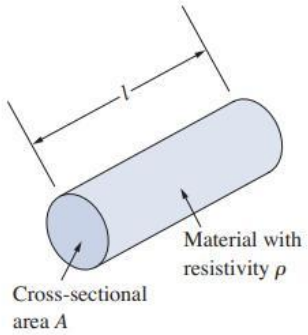
Introduction

Electrical & Electronic Circuits and Elements

Embedded Systems & Embedded Programming

Fundamentals of Electric Circuits (Resistance)

- Materials have a characteristic behavior of **resisting** the flow of electric charge
- This behavior is known as **resistance** and its magnitude:
  - Is dictated by electrical properties (**resistivity** - **ρ**) of the material and its geometry (**A** and **L**)
  - Is represented by **R** and expressed in **ohms** (**Ω**)
- The element used to model the current-resisting behavior of a material is known as **resistor**



$$R = \rho \frac{\ell}{A}$$

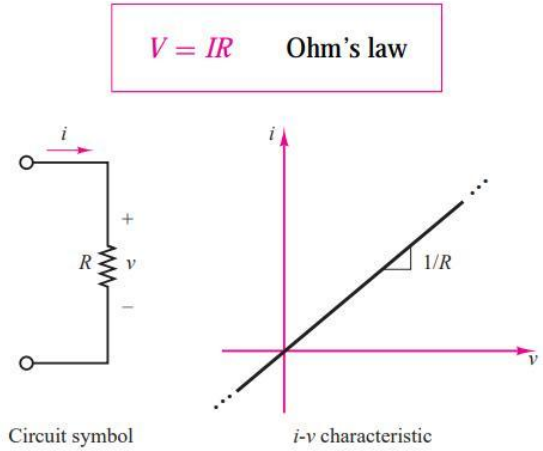
Resistivities of common materials.

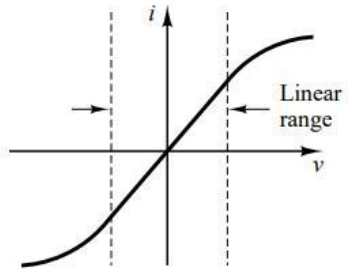
Material	Resistivity (Ω·m)	Usage
Silver	1.64×10^{-8}	Conductor
Copper	1.72×10^{-8}	Conductor
Aluminum	2.8×10^{-8}	Conductor
Gold	2.45×10^{-8}	Conductor
Carbon	4×10^{-5}	Semiconductor
Germanium	47×10^{-2}	Semiconductor
Silicon	6.4×10^{2}	Semiconductor
Paper	10^{10}	Insulator
Mica	5×10^{11}	Insulator
Glass	10^{12}	Insulator
Teflon	3×10^{12}	Insulator

Fundamentals of Electric Circuits (Ohm's Law)

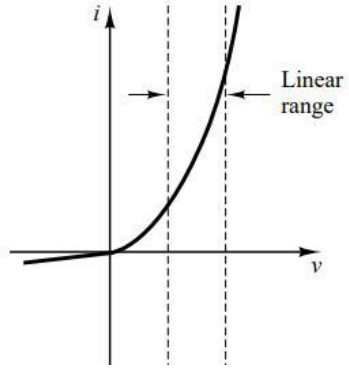
- The element used to model the current-resisting behavior of a material is known as **resistor**
- The **voltage** across a resistor is **directly proportional** to the **current** flowing through the **resistor**
  - Ohm's law is an approximation of the resisting behavior of materials
  - Typically, the relationship between current and voltage is not **linear**
  - i-v characteristic graphs can tell us so much about the behavior of elements
    - Resistance, power, passive/active etc.

Resistance and Ohm's law





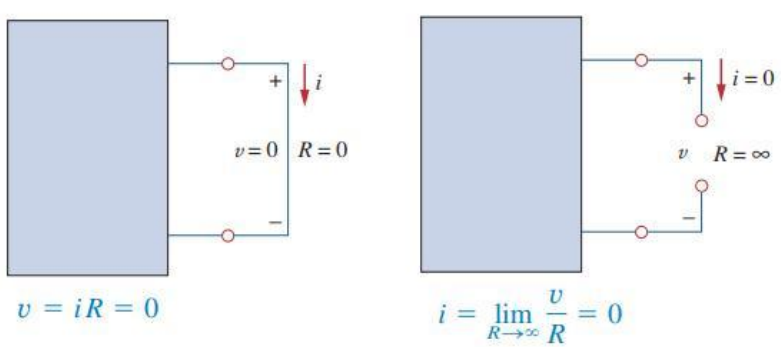
i-v characteristic of a filament lamp



i-v c of characteristic a semiconductor diode

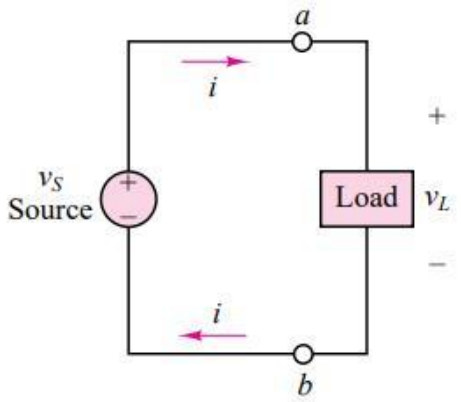
Fundamentals of Electric Circuits (Definitions)

- **Source**: Any element that provides energy to the circuit
- **Load**: Any device or circuit powered by electricity
  - Simple; like a lamp, complex; like a modern high-speed computer
- **Short circuit**: A circuit element with resistance approaching zero
- **Open circuit**: A circuit element with resistance approaching infinity



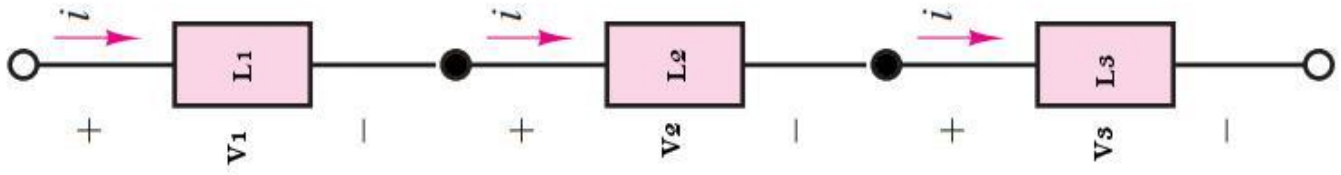
Short circuit

Open circuit

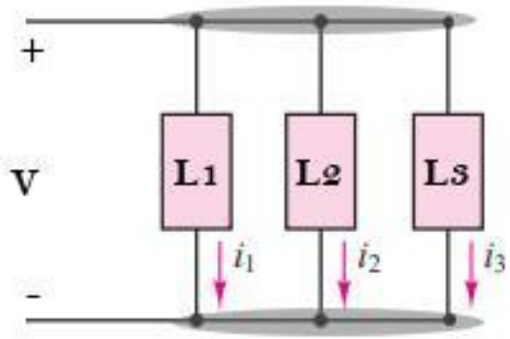


Fundamentals of Electric Circuits (Definitions)

- **Series Circuits**: Two or more elements are in series if they
  - Exclusively share a single node and
  - Consequently carry the same current

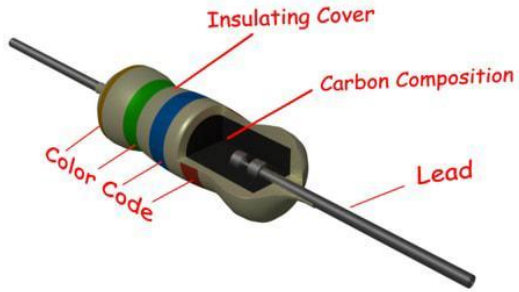


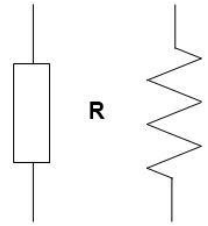
- **Parallel Circuits**: Two or more elements are in parallel if they
  - Are connected to the same two nodes
  - Consequently have the same voltage across them



Fundamentals of Electric Circuits (Resistors)

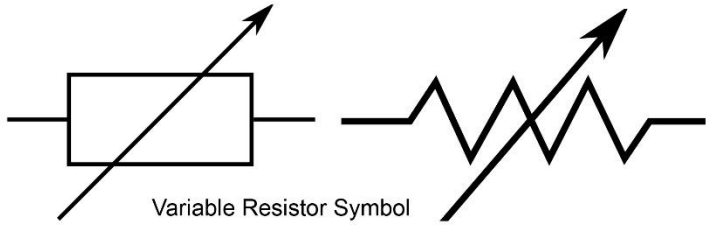
- **Resistor** is the element used to resist/control/limit electric current flow in circuits
- It is a passive element and it converts electrical energy to heat energy
- In a typical resistor, voltage-current relationship is linear (V = R × I)
- Types
  - Fixed resistors (constant resistance value)
  - Variable resistors (adjustable resistance value)
- Application
  - Limiting/dividing current in electric circuits
  - Lowering voltage levels (voltage divider)
  - As pull-up and pull-down
  - As sensor





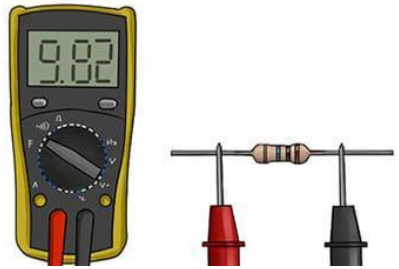
Fixed Resistor Symbol


Potentiometer


Variable Resistor Symbol

Fundamentals of Electric Circuits (Resistors)

- Most common resistors are made of either a **carbon**, **metal**, or **metal-oxide** film
- The resistance of a resistor can be measured by:
  - Ohmmeters (without any power supplied to the resistor)
  - The bands of color on a resistor (4 - 6 bands), Online Calculator

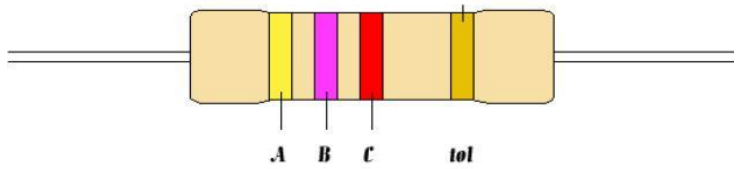


Color	Tolerance
Brown	±1%
Red	±2%
Gold	±5%
Silver	±10%
None	±20%

4 bands color tables

Band color	Digit	Multiplier
Black	0	X1
Brown	1	X10
Red	2	X100
Orange	3	X1000
Yellow	4	X10000
Green	5	X100000
Blue	6	X1000000
Purple	7	X10000000
Grey	8	X100000000
White	9	X1000000000
Silver	-	x.01
Gold	-	x.1

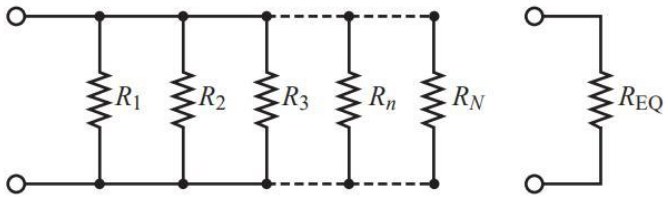
$$\text{Resistor value} = AB \times 10^{C} \pm tol\%(\Omega)$$



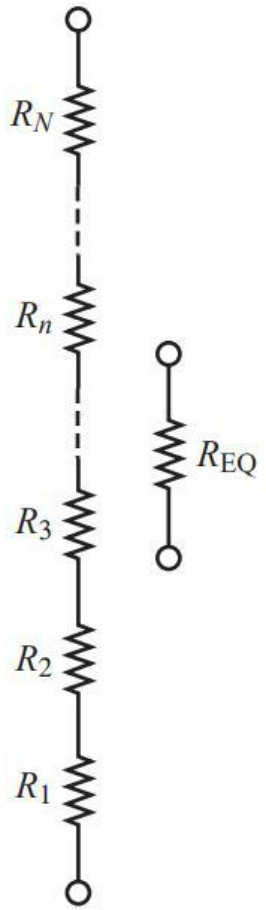
Fundamentals of Electric Circuits (Resistors)

- Resistors in Series and Parallel

$$v_n = \frac{R_n}{R_1 + R_2 + \cdots + R_n + \cdots + R_N} v_S$$ Voltage divider



$$R_{EQ} = \sum_{n=1}^{N} R_n$$ Equivalent series resistance



$$R_{EQ} = \frac{1}{1/R_1 + 1/R_2 + \cdots + 1/R_N}$$ Equivalent parallel resistance

$$i_n = \frac{1/R_n}{1/R_1 + 1/R_2 + \cdots + 1/R_n + \cdots + 1/R_N} i_S$$ Current divider

Fundamentals of Electric Circuits (Resistors)

- Some examples of variable resistors

A **potentiometer** is a manually adjustable variable resistor with 3 terminals

Varistors have a non-linear resistance which is dependent on the voltage over the varistor. They are used as **over-voltage protection** devices

Photoresistors (LDR) show a decrease in resistance when light intensity increases.

Thermistors are resistors of which the resistance changes significantly when temperature changes

MDR

The **magneto-resistor** type can be used to detect and measure magnetic fields.

[Read more about resistor at Resistor Guide]

Fundamentals of Electric Circuits

- References
  - Fundamentals of Electric Circuits, 5th Edition, Charles K. Alexander and Matthew N.O. Sadiku, ISBN 978-0-07-338057-5
  - Fundamentals of Electrical Engineering, First Edition, Giorgio Rizzoni, ISBN 978-0–07–338037–7
  - ***Most of the images have been copied from these two books***
- Some useful links
  - Resistors - Ohm's Law is not a real law
  - Resistors
  - I-V Characteristic Curves

The SI prefixes.

Multiplier	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a