Basic Concepts Overview

- SI Prefixes
- Definitions: Current, Voltage, Power, & Energy
- Passive sign convention
- Circuit elements
- Ideal Sources

SI Prefixes

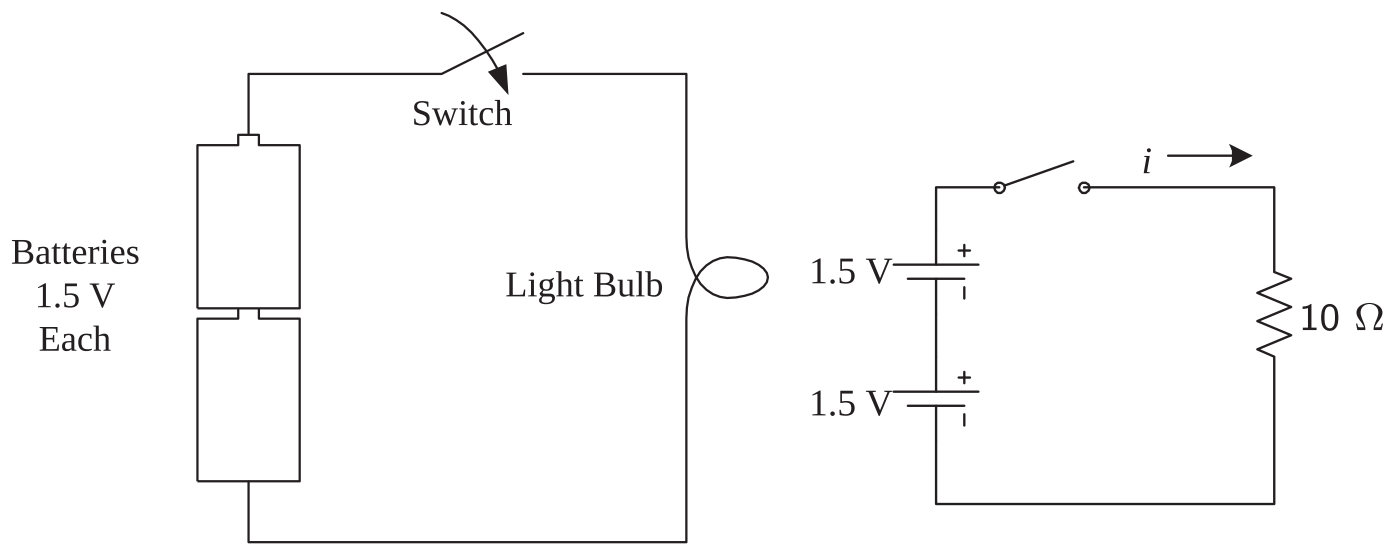
These are used throughout the curriculum and by engineers

Multiplier	**Prefix**	**Symbol**	**Example**
10^{12}	tera	T	TB
10^{9}	giga	G	GB
10^{6}	mega	M	MHz
10^{3}	kilo	k	kΩ
10^{0}			V
10^{-3}	milli	m	mH
10^{-6}	micro	μ	μA
10^{-9}	nano	n	ns
10^{-12}	pico	p	pF
10^{-15}	femto	f	
10^{-18}	atto	a	

Circuit Analysis: Introduction

- An **electric circuit** is an interconnection of electrical elements
- **Charge** is an electrical property of the atomic particles which matter consists, measured in coulombs (C)
- 1 C of charge requires 6.24×10^{18} electrons
- **Law of conservation of charge**: charge cannot be created or destroyed, only transferred.

Flashlight Circuit



- A flashlight circuit has 4 circuit elements
- We will use symbols for circuit elements
- Facilitates analysis

Electric Current

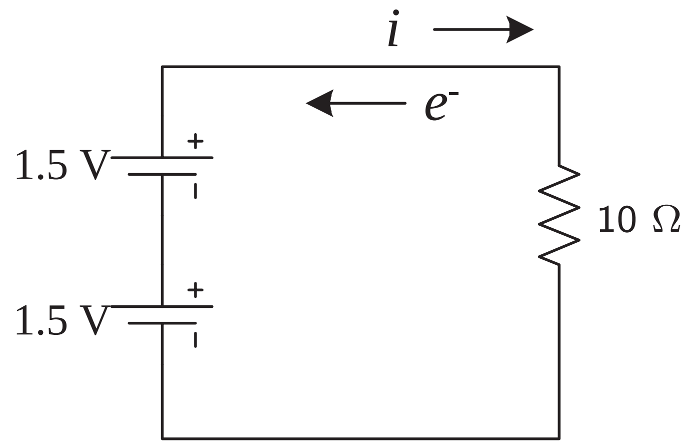
- **Electric Current** is the rate of change of charge, measured in amperes (A)
- 1 A = 1 C/s
- Two main types
  - **Direct Current (DC)**: Current remains constant
  - **Alternating Current (AC)**: Current varies sinusoidally with time

$$i = \frac{\mathrm{d}q}{\mathrm{d}t}$$

where

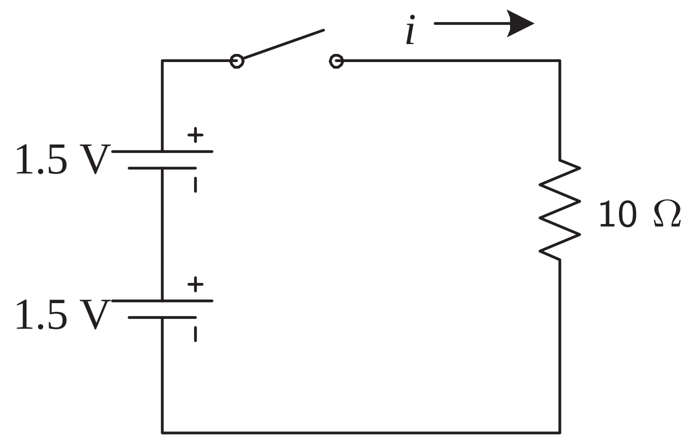
$$\begin{aligned} i &= \quad \text{current in amperes} \\ q &= \quad \text{charge in coulombs} \\ t &= \quad \text{time in seconds} \end{aligned}$$

Notes on Current



- Current in circuits physically realized by movement of electrons
- Direction of current must be specified by an **arrow**
- By convention, current direction defined as flow of **positive** charge
- Note positive charge is not flowing physically
- Electrons have a negative charge
- They move in the opposite direction of current

Propagation Rate



- Average drift velocity is very small (mm/sec)
- Propagation is very fast (close to speed of light)
- Effects appear to be instantaneous
- Similar to a hose full of water

Key Assumptions

For the duration of this class, we will make the following assumptions.

- Propagation is instantaneous (lumped-parameter system)
- Net charge stored by all circuit elements is 0 (zero)
  - Nothing can store electrons
- No magnetic coupling between wires or circuit elements

Voltage

- Voltage is the energy absorbed or expended as a unit charge moves through a circuit element
- Analogous to pressure in a hydraulic system
- Sometimes called potential difference
- Can be created by a separation of charge
- Is a measure of the potential between **two points**
- Voltage pushes charge in one direction
- We use polarity ($+$ and $-$ on batteries) to indicate which direction the charge is being pushed

$$v = \frac{\mathrm{d}w}{\mathrm{d}q}$$

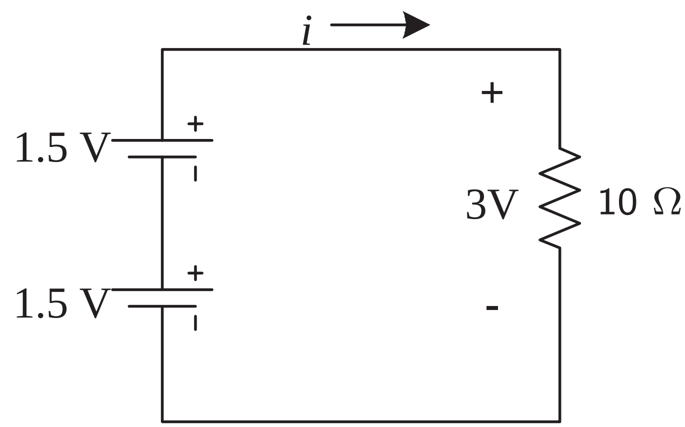
where

$v =$ voltage in volts

$w =$ energy in Joules

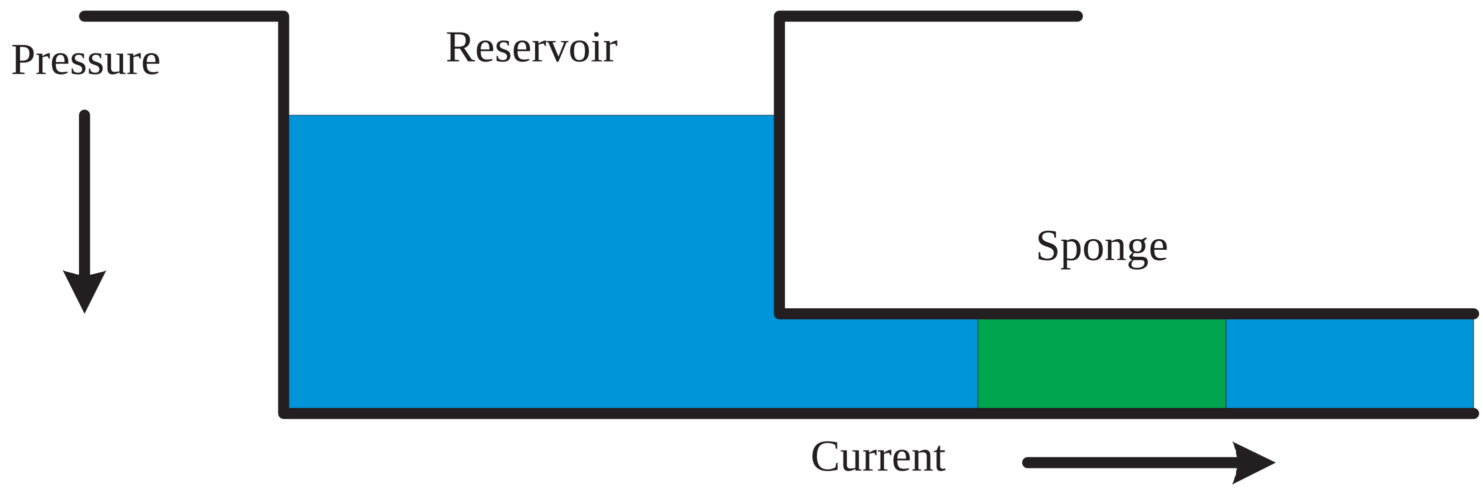
$q =$ charge in coulombs

Voltage Concept



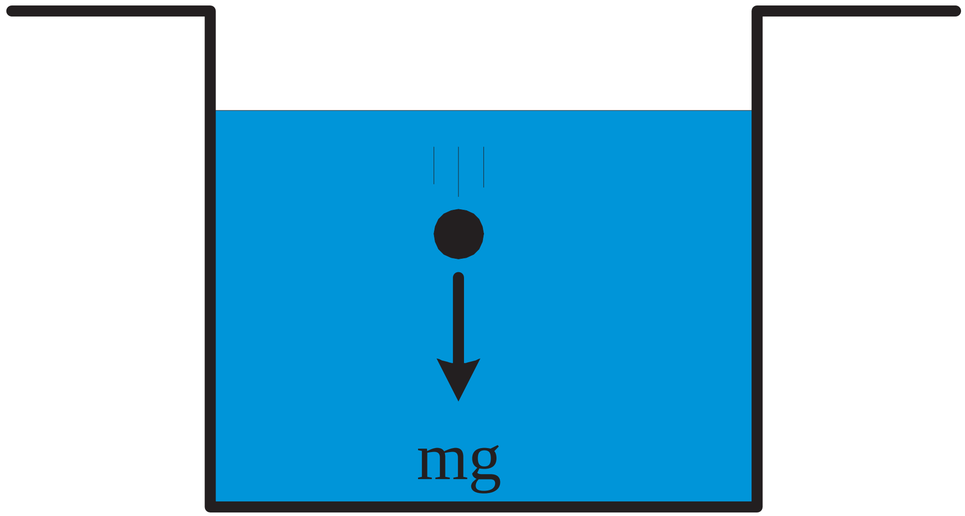
- The voltage sources push current through the circuit
- The current is the rate of flow of charge (i.e. electrons)
- The light bulb (resistor) resists the flow of current

Example 1: Voltage Concept



- Voltage $\sim$ Pressure
- Electric Current $\sim$ Water Current
- Sponge Porosity $\sim$ Resistance

Example 2: Voltage Concept



- Voltage $\sim$ Force due to gravity (mg)
- Electric Current $\sim$ Marble velocity
- Viscosity $\sim$ Resistance

Power

- Power: time rate of expending or absorbing energy
- Denoted by p
- By convention
  - Circuit elements that **absorb** power have a **positive** value of p
  - Circuit elements that **produce** power have a **negative** value of p

$$p = \frac{\mathrm{d}w}{\mathrm{d}t} \qquad\qquad p = \pm vi$$

where

$$\begin{aligned}
p &= \quad \text{power in watts (W = J/s)} \\
w &= \quad \text{energy in joules (J)} \\
t &= \quad \text{time in seconds (s)} \\
v &= \quad \text{voltage in volts (V)} \\
i &= \quad \text{current in amperes (A)}
\end{aligned}$$

Energy

- **Law of Conservation of Energy**: the net power absorbed by a circuit is equal to 0
- In other words
  - The total energy produced in a circuit is equal to the total energy absorbed
  - Every Watt absorbed by an element must be produced by some other element(s)
- **Energy**: capacity to do work, measured in joules (J)

$$w = \int_{t_0}^{t} p(t)\,\mathrm{d}t = \int_{t_0}^{t} \pm v(t)i(t)\,\mathrm{d}t$$

If current and voltage are constant (DC),

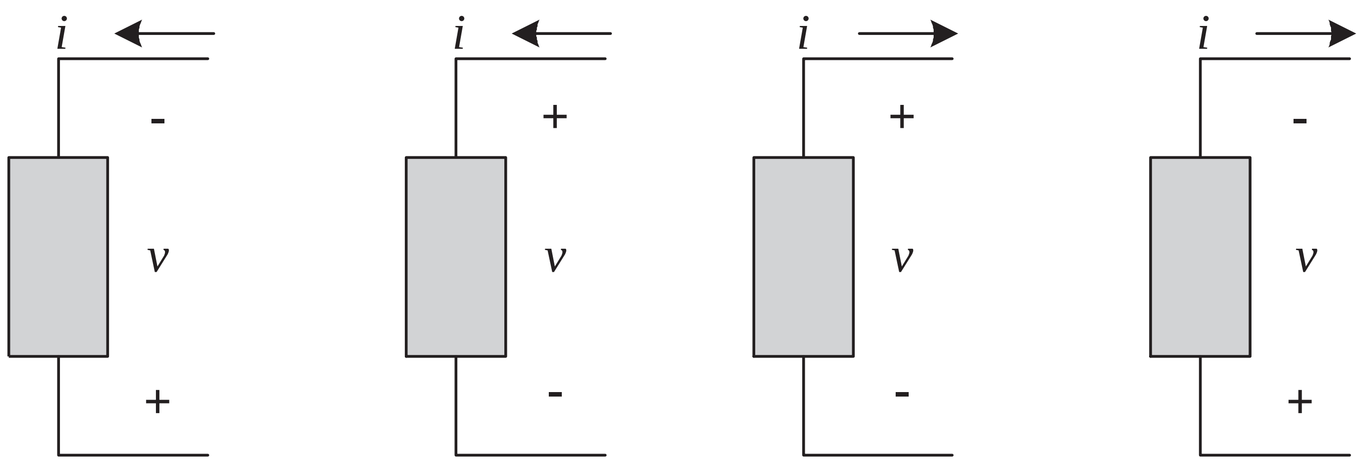
$$w = \int_{t_0}^{t} p\,\mathrm{d}t = p(t - t_0)$$

Passive Sign Convention

- **Passive Sign Convention (PSC):** Current enters the positive terminal of an element
  - Equivalent: Current leaves the negative terminal
- Most two-terminal circuit elements (e.g. batteries, light bulbs, resistors, switches) are characterized by a single equation that relates voltage to current: $v = \pm f(i)$ or $i = \pm g(v)$
- Called the **defining equation**
- The PSC determines the sign of the relationship
  - If PSC is satisfied: $v = f(i)$ or $i = g(v)$
  - If PSC is not satisfied: $v = -f(i)$ or $i = -g(v)$
- This is also true of power
  - If PSC is satisfied: $p = +vi$
  - If PSC is not satisfied: $p = -vi$

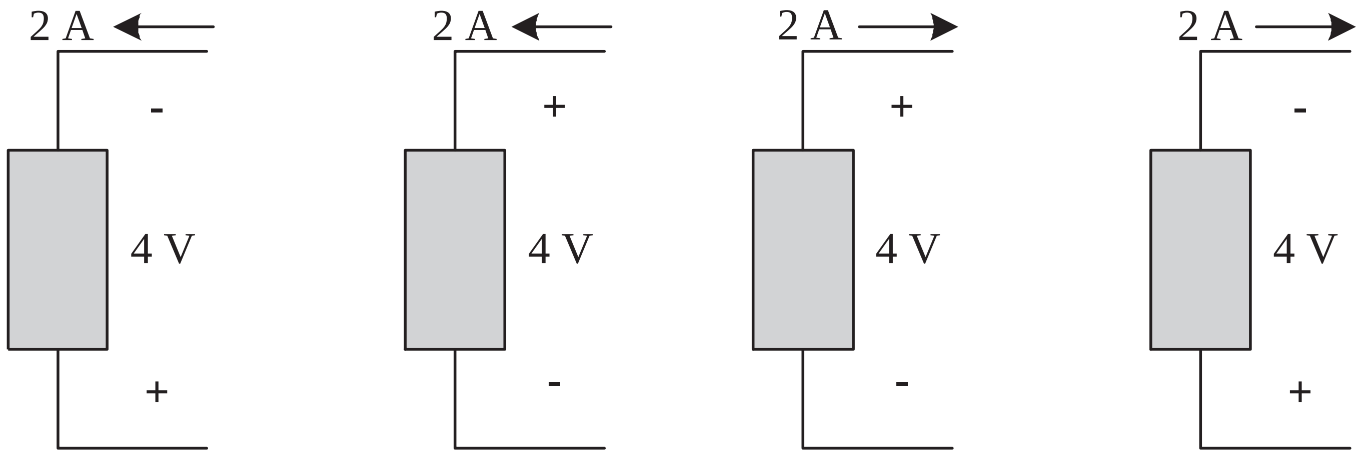
Example 3: Passive Sign Convention

Suppose the circuit element shown below is characterized by $v = \pm f(i)$ and $i = \pm g(v)$. Determine whether the PSC is satisfied and write the equations for the voltage, current, and power for each of the diagrams below.



Example 4: Passive Sign Convention

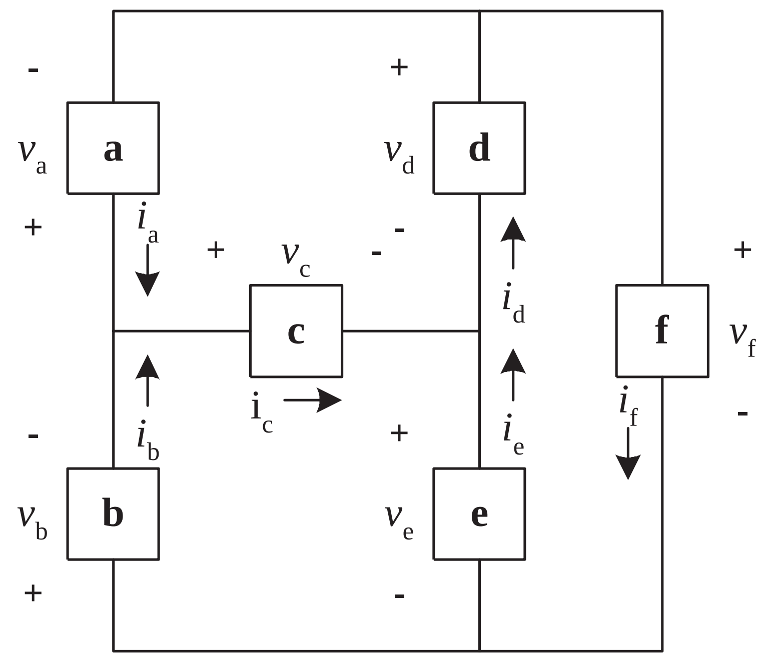
Find the power (absorbed) for each element.



Example 5: Passive Sign Convention

Find the total power absorbed in the circuit.

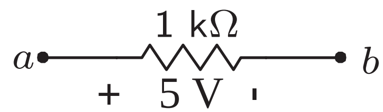
	Voltage (V)	Current (A)	Power (W)
a	-18	-51	
b	-18	45	
c	2	-6	
d	20	-20	
e	16	-14	
f	36	31	



Passive Sign Convention Remarks

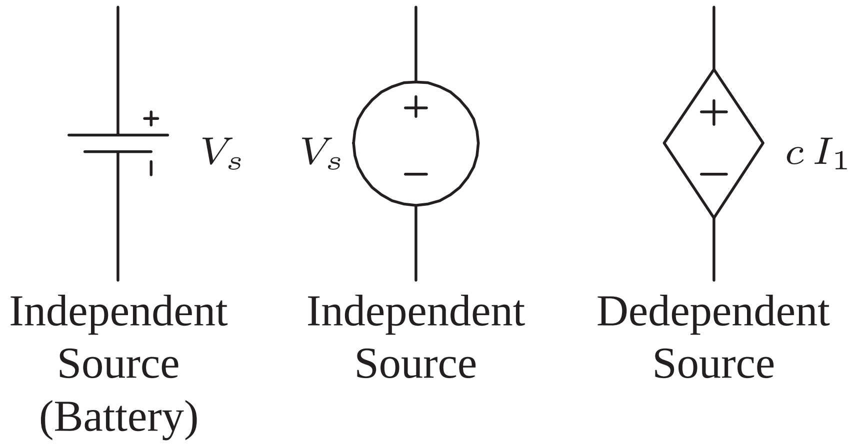
- Failure to comply with the PSC will result in a wrong equation in the early stages of circuit analysis
- All of the results that follow will be wrong
- This translates to many lost points on exams
- One of the key ideas is that the defining equations depend on the voltage polarity and current direction
- Example: $p = \pm vi$
- You must examine how the polarity of v and the direction of i is labeled on the circuit diagram to determine the sign

Voltage Drops & Rises Defined

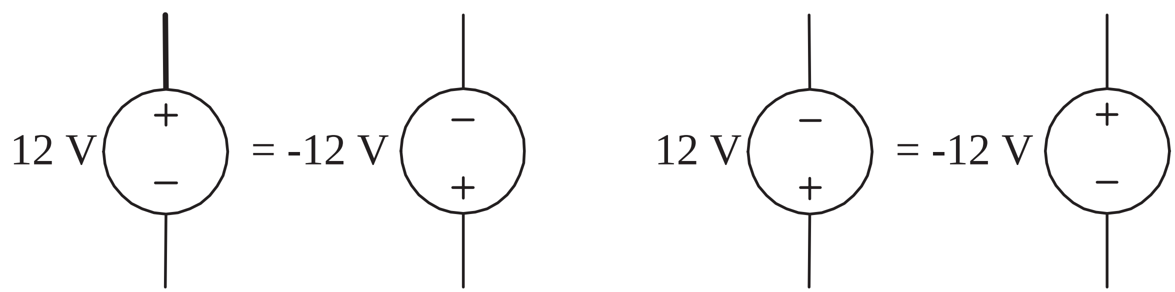


- The following statements are true and equivalent
  - There is a 5 V **drop** from a to b
  - There is a 5 V **rise** from b to a
  - There is a -5 V **rise** from a to b
  - There is a -5 V **drop** from b to a
- The first expression is the most common
- In most cases, we will be concerned with voltage drops

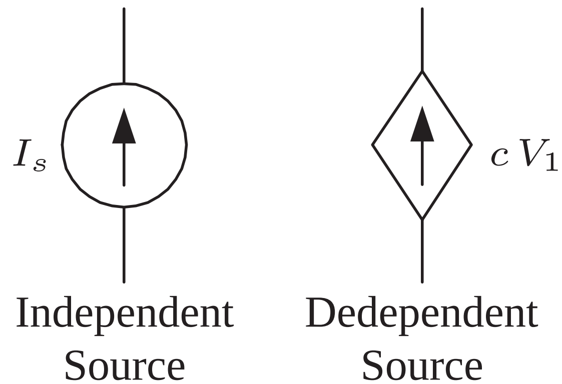
Ideal Voltage Sources



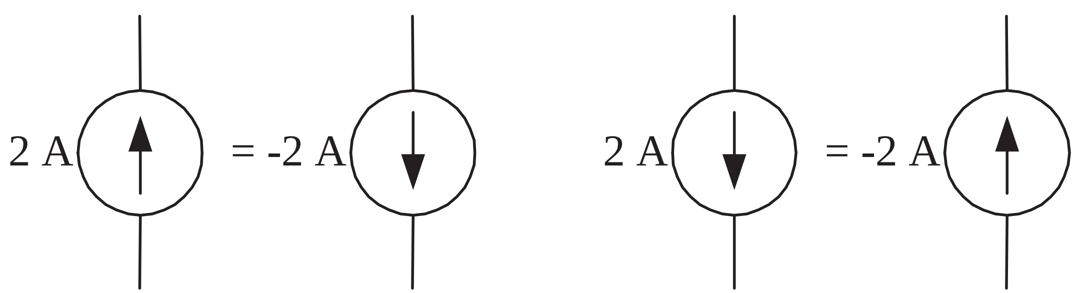
- **Ideal Voltage Source**: produces V_s volts regardless of the current absorbed or produced by the device
- The voltage produced may depend on some other circuit variable (current or voltage)
- The sign of V_s can be negative



Ideal Current Sources



- **Ideal Current Source**: produces I_s amps regardless of the current in the device
- The current produced may depend on some other circuit variable (current or voltage)
- Note the sign of I_s can be negative



Notes on Ideal Sources

- Ideal sources are models used to simplify analysis
- These devices do not exist physically
  - How much power can an ideal source produce?
  - How much power can a battery produce?
- Ideal models serve as a good approximation of physical devices, but only over a limited operating range
- We will use and discuss more accurate models later in the term