- Introduction to Circuit Analysis

Key Question

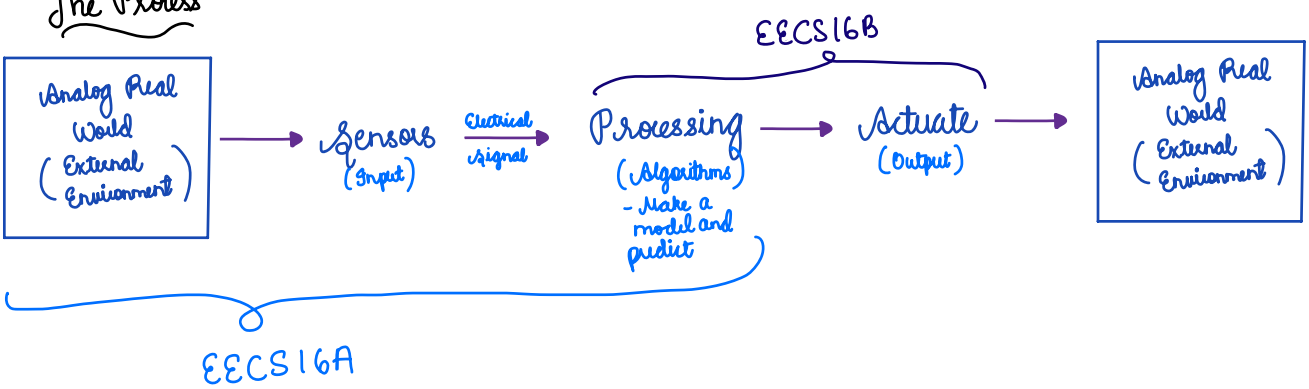
- What are the tools we need to model and analyze systems as circuits?

Key Terms

- Voltage
- Current
- Resistance
- Wire
- Open Circuit
- Voltage Source
- Current Source
- Resistor
- Node
- Conductor
- Insulator
- Ohm's law
- Passive Sign Convention

In this class, we will learn how to design and build devices and systems.

The Process



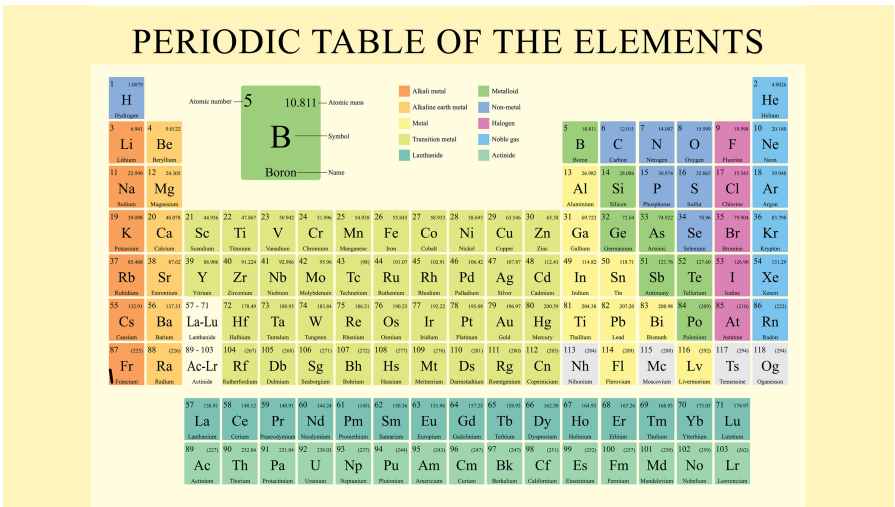
Example: Self-Driving Cars

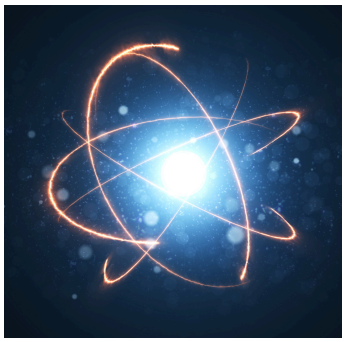
Example: Turn on a fan when the temperature in a room is too high and turn it off when the temperature reaches a desired state.

Example: Start a pancake-making machine when sunlight is detected and stop when ten pancakes are made.

How do we make models?
There is a level of abstraction involved, but let's start with the tools we need.

Our world is made up of tiny particles we call atoms.





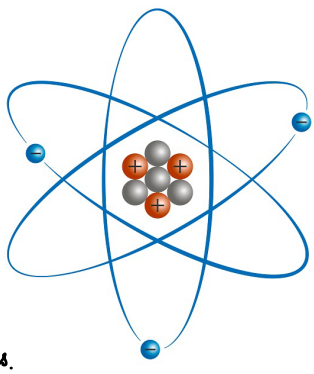
Atom

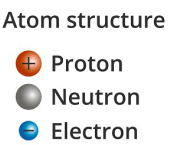
An atom consists of three types of subatomic particles:

- Protons: positive electrical charge
- Neutrons: electrically neutral (no charge)
- Electrons: negative electrical charge → light and free to move

} Nucleus (tightly bound, dense, and heavy)

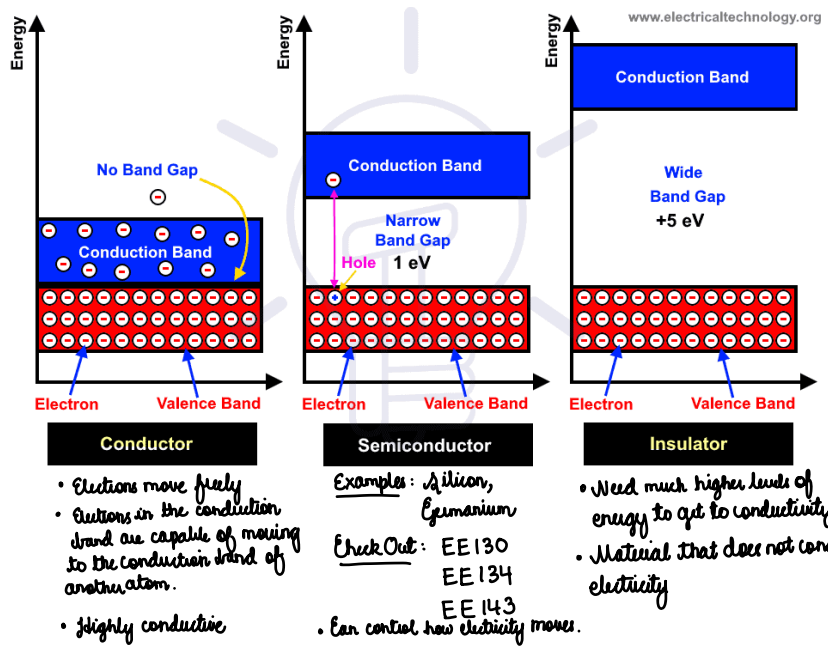
- like charges repel each other and unlike charges attract.





Let's talk about electrons in solid-state physics:

- Electrons exist in shells surrounding the nucleus with different energies.
- Valence electrons are located in the outermost shell of an atom and have the highest energy.
- The valence band is the outermost electron orbital of the atom of a material. When excited, those electrons move into the conduction band
- Band Gap: energy range in a solid where no electron states can exist



- Electrons move freely
- Electrons in the conduction band are capable of moving to the conduction band of another atom.
- Highly conductive

Examples: Silicon, Germanium

Check Out: EE130, EE134, EE143

- Can control how electricity moves.

- Need much higher levels of energy to get to conductivity
- Material that does not conduct electricity

Summary:

Conductivity is the ease with which electrons can flow through a material.

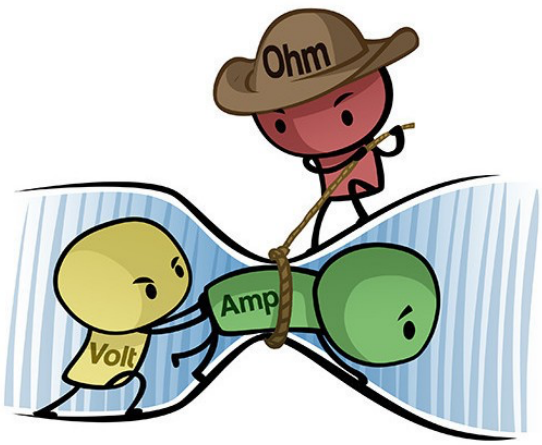
Our electronic devices depend on this movement of charges through material.

Charge: represented as Q
measured in Coulombs (C).
$-1C \approx 6.2415 \times 10^{18}\ e^-$

The movement of this charge over time, or the rate of flow, is called current. ($\frac{dQ}{dt} = I$)

What is driving these electrons to move? Voltage (like pressure or a pushing force) is the potential difference between two points. Think of it like an altitude. It is defined relative to a zero, or ground for reference.

What could oppose the path of current? Resistance (a property of an element) opposes the flow of current.



The Water Pipe Analogy

Think of water flowing in a pipe.

- The amount of water at any cross-section of the pipe is current.
- The force of the flowing water is voltage.
- Rocks and debris obstructing the flow of water causes resistance.

Quantity	Symbol	Unit
Current	I	Amperes (A) (flows through an element)
Voltage	V	Volts (V) (applied across an element)
Resistance	R	Ohms (Ω)

Let's consider the relationship between these three:

If the resistance to water flow stayed the same, but the pressure of water increased, the flow rate would increase.

$V \uparrow \Rightarrow I \uparrow$ when R is unchanged

If the pressure stayed the same, but the resistance increased, then the flow rate would decrease.

$R \uparrow \Rightarrow I \downarrow$ when V is unchanged.

If the flow rate stayed the same, but the resistance decreased, the pressure required to move the water would decrease.

$R \downarrow \Rightarrow V \downarrow$ when I is unchanged.

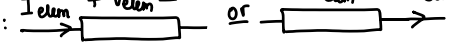
This relationship is described by Ohm's law.

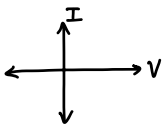
$$V = IR$$

How does this all fit together? Circuit

A circuit is a closed loop or complete path for electricity to flow through.

There are different kinds of elements that make up a circuit, each of which has a voltage across it and a current flowing through it.

General Element : 

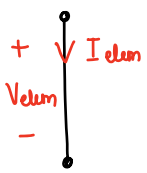


I-V Characteristic or I-V Curve.

When labeling, we follow passive sign convention, which means current flows from positive voltage to negative voltage. (+ to −)

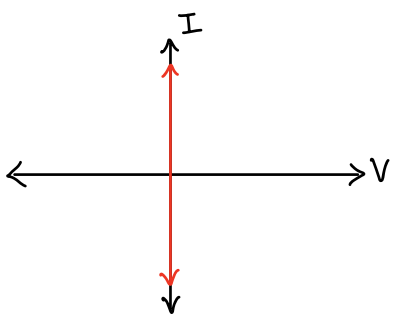
Circuit Elements

① Wire

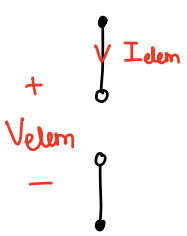


$V_{elem} = 0$

I_{elem} is set by the external circuit.

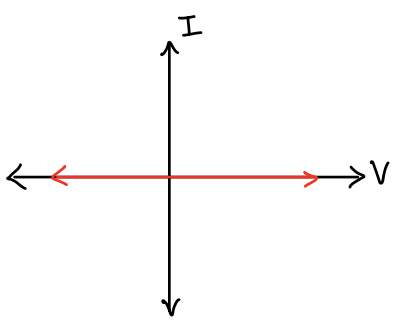


② Open Circuit



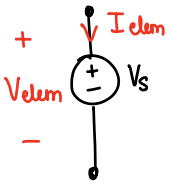
$I_{elem} = 0$

V_{elem} is set by the external circuit.



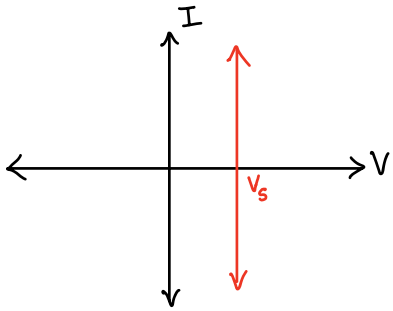
(3) Voltage Source

Ex: Battery

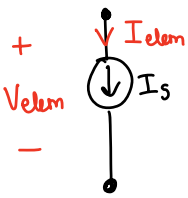


$V_{elem} = V_s$

I_{elem} is set by the external circuit.

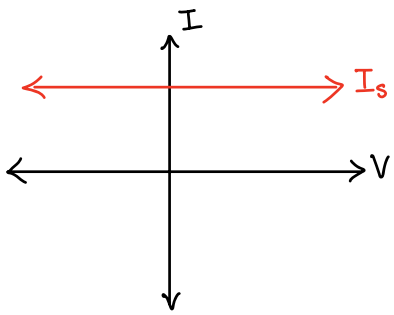


(4) Current Source

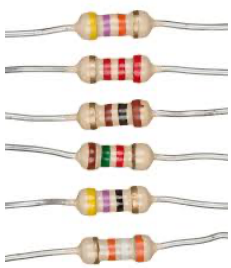


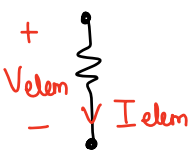
$I_{elem} = I_s$

V_{elem} is set by the external circuit.



(5) Resistor

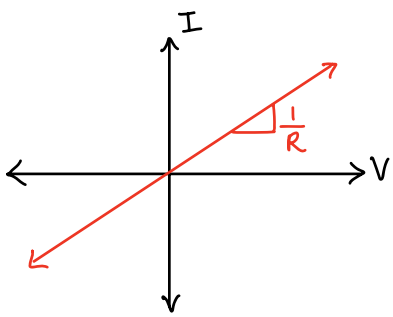




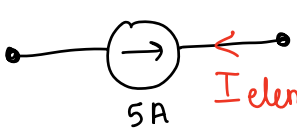
$V_{elem} = I_{elem} \cdot R$

Ohm's law

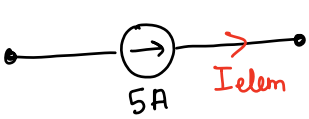
$I_{elem} = \frac{V_{elem}}{R}$



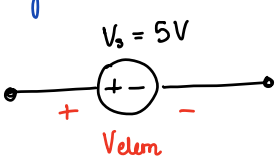
Remember that V_{elem} and I_{elem} can be positive or negative.



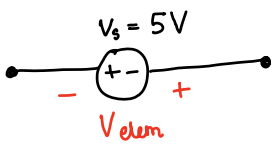
$I_{elem} = -5A$



$I_{elem} = 5A$

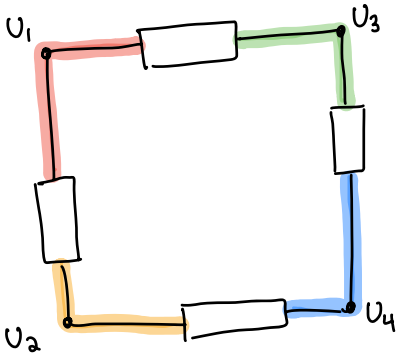


$V_{elem} = 5\,V$



$V_{elem} = -5\,V$

Circuit Diagram

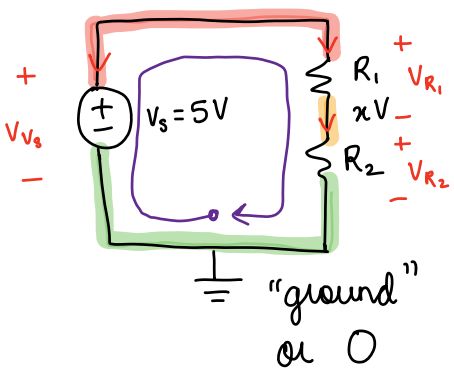


A closed path for electrons to flow is a closed circuit.

(A loop - we will end up where we started, and current is the same throughout the loop).

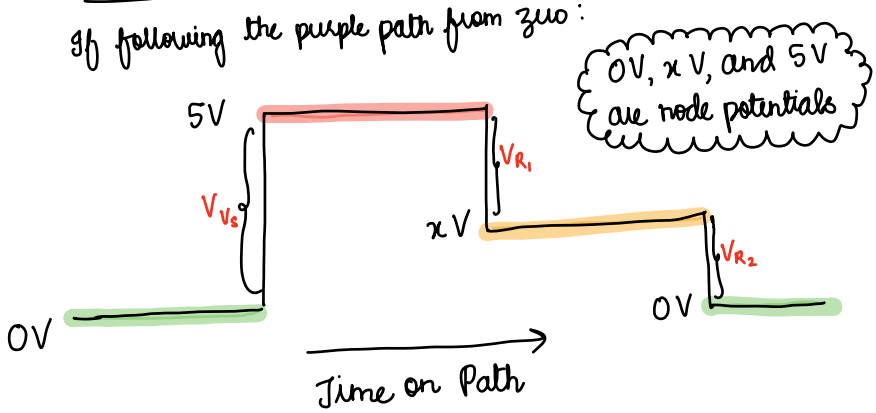
Node: region between circuit elements with the same potential.
(everything you can connect without lifting your pen)

Let's put together some elements in a circuit. Let's use this diagram to understand voltage better.



The Mountain Climbing Analogy

If following the purple path from zero:



The voltage across an element is the difference in potential from the + to − terminal.

So, $V_{V_s} =$ ● − ● $= 5V - 0V = 5V = V_s$

$V_{R_1} =$ ● − ● $= 5V - xV$

$V_{R_2} =$ ● − ● $= xV - 0V = xV$