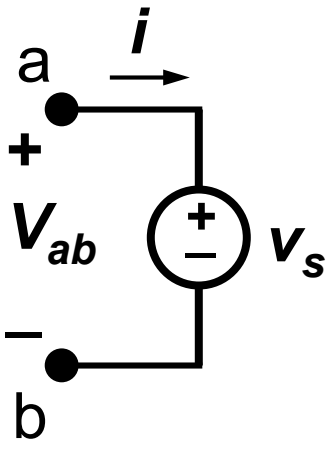
I-V Characteristic of Ideal Voltage Source

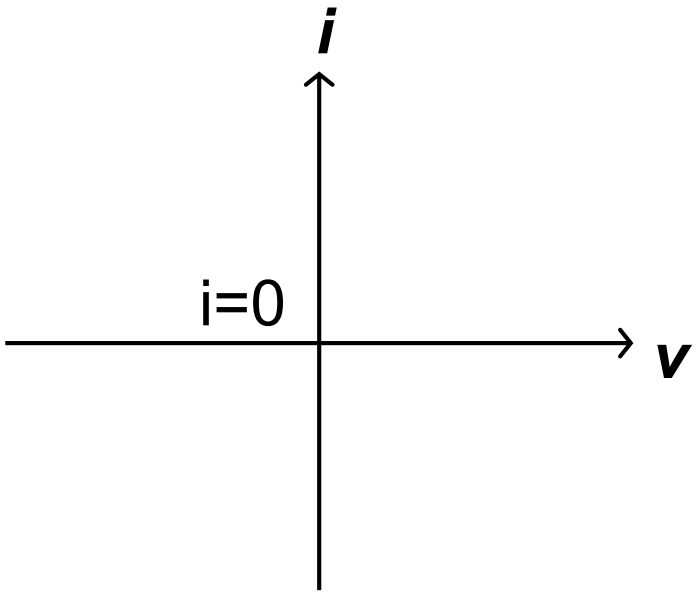


Plot the *I-V* characteristic for $v_s > 0$. For what values of i does the source absorb power? For what values of i does the source release power?

[Source: Berkeley]

I-V Characteristic of Ideal Voltage Source

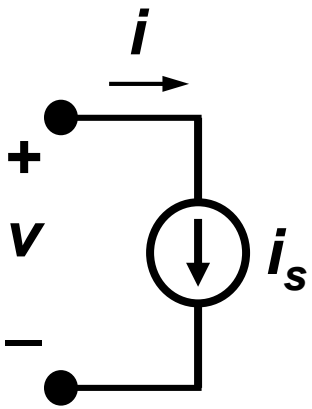


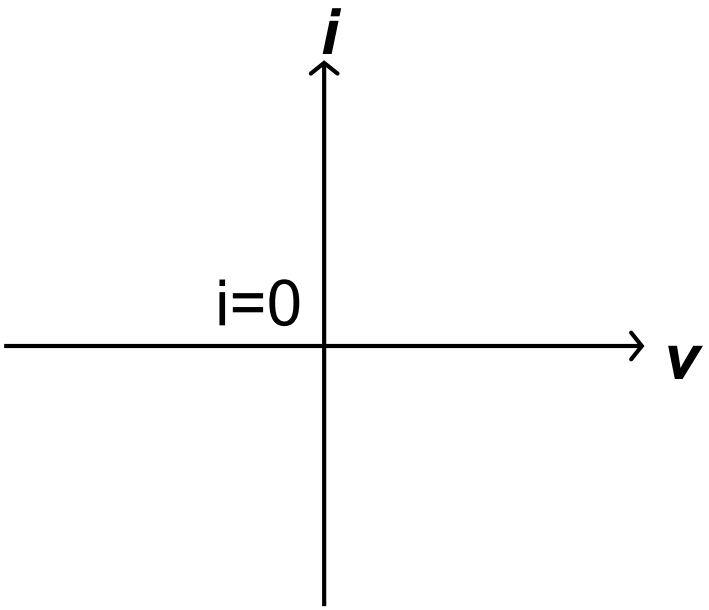


Plot the *I-V* characteristic for $v_s < 0$. For what values of *I* does the source absorb power? For what values of *i* does the source release power?

[Source: Berkeley]

I-V Characteristic of Ideal Current Source

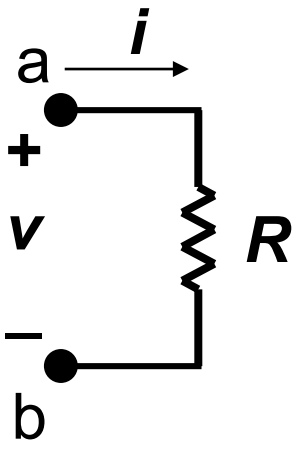


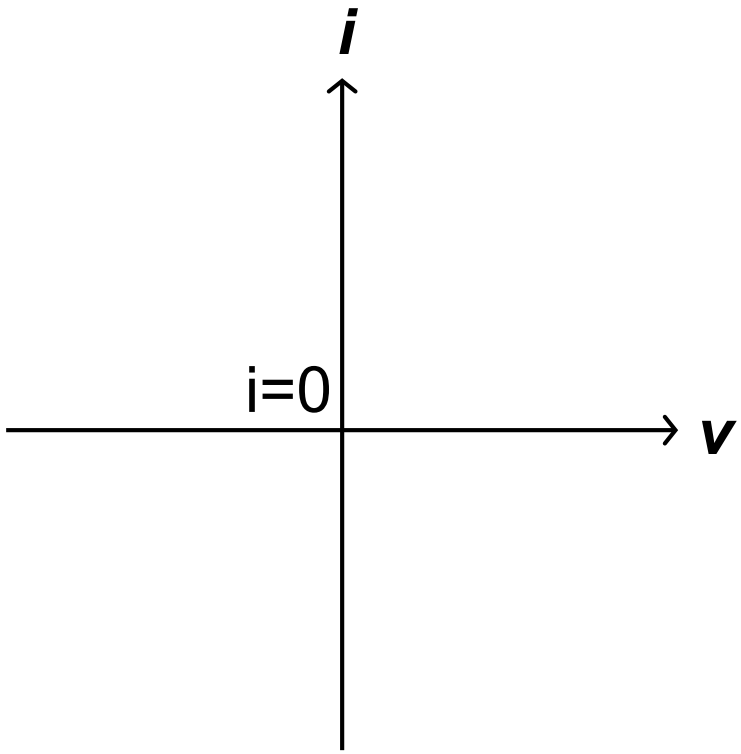


Plot the *I-V* characteristic for $i_s > 0$. For what values of *v* does the source absorb power? For what values of *v* does the source release power?

[Source: Berkeley]

I-V Characteristic of Ideal Resistor





Plot the *I-V* characteristic for *R* = 1 k ohm.

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: $v = iR$ (Ohm's law)