Electric Circuits
Chapter 1-2

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	

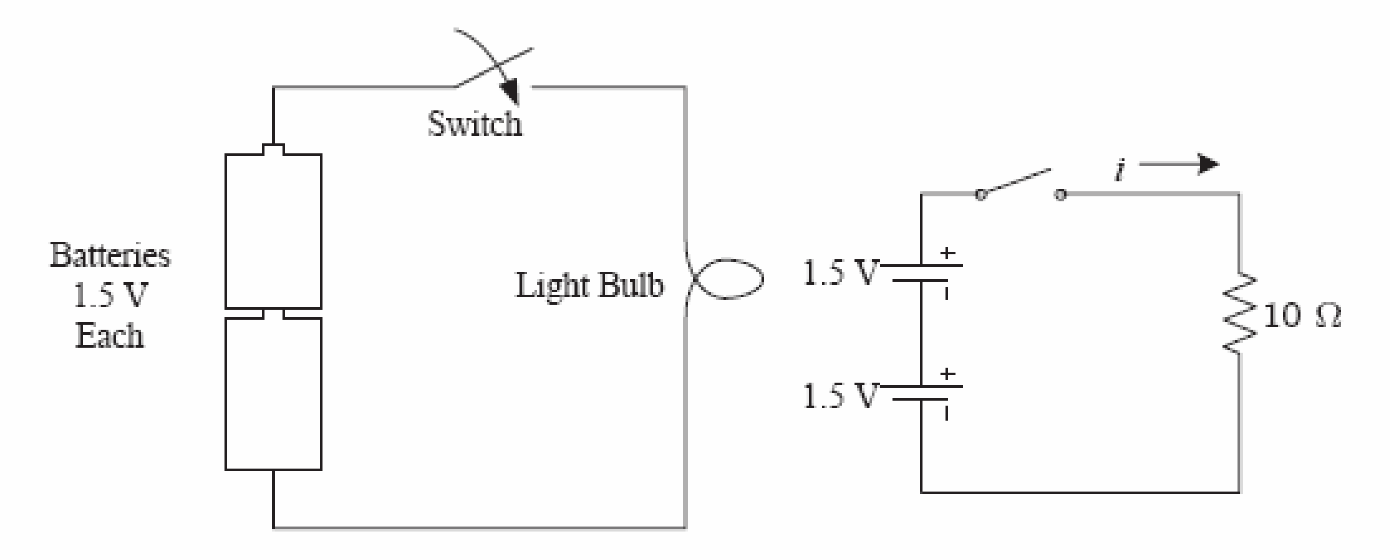
Circuit Analysis: Introduction

- 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

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

where

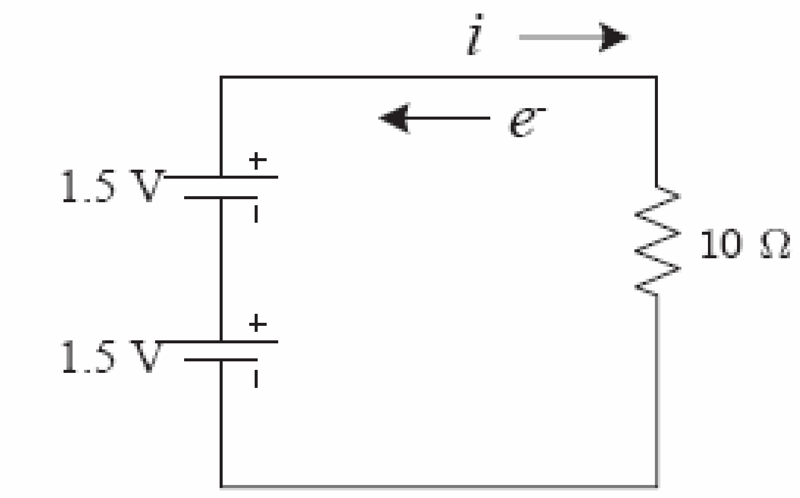
i = current in amperes

q = charge in coulombs

t = time in seconds

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



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

$v = dw/dq$

where

v = voltage in volts

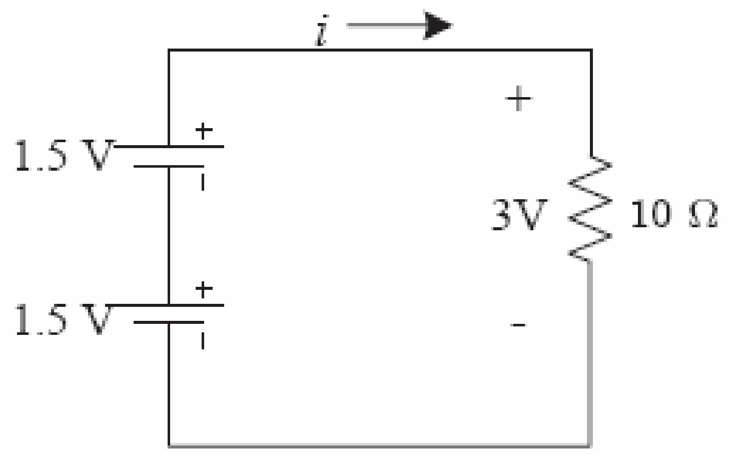
w = energy in Joules

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



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

$p = dw/dt$

$p = \pm vi$

where

p = power in watts (W = J/s)

w = energy in joules (J)

t = time in seconds (s)

v = voltage in volts (V)

i = current in amperes (A)

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 someother element(s)

- **Energy**: capacity to do work, measured in joules (J)

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

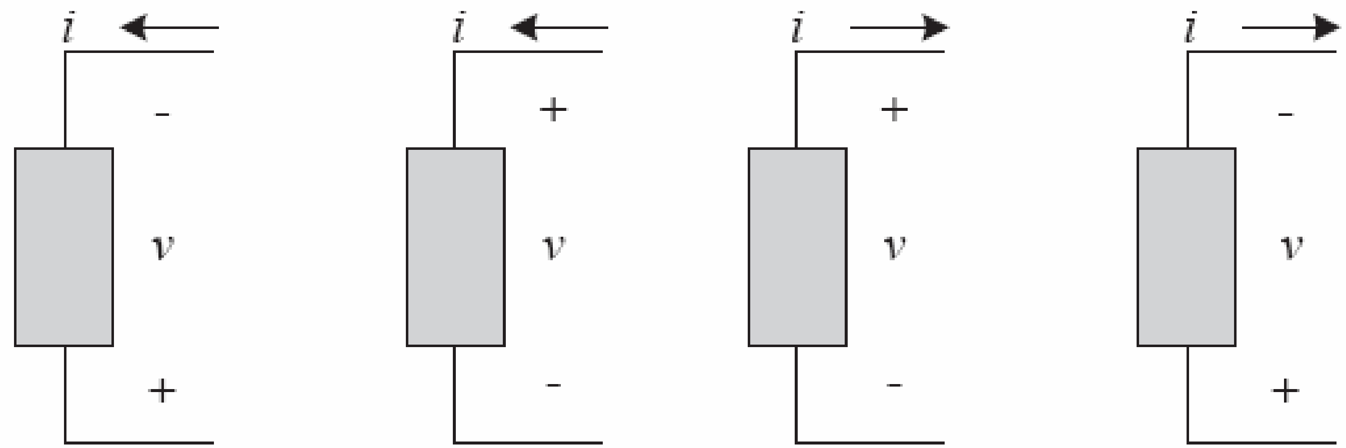
If current and voltage are constant (DC),

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

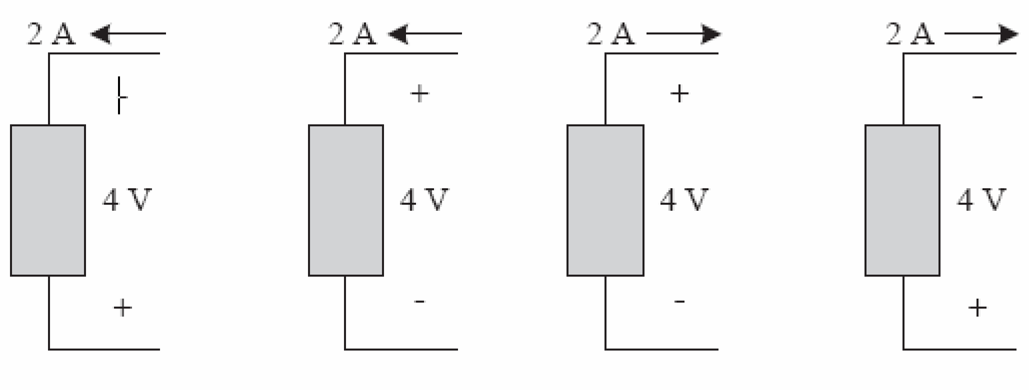
Passive Sign Convention

- **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 $i = \pm g(v)$

- 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.



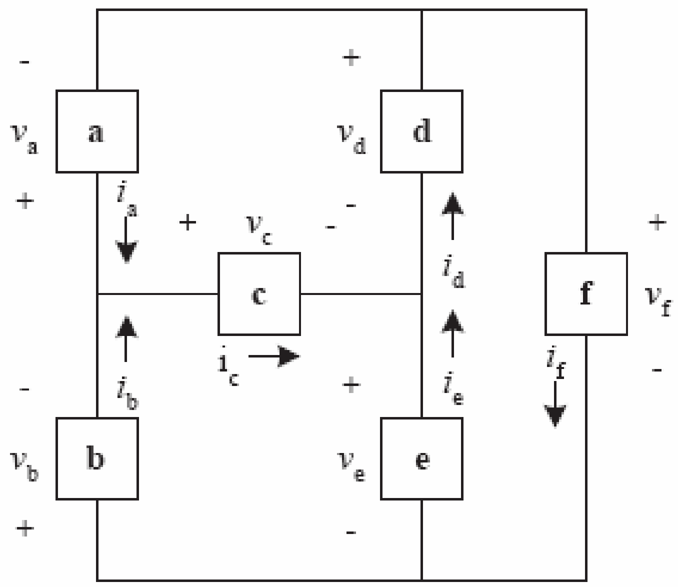
- Find the power (absorbed) for each element.



- **Example : 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

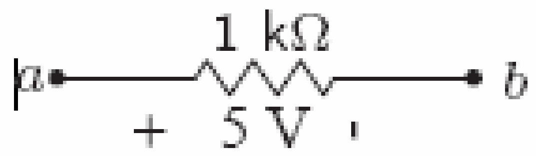
• This translates to many lost points on exams

• 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

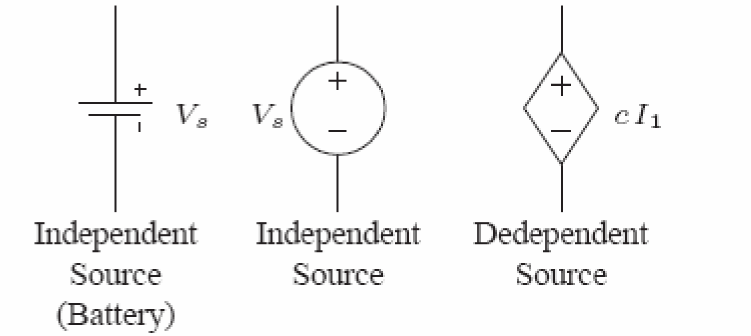


- The following statements are true and equivalent
  - There is a 5 V **drop** from *a* to *b*
  - There is a 5 V **rise** from *b* to *a*
  - There is a −5 V **rise** from *a* to *b*
  - There is a −5 V **drop** from *b* to *a*
- The first expression is the most common
- In most cases, we will be concerned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

Chapter 2- Circuit Elements

- We begin the study of circuit with five ideal circuit elements:
- voltage sources
- Current sources
- Resistors
- İnductors and
- capacitors

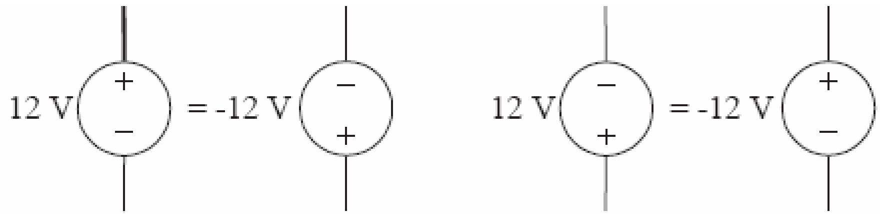
- A source is a device which is capable of converting nonelectric energy to electric energy and vice versa. (e.g ,batteries, dynamos, motors, etc.
- Maintains either voltage or current.
- Led to the creation of ideal voltage source and ideal current source as basic circuit elements.
  - ideal voltage sources and ideal current sources can be divided into two categories: independent and dependant sources.
  - An indepent source is indepent of any other voltage or current.
  - A dependent source depend on a voltage or current somewhere else in the circuit.



• **Ideal Voltage Source**: produces *Vs* volts regardless of the current absorbed or produced by the device(i.e,independent source)

• The voltage produced may depend on some other circuit variable (current or voltage) (i.e,dependent source)

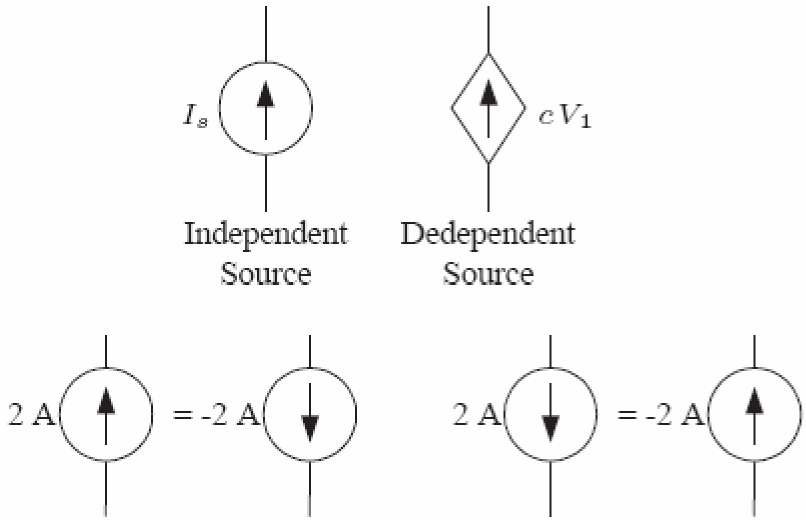
• The sign of *Vs* can be negative



Ideal Current Source: produces *Is* amps regardless of the current in the device (i.e independent source)

• The current produced may depend on some other circuit variable (current or voltage) (i.e dependent source)

• Note the sign of *Is* can be negative

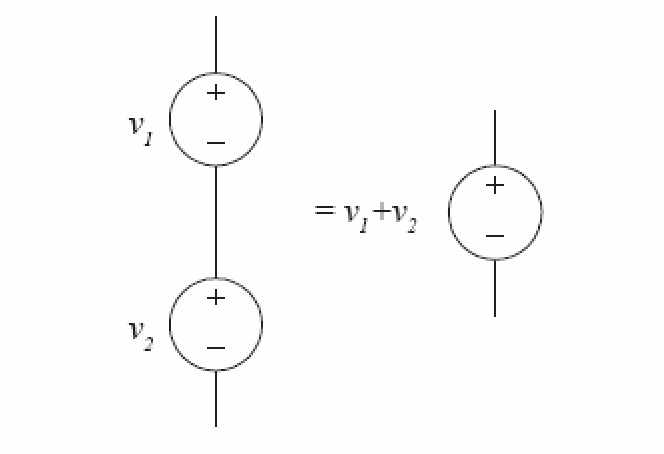


Notes on Ideal Sources

- 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

Ideal Voltage Sources: Series

- Ideal voltage sources connected in series add



Ideal Voltage Sources: Parallel

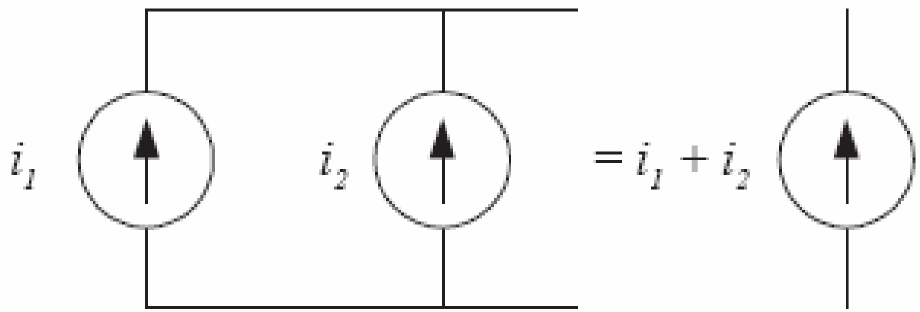
- Ideal voltage sources *cannot* be connected in parallel
- Recall: ideal voltage sources guarantee the voltage between two terminals is at the specified potential (voltage)
- In practice, the stronger source would win
- Could easily cause component failure (smoke)
- Ideal sources do not exist
- Technically allowed if $V1 = V2$, but is a bad idea

Ideal Current Sources: Series

- Ideal current sources *cannot* be connected in series
- Recall: ideal current sources guarantee the current flowing through source at specified value
- Recall: the current entering a circuit element must equal the current leaving a circuit element, $I_{in} = I_{out}$
- Could easily cause component failure (smoke)
- Ideal sources do not exist
- Technically allowed if $I1 = I2$, but is a bad idea

Ideal Current Sources: Parallel

- Ideal current sources in parallel add



Ohm’s Law

- Many useful electrical devices are designed to convert electric energy to thermal energy.(e.g. Stoves, toasters, irons, etc.)
  - Take advantage of the thermal energy caused by flowing charge carriers through metal.
  - The behavior of metal is the resistance to the flow of electric charge.
  - Model it with the resistor.

Resistance: Defined

- All materials resist the flow of current.
- Resistance is usually represented by the variable *R*
- Depends on geometry and resistivity of the material
- $R = \rho.(l/A)$

where

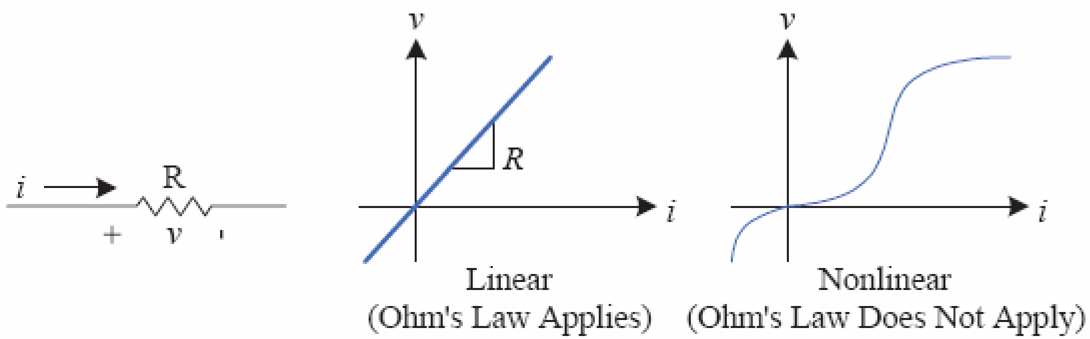
R = resistance of an element in ohms (Ω)

ρ = resistivity of the material in ohm-meters

l = length of cylindrical material in meters

A = Cross sectional area of material in meters^2

Ohm’s Law

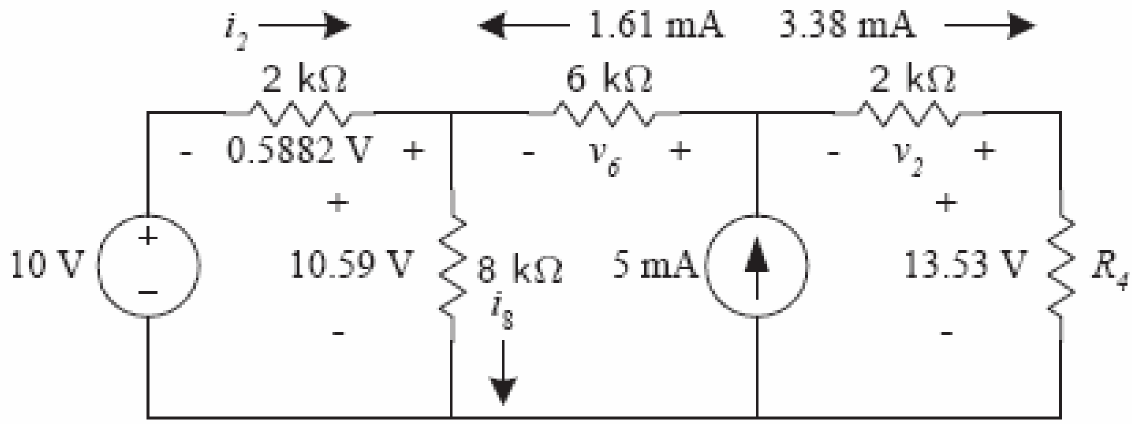


As with all circuit elements, we need to know how the current through and voltage across the device are related

- **Ohm’s Law**: $v = iR$

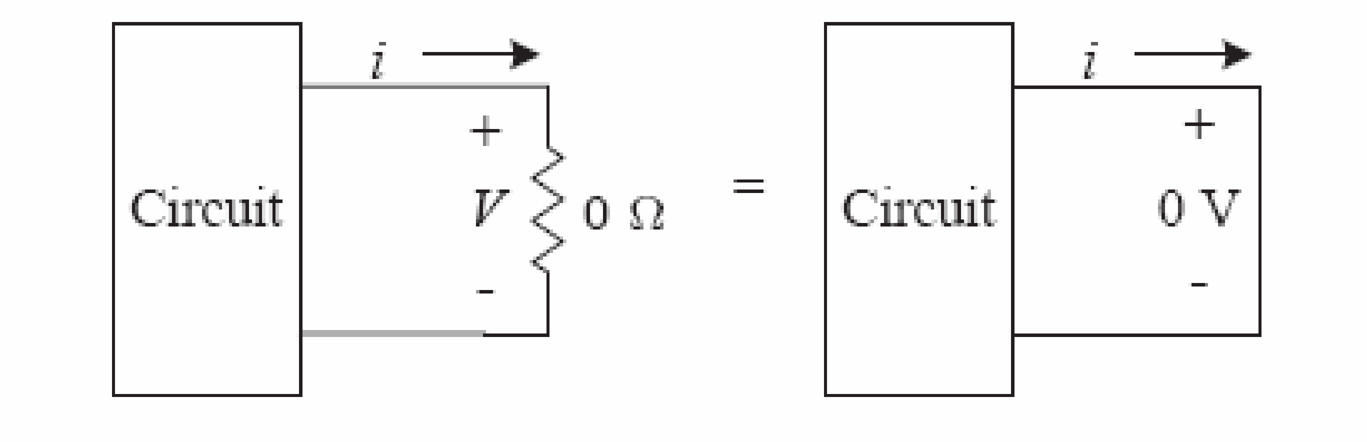
- Recall $p = \pm vi$. Therefore
- $p = v$ ^2/R
- $p = (iR)i = i$^2.R
- Resistors cannot produce power
- Therefore, the power absorbed by a resistor will always be positive.

- Example



$$
\begin{aligned}
i_2 &= \\
v_6 &= \\
R_4 &= \\
v_2 &= \\
i_8 &=
\end{aligned}
$$

- An element (or wire) with R = 0 is called a **short circuit**
- Often just drawn as a wire (line).



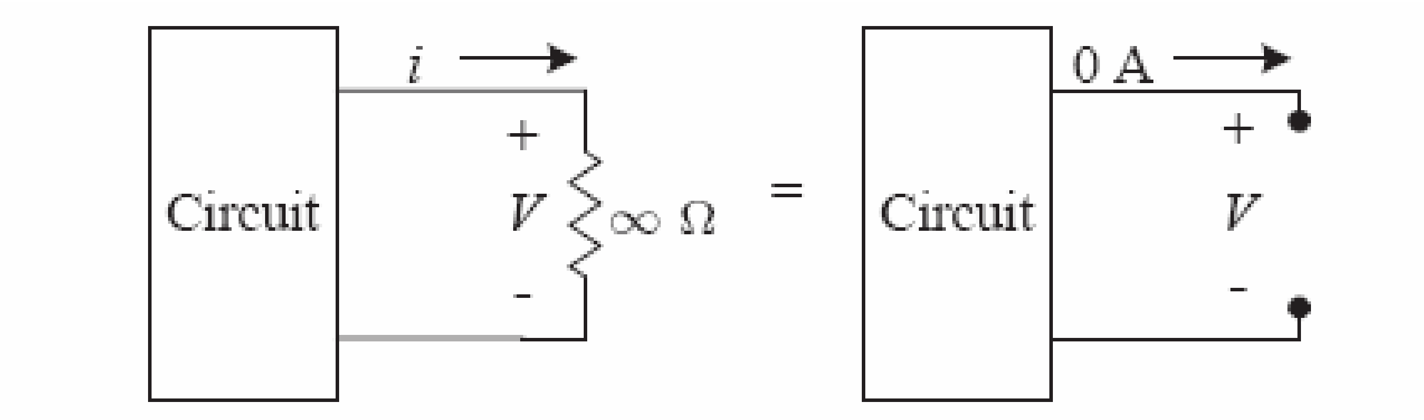
- An ideal voltage source V_s = 0 V is also equivalent to a short circuit

Since $v = iR$ and $R = 0$, $v = 0$ regardless of i

- Could draw a source with V_s = 0 V, but is not done in practice

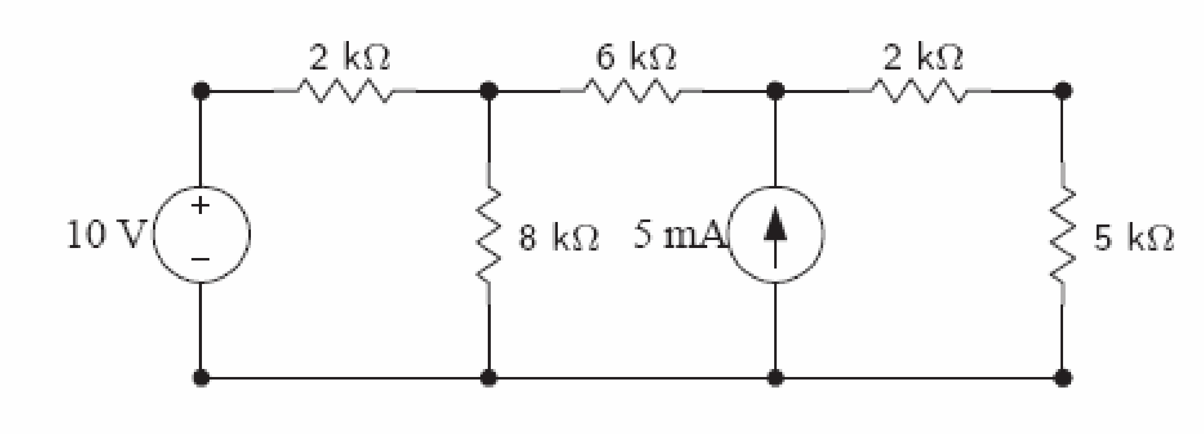
Open Circuit

- An element with $R = \infty$ is called a **open circuit**
- Often just omitted
- Could draw a resistor with $R = \infty$, but is unnecessary
- An ideal current source $I = 0$ A is also equivalent to an open circuit

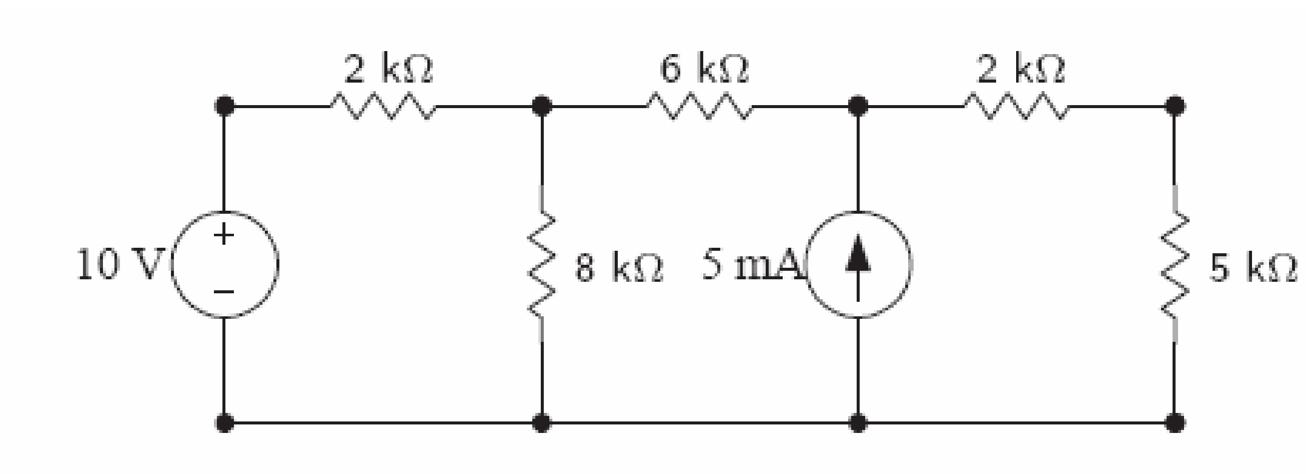


- **Circuit Building Blocks**
- Before we can begin analysis, we need a common language and framework for describing circuits
- **Circuits** are composed of nodes, branches, and loops

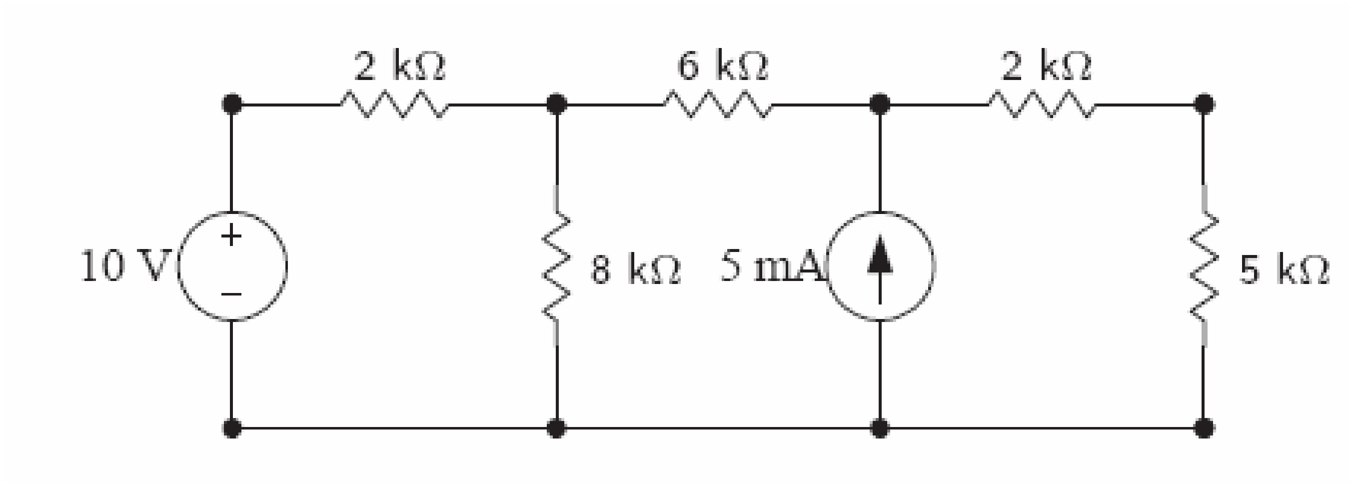
- **Branch**: a single two-terminal element in a circuit
- Segments of wire are not counted as elements (or branches)
- Examples: voltage source, resistor, current source
- Example: How many branches?



- **Node**: the point of connection between two or more branches
- **Essential Node**: the point of connection between three or more Branches
- Example: How many nodes? How many essential nodes?



- **Loop**: any closed path in a circuit
  Example: How many loops?



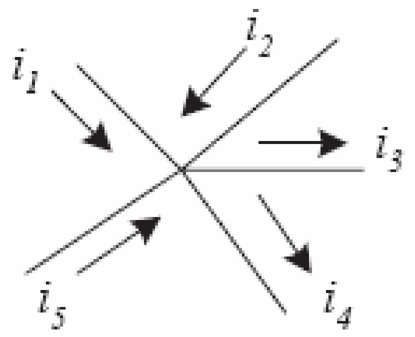
Overview of Kirchhoff’s Laws

- The foundation of circuit analysis is
  - The defining equations for circuit elements (e.g. Ohm’s law)
  - Kirchhoff’s current law (KCL)
  - Kirchhoff’s voltage law (KVL)
- The defining equations tell us how the voltage and current within a circuit element are related
- Kirchhoff’s laws tell us how the voltages and currents in different branches are related

Kirchhoff's Current Law

Kirchhoff's Current Law (KCL): the algebraic sum of currents entering a node is zero

- The sum of currents entering a node is equal to the sum of the currents leaving a node
- Common sense:
  - All of the electrons have to go somewhere
  - The current that goes in, has to come out some place
- Based on law of conservation of charge



$$\begin{aligned} i_1 + i_2 - i_3 - i_4 + i_5 &= 0 \\ i_1 + i_2 + i_5 &= i_3 + i_4 \end{aligned}$$

Kirchhoff's Voltage Law

- **Kirchhoff's Voltage Law (KVL)**: the algebraic sum of voltages around a closed path (or loop) is zero

$$\sum_{m=1}^{M} V_m \quad = \quad 0$$

- Based on the conservation of energy

Comments on Ohm’s Law, KCL, and KVL

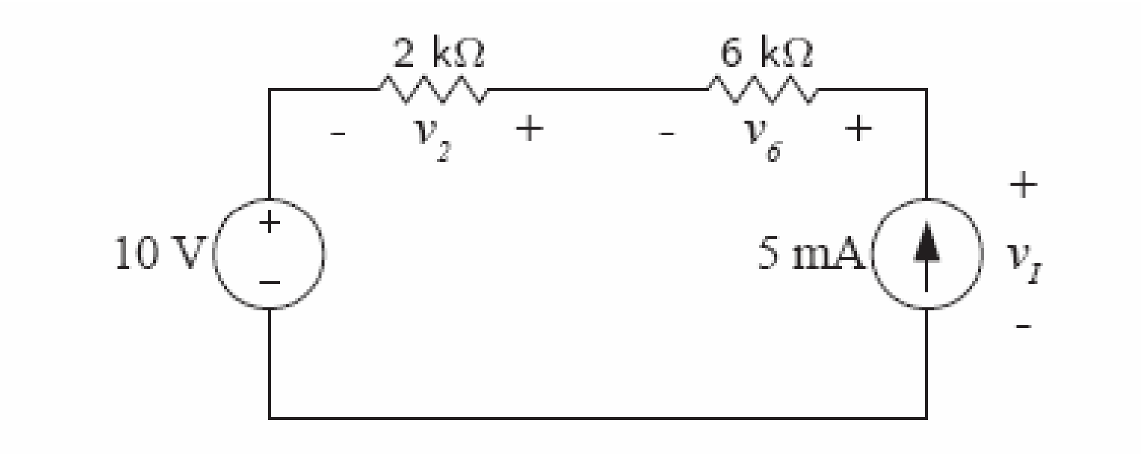
Ohm’s Law: $v = iR$

KCL: $In = 0$

KVL: $Vm = 0$

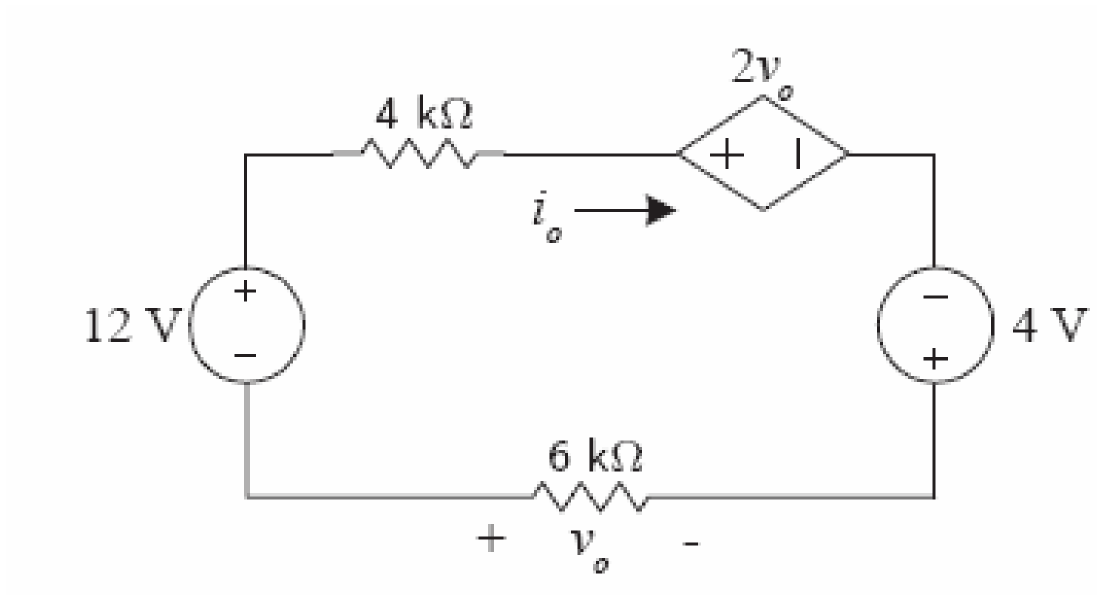
- Much of the circuit analysis that we will do is based on these three laws
- These laws alone are sufficient to analyze many circuits

Example



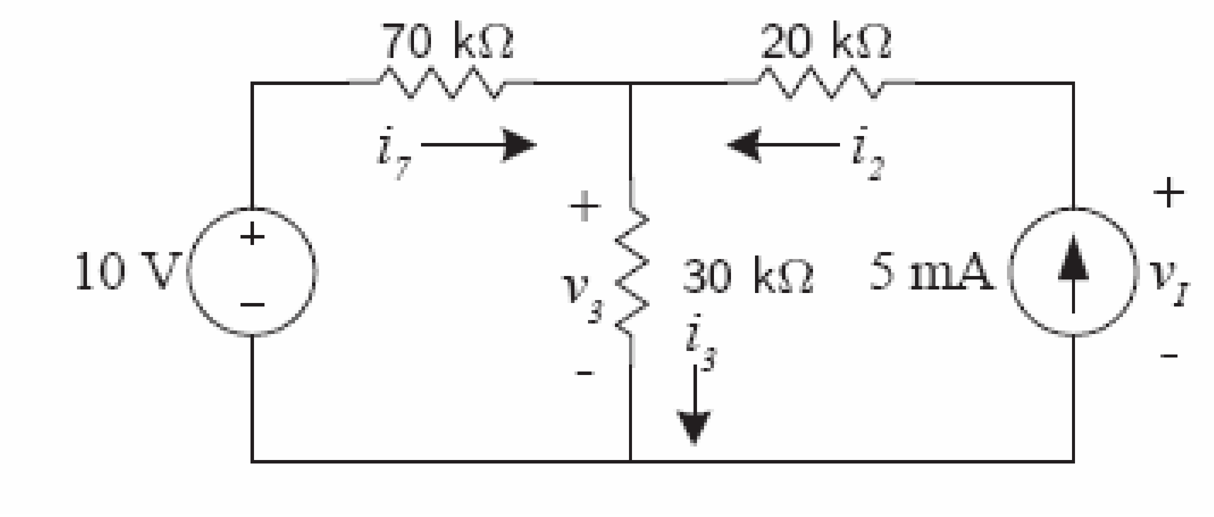
Find $v2$, $v6$ and vI .

example



Find *io* and *vo*.

example



Find *i*7, *i*3, *i*2, *v*3, and *vI* .