University of Dhaka
Department of Computer Science and Engineering
CSE-2205: Introduction to Mechatronics

Lec-6: Temperature Sensors + Light Sensors

Mechatronics: Electronic Control Systems in Mechanical Engineering by W. Bolton

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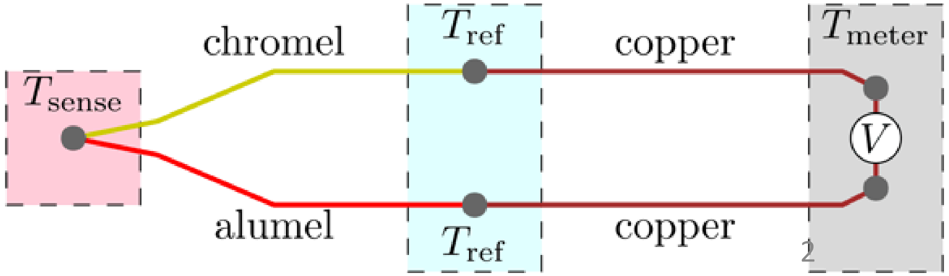
1. Thermocouple

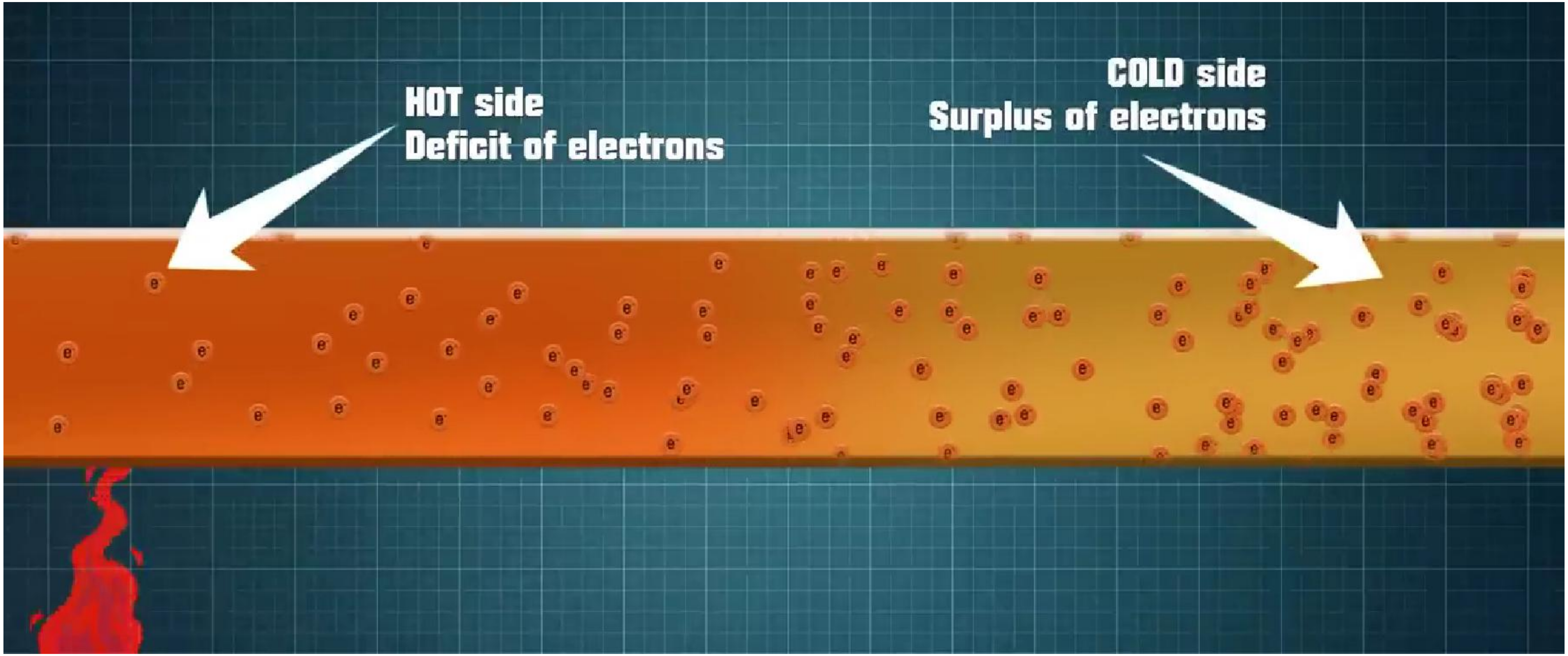
A thermocouple works by *generating a small electrical voltage* in response to a *temperature difference between two junctions* of different metals. This phenomenon is known as the **Seebeck effect**.

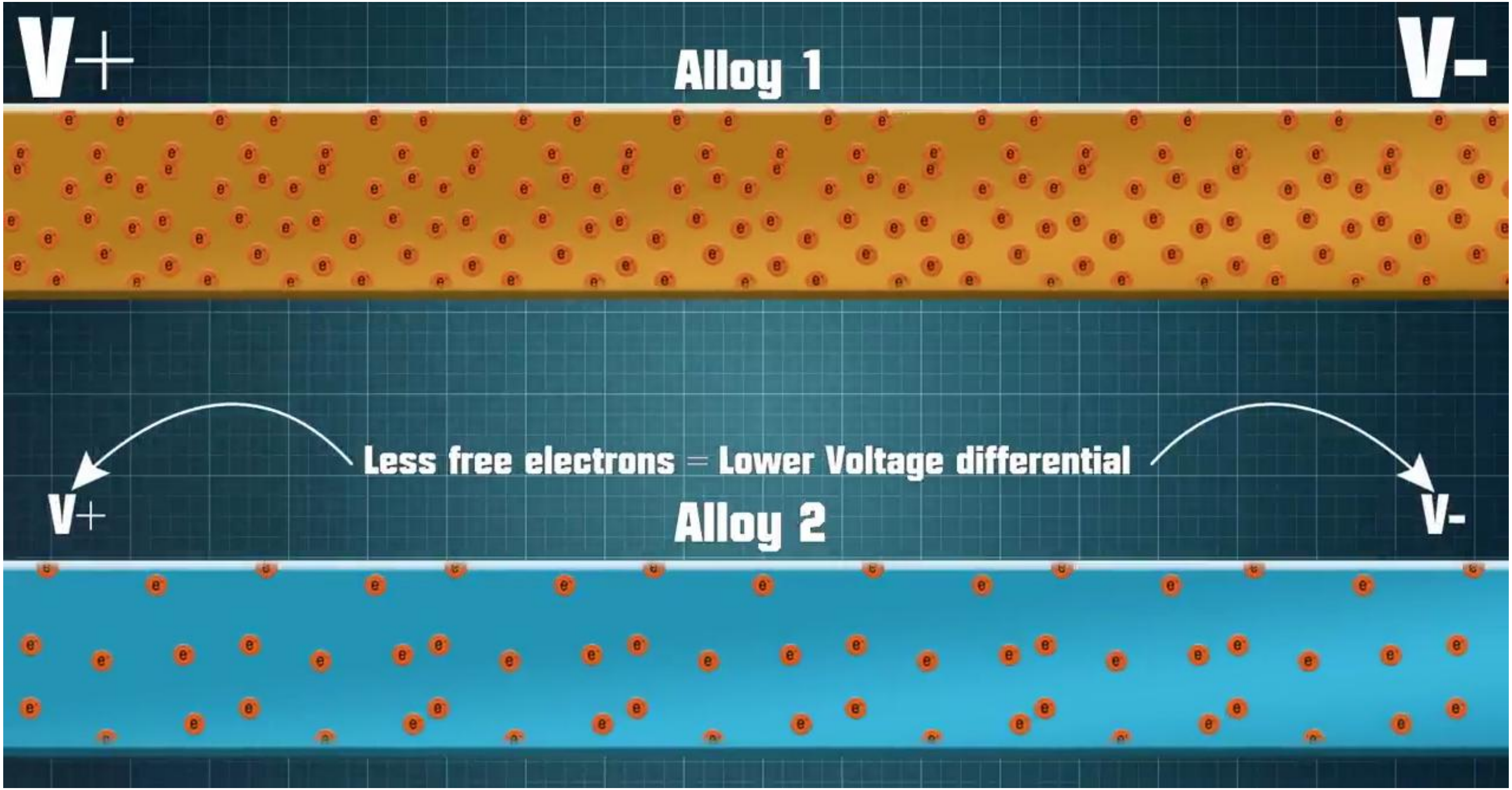
Two Different Metals: A thermocouple *consists of two wires made of different metals (or alloys),* which are joined at two ends to form two junctions:

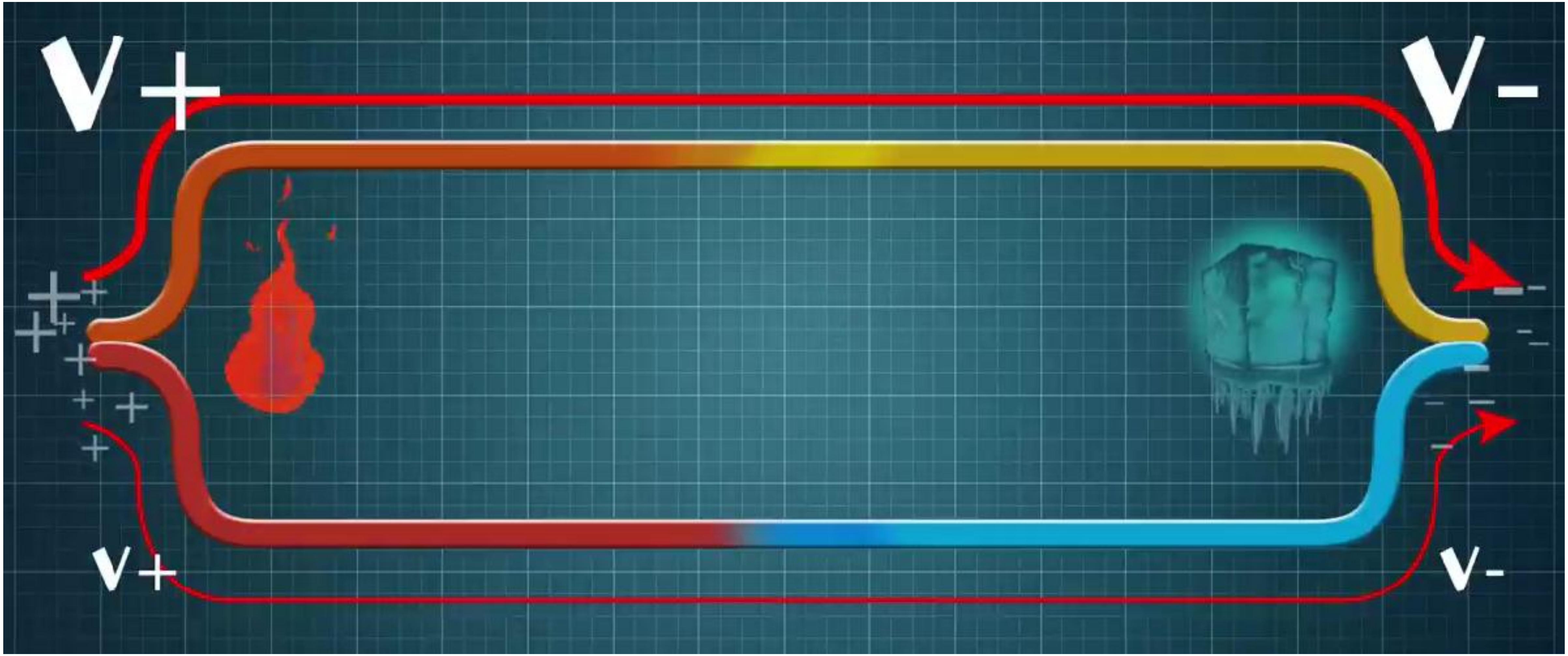
1. **Hot Junction** (measuring junction): *Exposed to the temperature* being measured.
2. **Cold Junction** (reference junction): Kept at a known or *constant temperature*, often room temperature or near it.

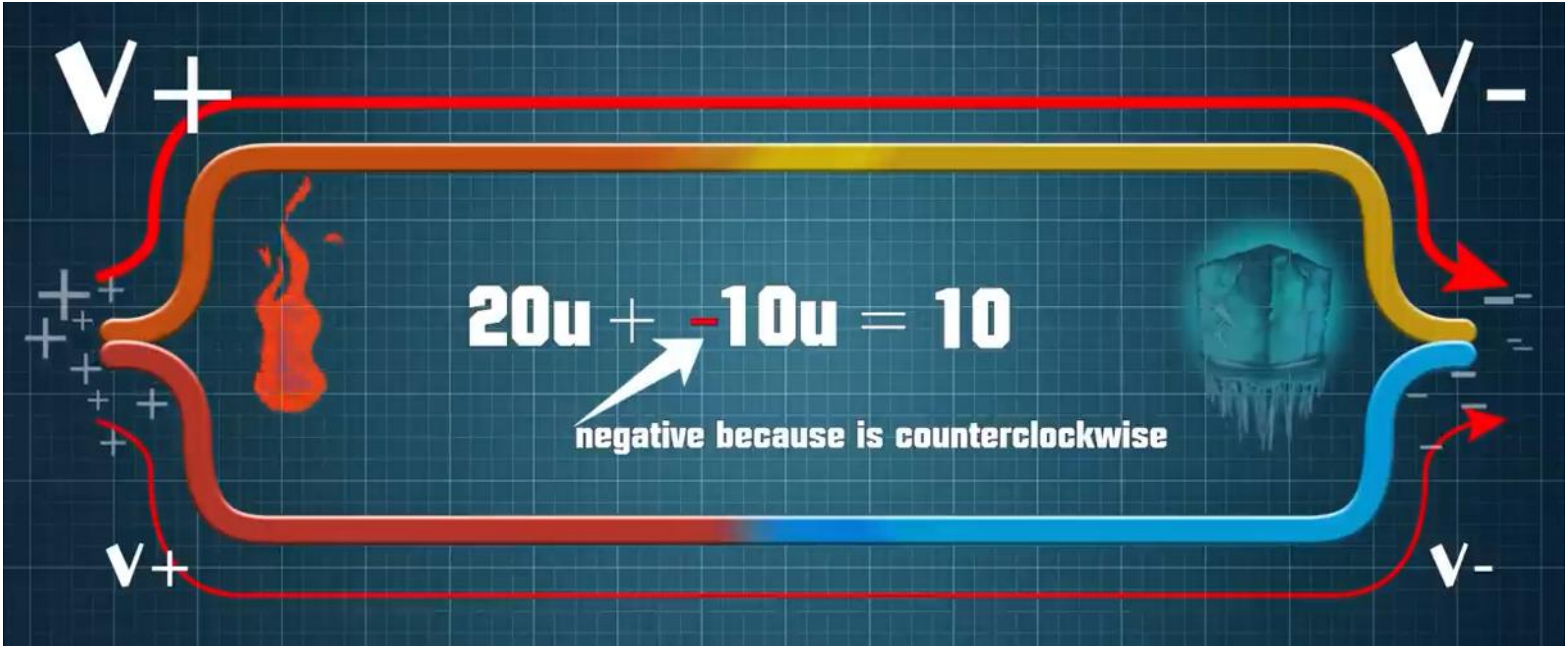


Seebeck Effect: When *two different metals* are joined and *exposed to a temperature difference* between the two junctions (hot and cold), a *voltage is generated*.




V+
Alloy 1
V-
Less free electrons = Lower Voltage differential
V+
Alloy 2
V-


V+
V-
V+
V-

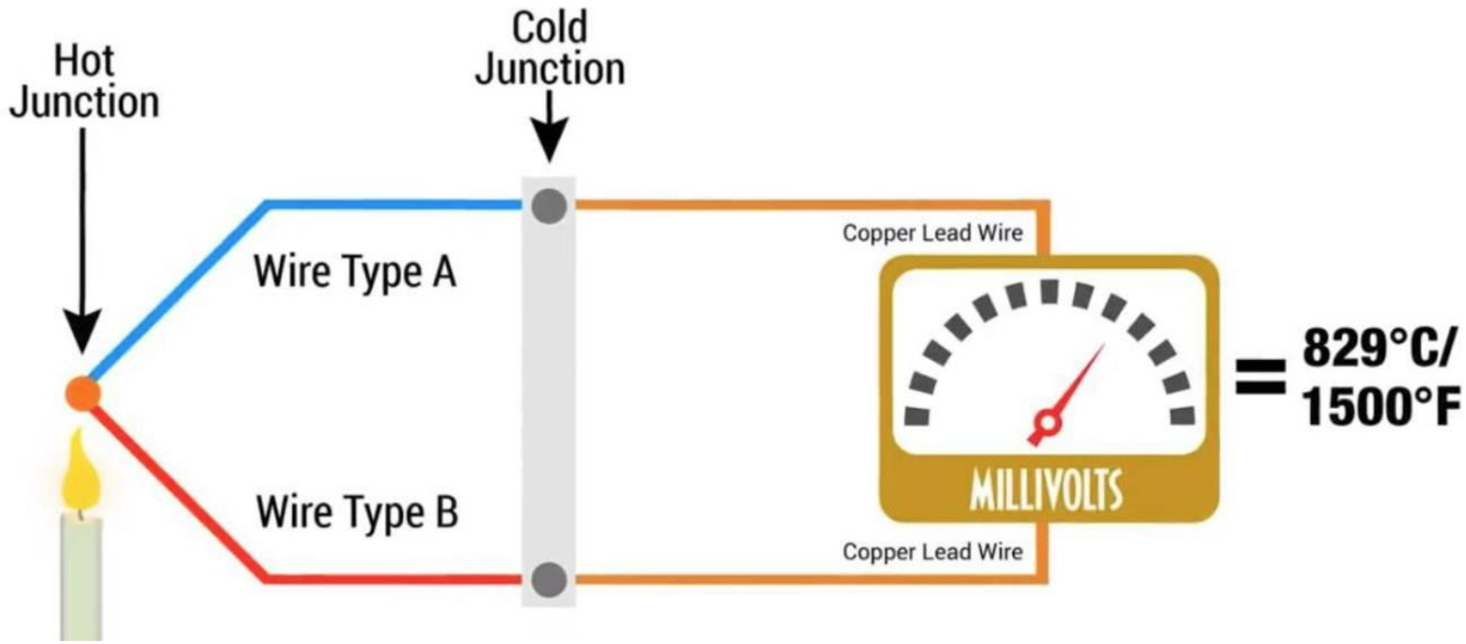

V+
V-
20u + -10u = 10
negative because is counterclockwise
v+
v-

Voltage Measurement: The *generated voltage is directly related to the temperature difference*, so by measuring this voltage, the temperature at the hot junction can be determined.

Type J (Iron–Constantan): $\alpha \approx 52\,\mu\mathrm{V}/^\circ\mathrm{C}$

Type K (Chromel–Alumel): $\alpha \approx 41\,\mu\mathrm{V}/^\circ\mathrm{C}$

$$V = \alpha\,\Delta T$$



α is the **Seebeck coefficient** for the specific pair of metals (measured in volts per degree Celsius or $\mathrm{V}/^\circ\mathrm{C}$).

$\Delta T = T_{hot} - T_{cold}$ is the temperature difference between the hot and cold junctions.

A Type K thermocouple with a Seebeck coefficient of $41\,\mu\mathrm{V}/^{\circ}\mathrm{C}$ is used to measure the temperature difference between two junctions. If the temperature at the hot junction is $250^{\circ}\mathrm{C}$ and the cold (reference) junction is at $25^{\circ}\mathrm{C}$, calculate the voltage output of the thermocouple.

Determine the Temperature Difference:

$$\Delta T = T_{hot} - T_{cold} = 250^{\circ}\mathrm{C} - 25^{\circ}\mathrm{C} = 225^{\circ}\mathrm{C}$$

Calculate the Voltage Output: Using the formula $V = \alpha \cdot \Delta T$, where $\alpha = 41\,\mu\mathrm{V}/^{\circ}\mathrm{C}$:

$$V = 41\,\mu\mathrm{V}/^{\circ}\mathrm{C} \times 225^{\circ}\mathrm{C}$$

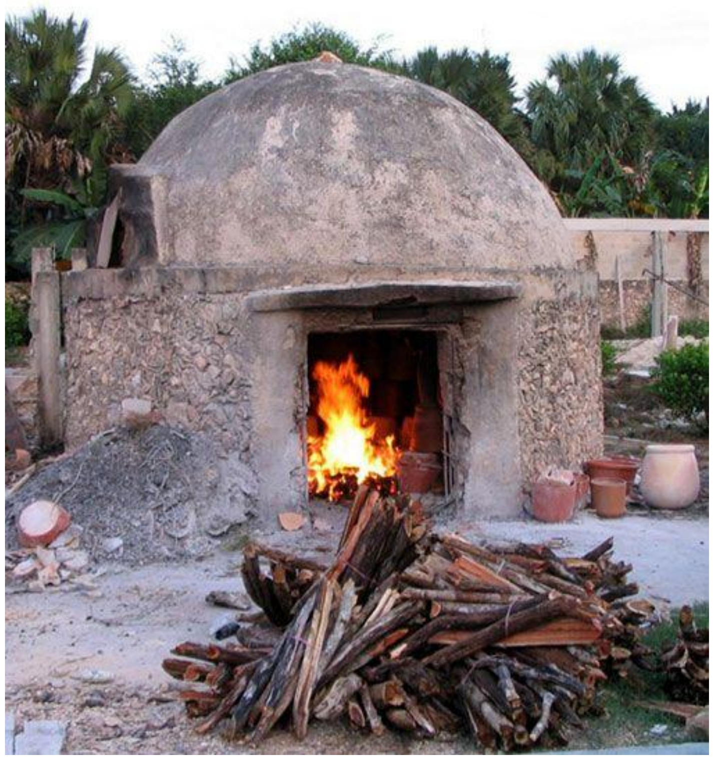
$$V = 9.225\,\mathrm{mV}$$

1.1 Applications of Thermocouples

1.1.1 Thermocouples monitor and control *furnaces, reactors, and kilns* to ensure optimal operating temperatures.

furnaces

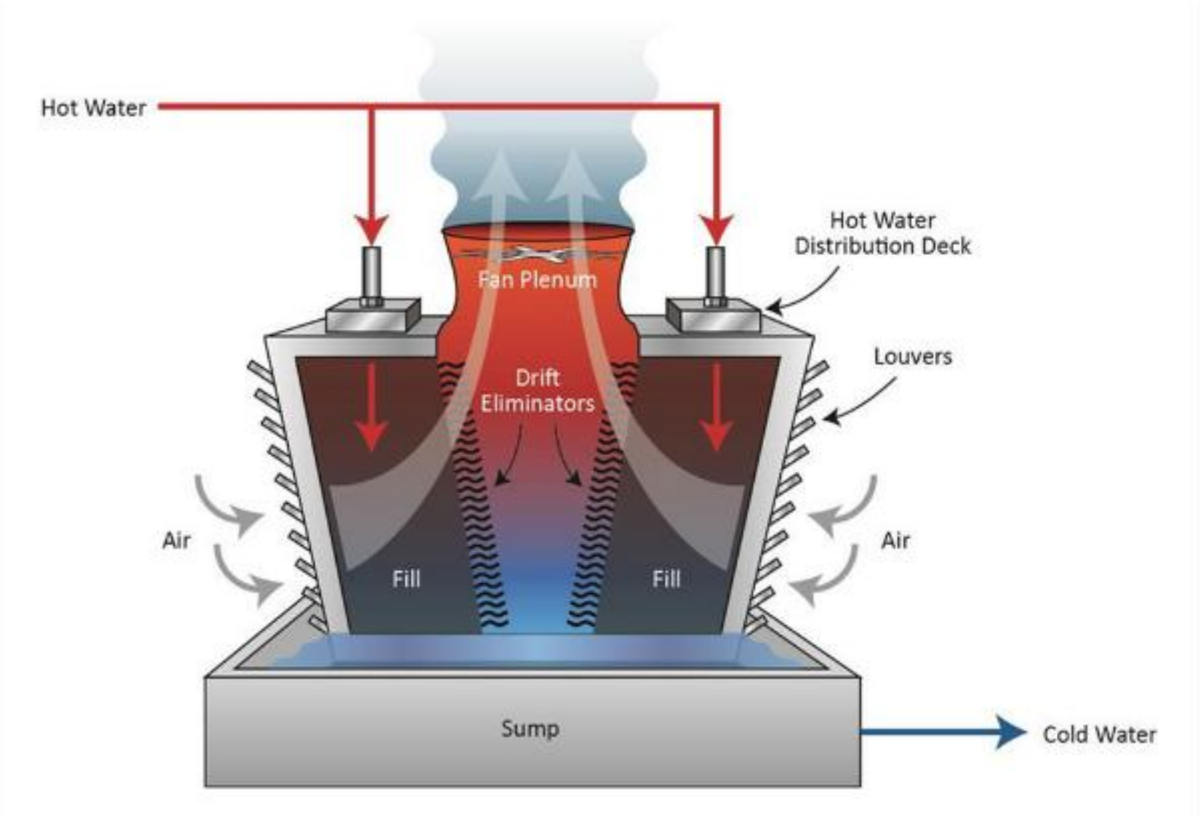
reactors



kilns

1.1.2 Thermocouples ensure food reaches *<u>safe temperatures to avoid bacterial contamination</u>* and monitor storage conditions.

1.1.3 Thermocouples monitor *boiler and turbine temperatures* and ensure heat exchangers operate efficiently.

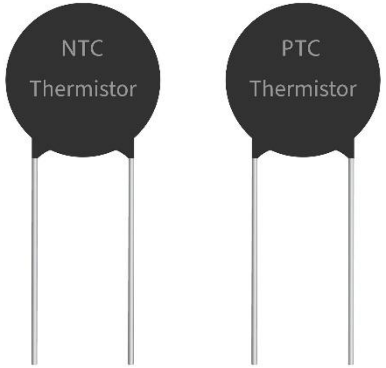


2. Thermistors

Thermistors are *temperature-sensitive resistors* made primarily from ceramic or polymer materials. Their *resistance changes significantly with temperature*, and they come in two main types based on their resistance-temperature behavior:

NTC (Negative Temperature Coefficient): *Resistance decreases* as temperature increases.

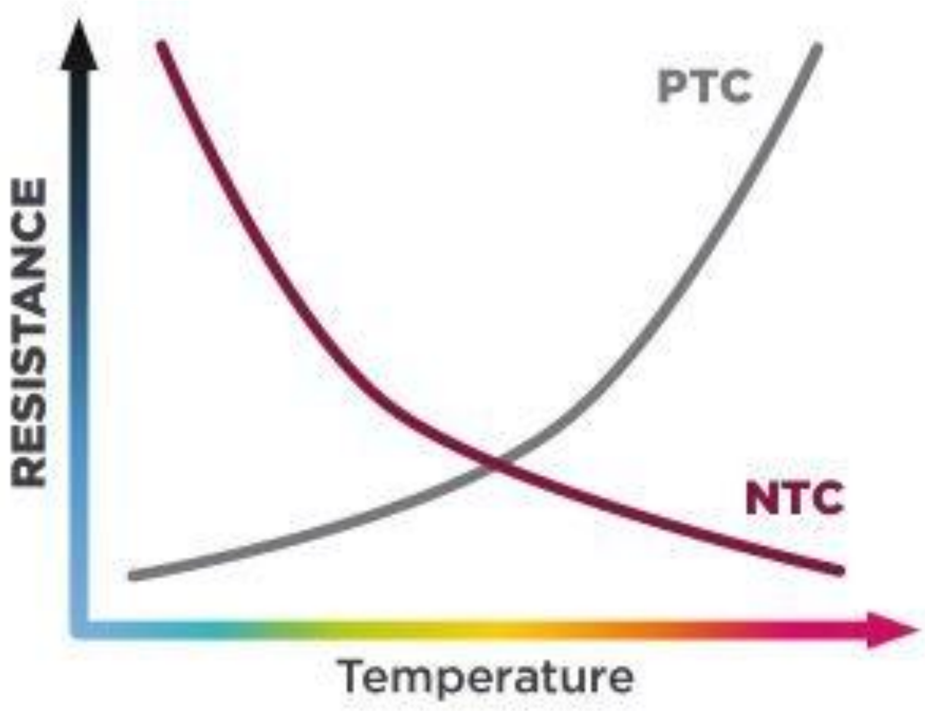
PTC (Positive Temperature Coefficient): *Resistance increases* as temperature increases.



2.1 PTC Thermistor

In a Positive Temperature Coefficient (PTC) thermistor, the *resistance increases as the temperature rises*.

This behavior is *due to a phase transition in the thermistor material* that occurs at a specific temperature.



Phase Transition:

When the temperature reaches a certain threshold (often called the "**Curie temperature**"), the material *undergoes a change in its internal structure* or *molecular arrangement*.

This phase transition *reduces the ability of electrons to move freely*, causing a sharp increase in resistance.

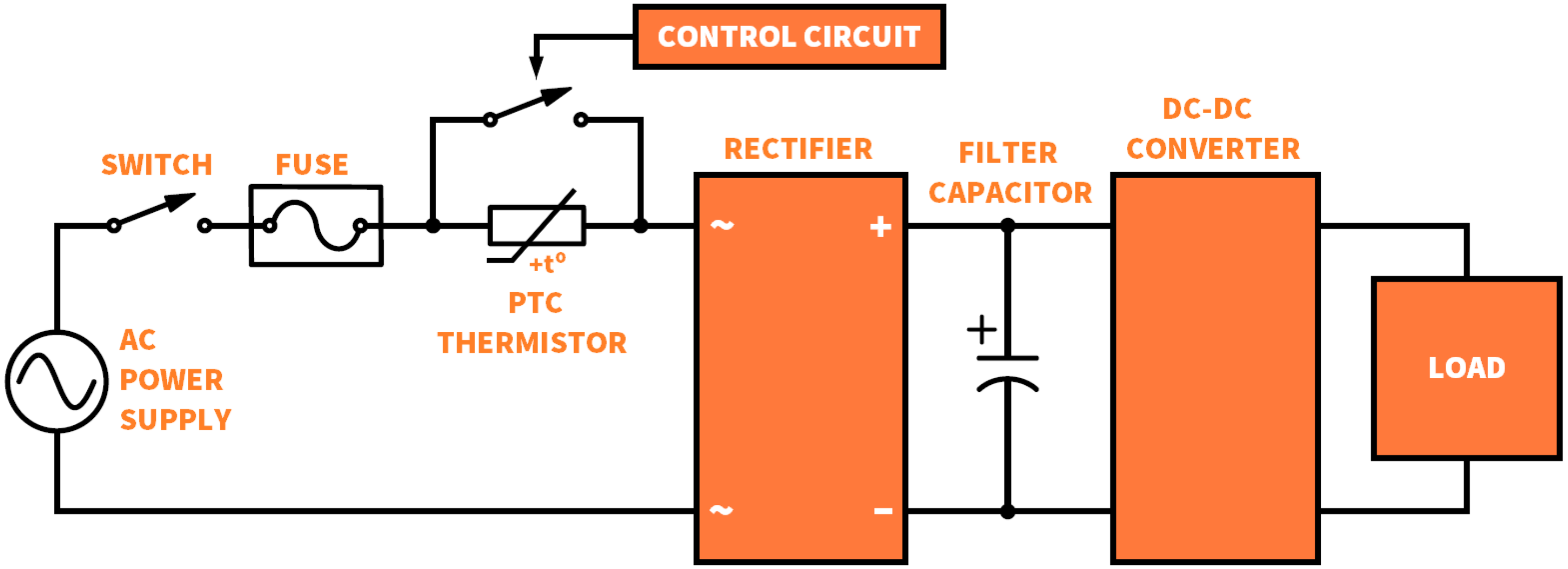
Reduced Conductivity:

Above the Curie temperature, the material *becomes less conductive* because the rearranged structure obstructs the flow of electrons. This *limits the current through the thermistor*, making it more resistant as the temperature continues to rise.

Applications:

This characteristic is useful in applications where *over-current protection* or *temperature-based circuit control* is needed.

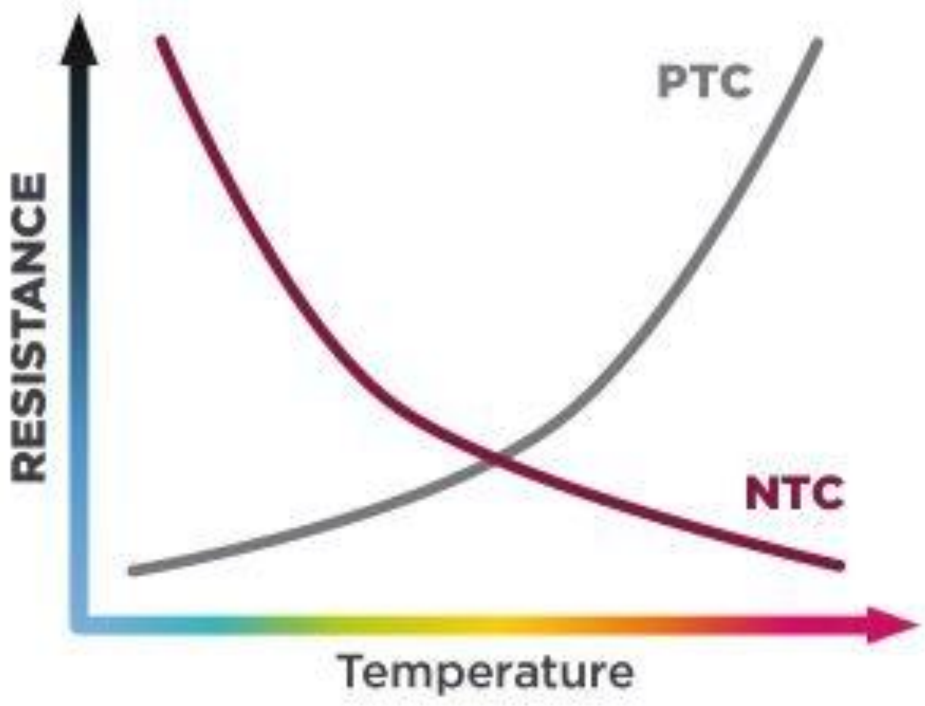
if a circuit starts to overheat, a PTC thermistor's *increasing resistance will limit current flow*, effectively acting as a *self-regulating safeguard* against overheating.



2.2 NTC Thermistor

In an NTC thermistor, for example, as *temperature increases, the thermistor's resistance decreases*.

This is due to *increased conductivity as more charge carriers (like electrons) are released* within the material at higher temperatures.



Applications:

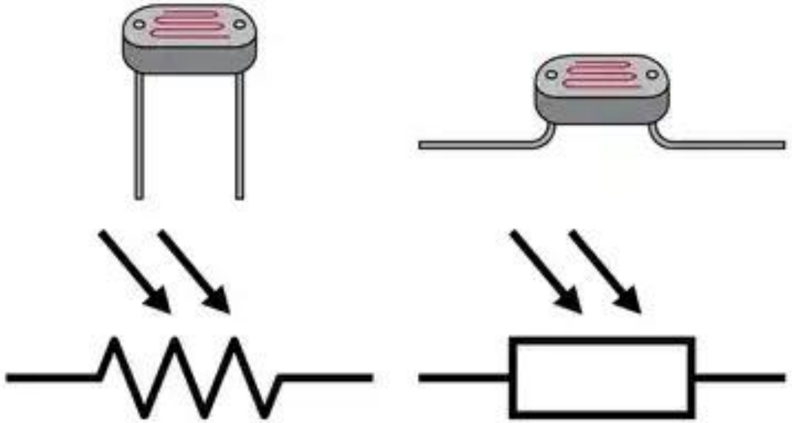
NTC thermistors are commonly used in applications such as ***temperature sensing*** (e.g., *digital thermometers*).

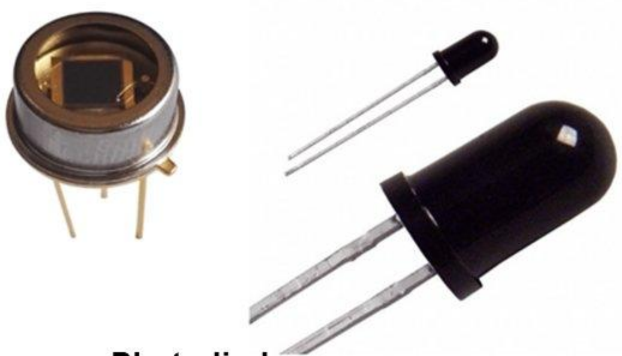
Light Sensors

1. Light Sensors

Light sensors are devices that *detect and measure light intensity*, converting it into an *electrical signal for further processing*.

Light Dependent Resistor (LDR)

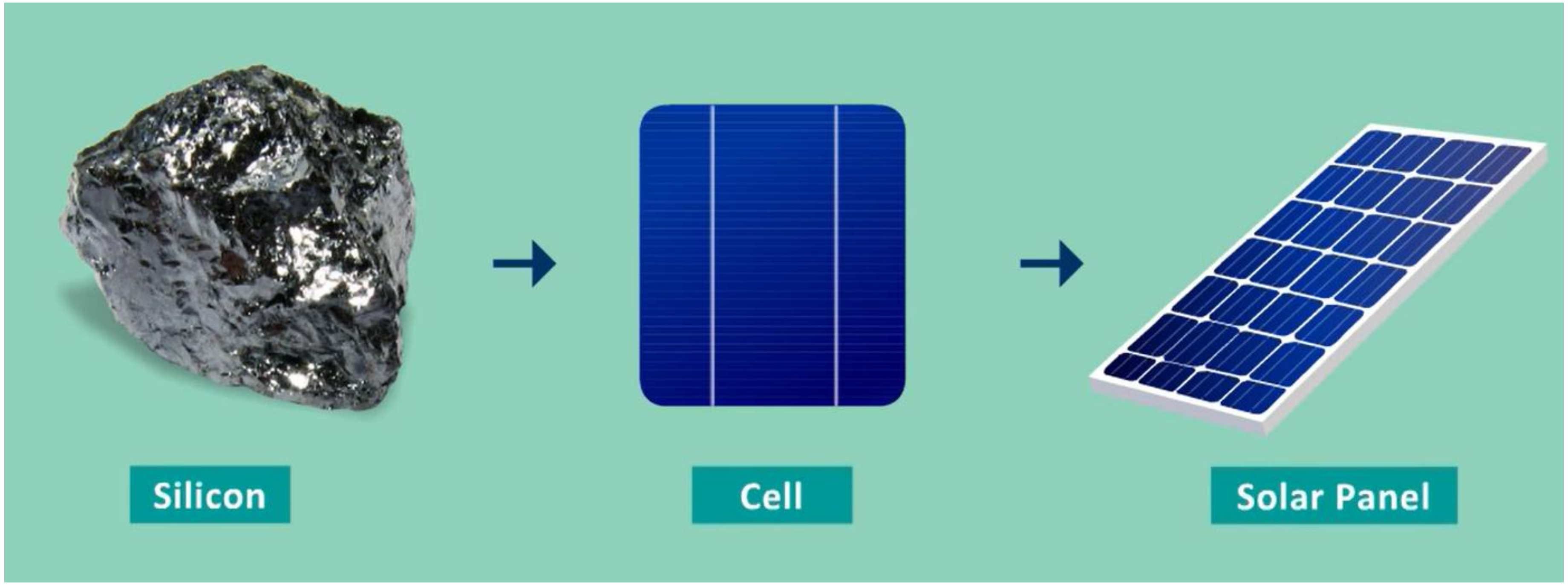


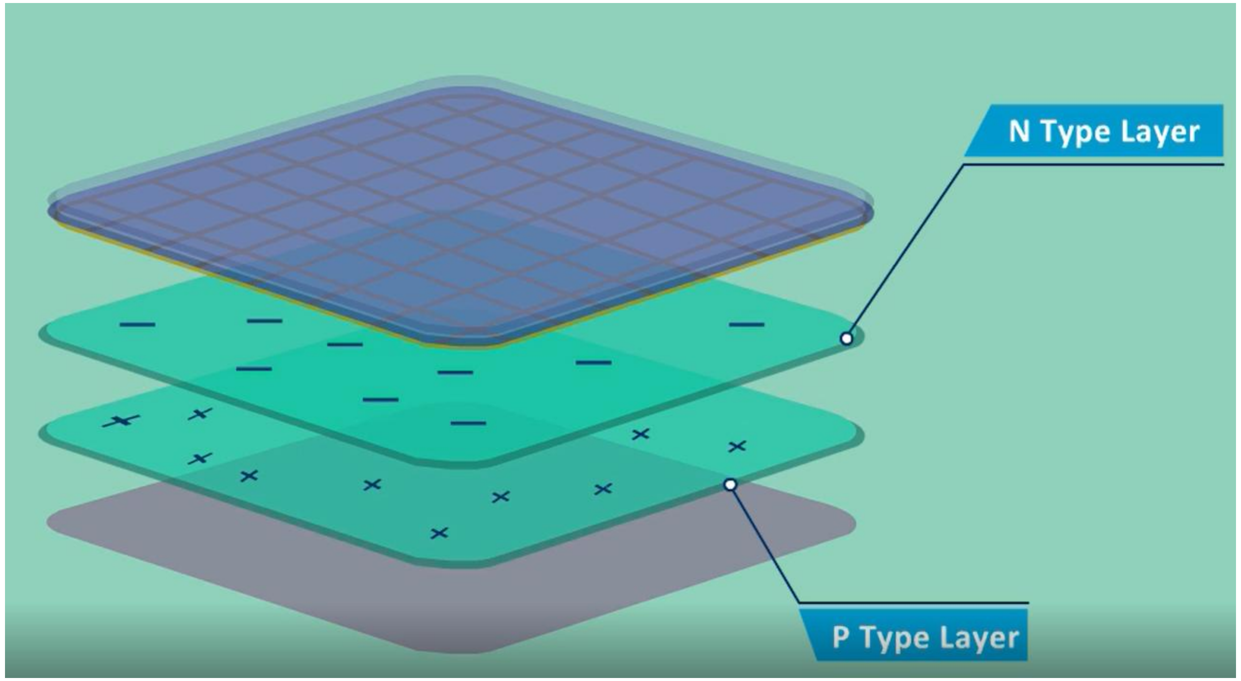


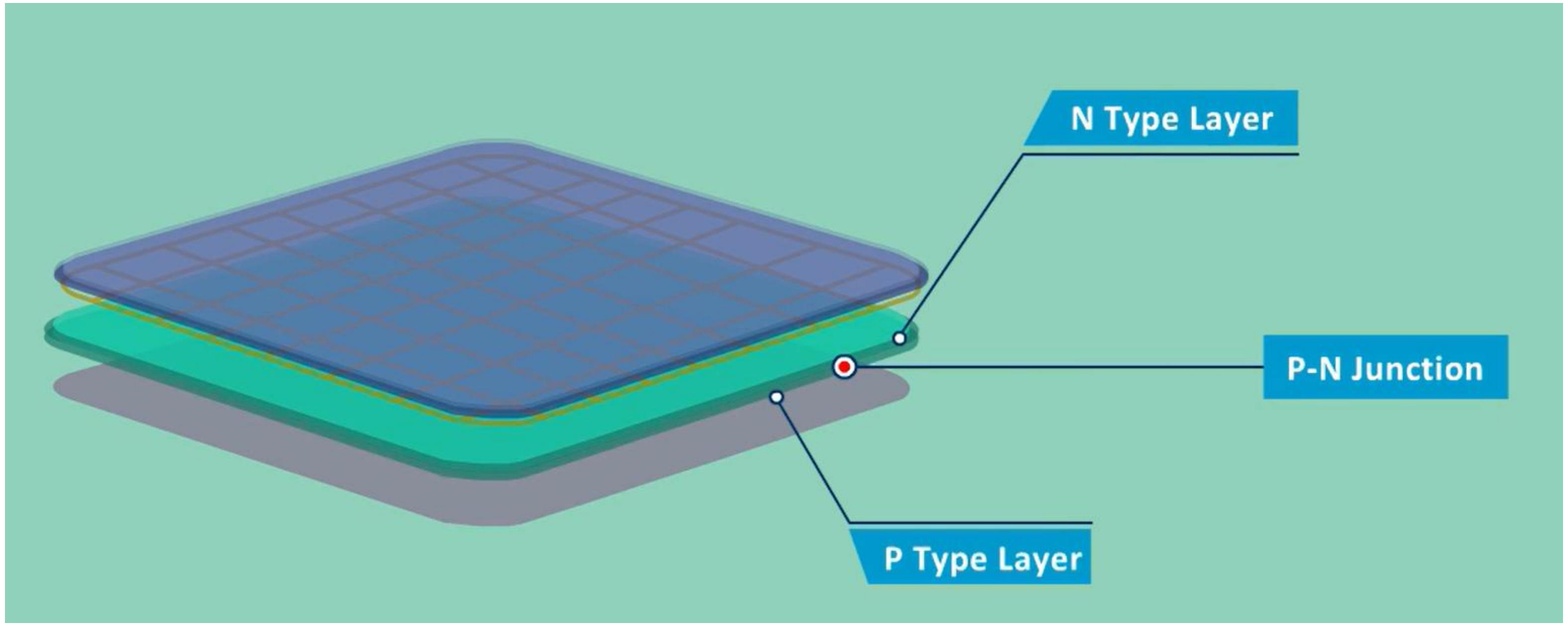
Photodiode

1.1 Photovoltaic Sensors (Solar Cells)

Made from semiconductor materials, typically silicon, that *generate voltage upon exposure to light*.

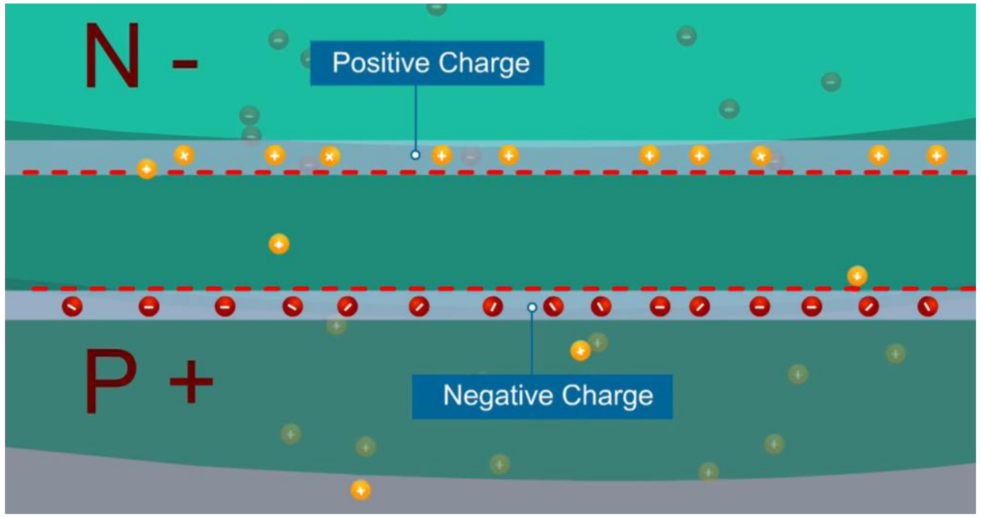


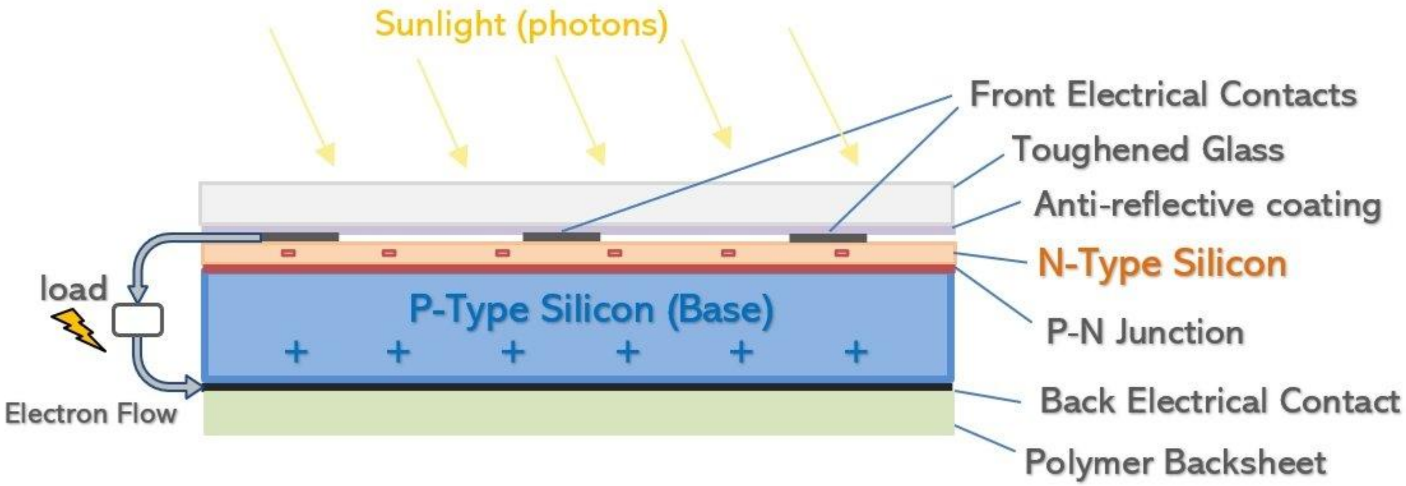

N Type Layer
P Type Layer


N Type Layer
P-N Junction
P Type Layer

Photon Absorption:

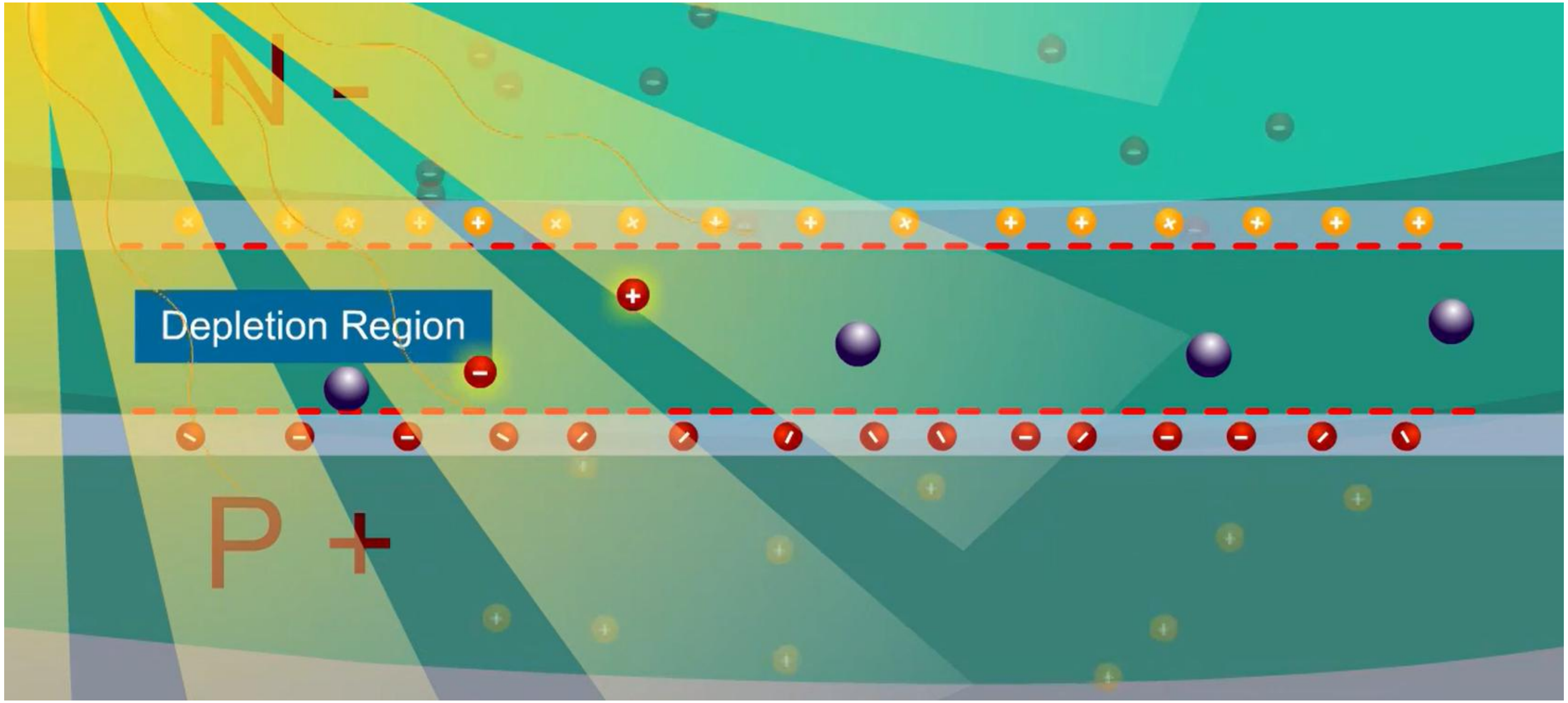
When sunlight (or other light sources) <u>*strikes the surface of a solar cell*</u>, photons (light particles) <u>*penetrate the semiconductor material*</u>, usually silicon.





Electron Excitation:

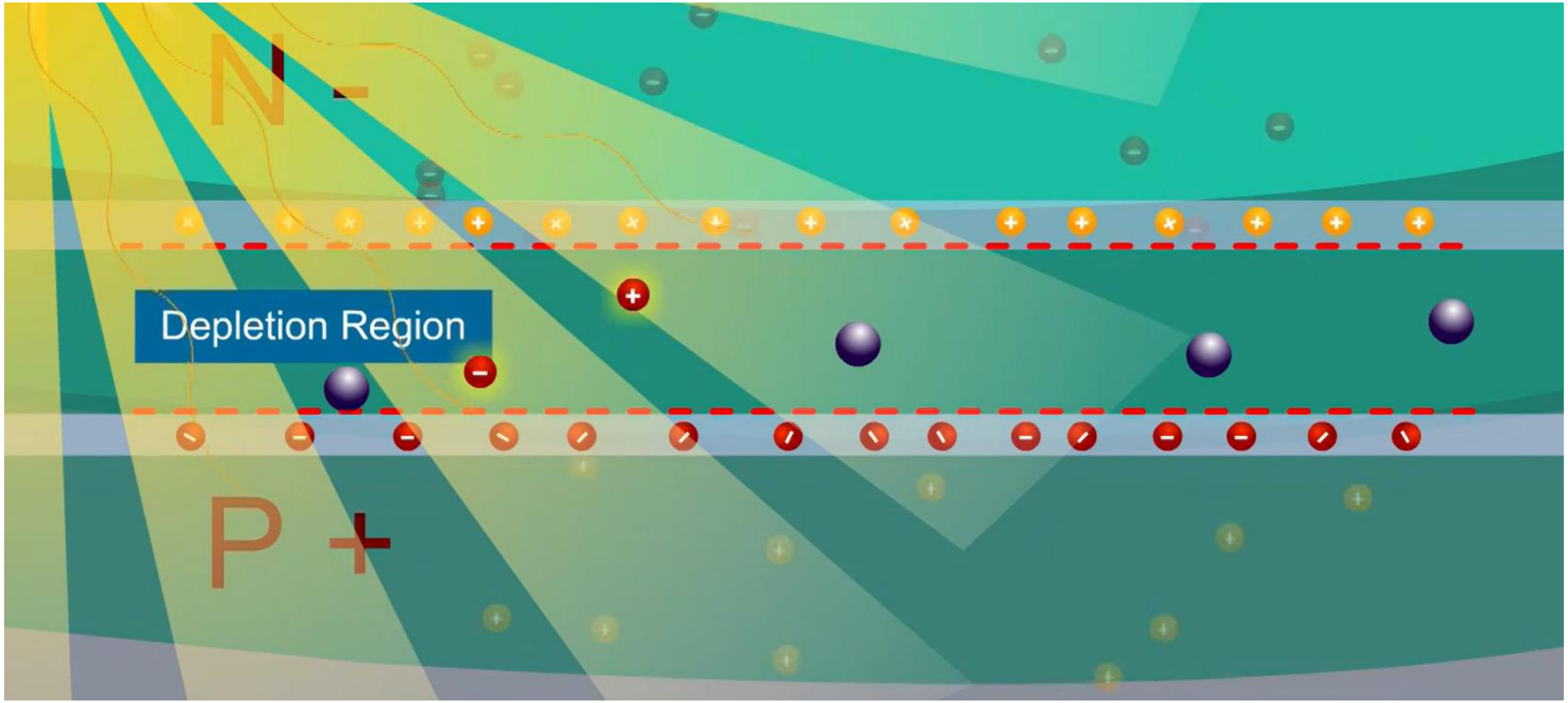
The energy from the photons *<u>excites electrons</u>* in the silicon, *<u>freeing them from their atomic bonds</u>*.



Creation of Electron-Hole Pairs:

This excitation *generates electron-hole pairs*—free electrons and positive holes.

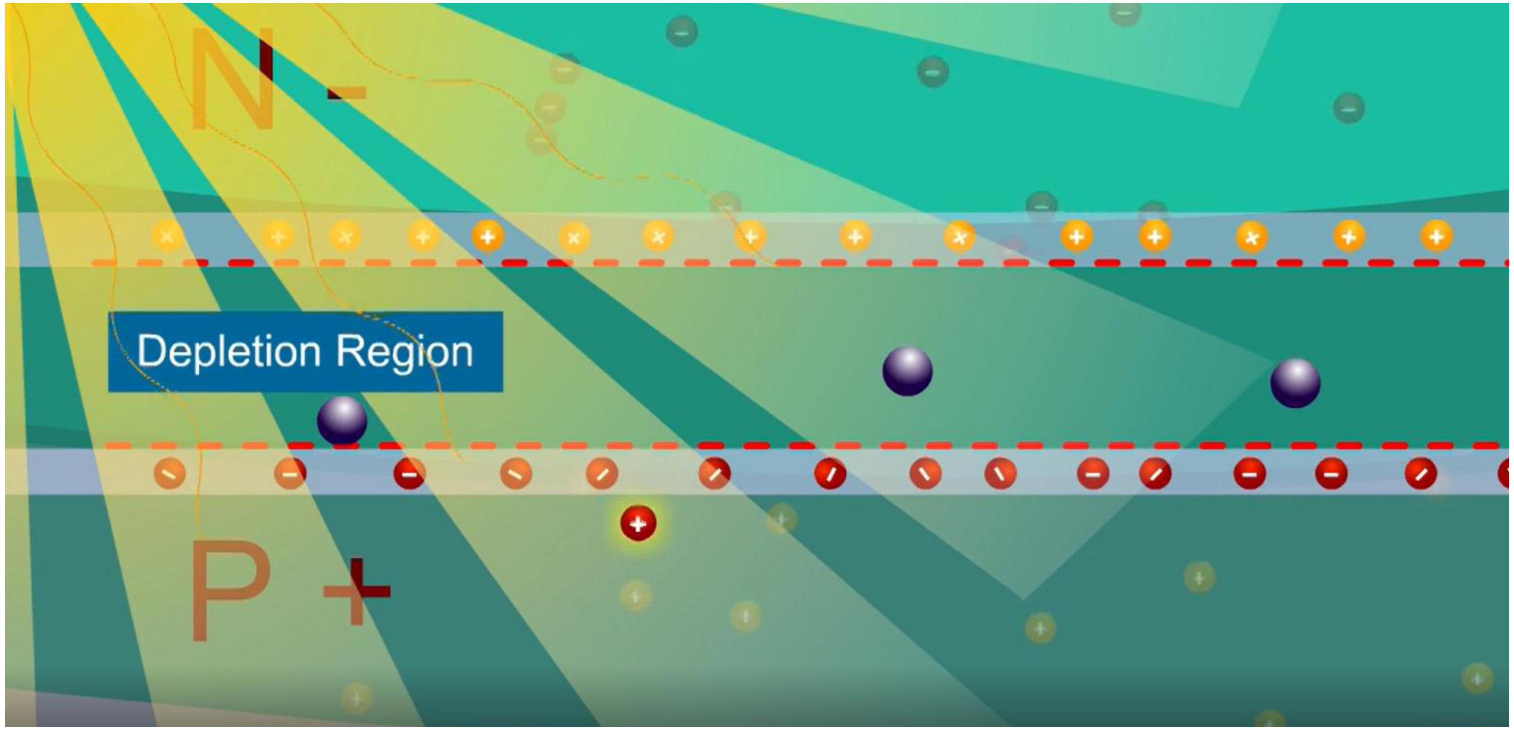
These pairs are *critical for current flow within the cell*.



Electric Field and Current Flow:

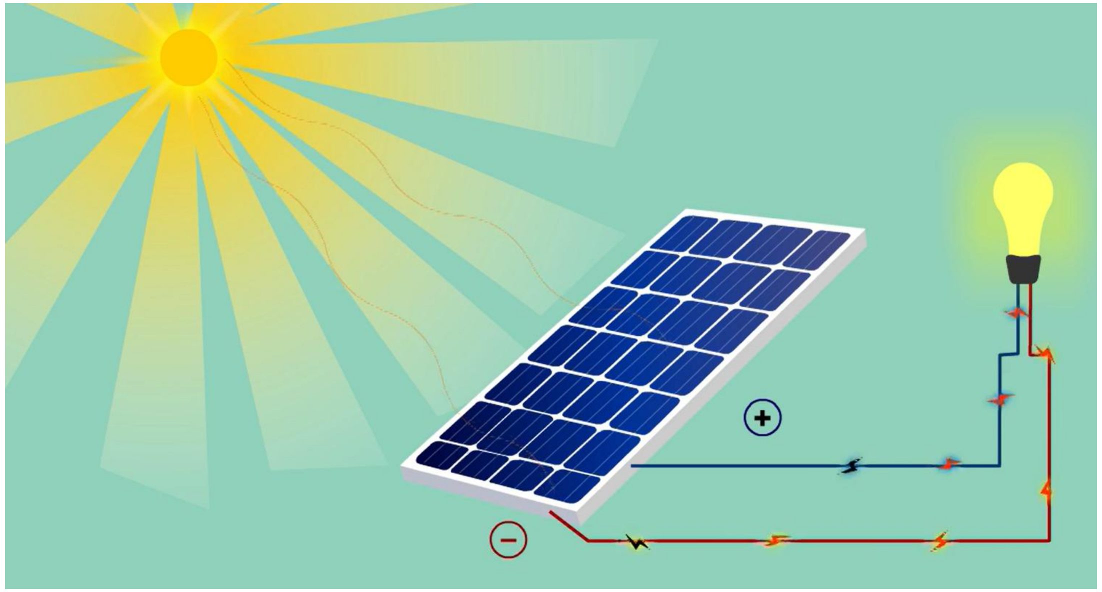
The solar cell has a *built-in electric field due to the p-n junction* (where positively and negatively doped silicon layers meet).

This field *pushes the free electrons towards the negative layer* and the *holes towards the positive layer*, generating a flow of electric current.



External Circuit:

When connected to an external circuit, the ***flow of electrons through this circuit creates usable electrical power***, which can drive loads or charge batteries.

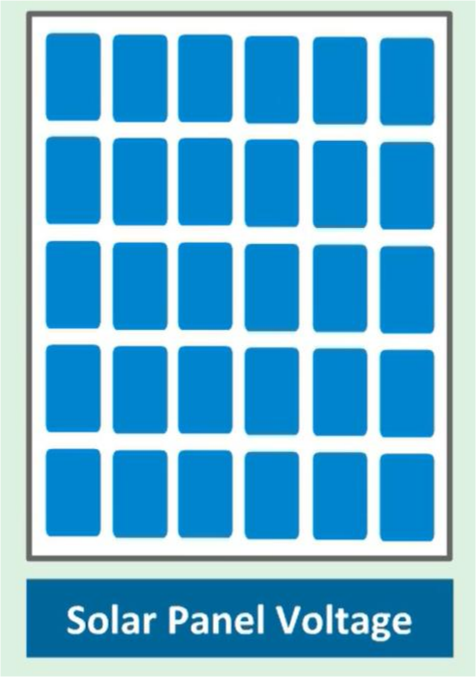


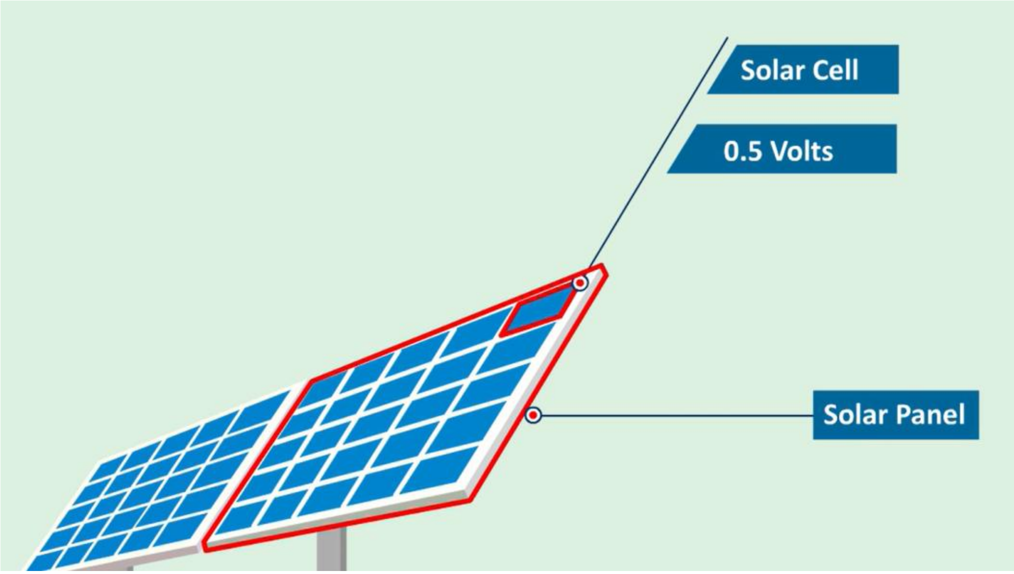
$$I_{ph} = k \cdot E$$

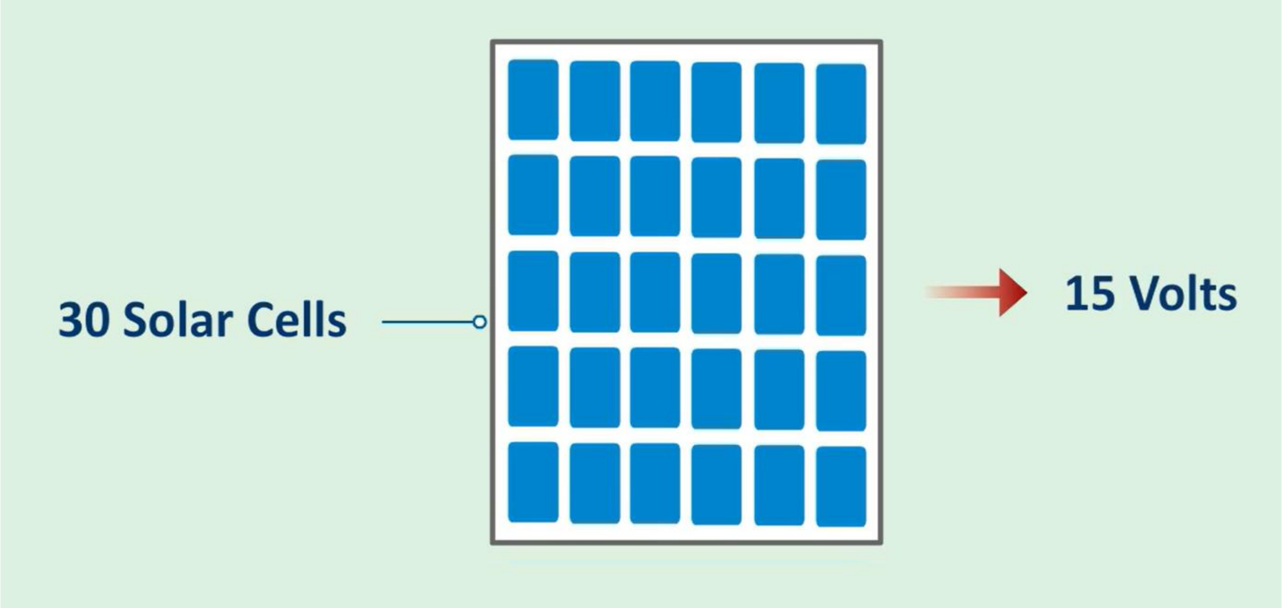
I_{ph} = Photocurrent (A)

k = Proportionality constant depending on the cell material and design

E = Light intensity (W/m²)


Solar Panel Voltage


Solar Cell
0.5 Volts
Solar Panel


30 Solar Cells
15 Volts

I-V (Current-Voltage) Characteristics

$$I = I_{ph} - I_0 \left(e^{\frac{qV}{kT}} - 1 \right)$$

I = Current (A)

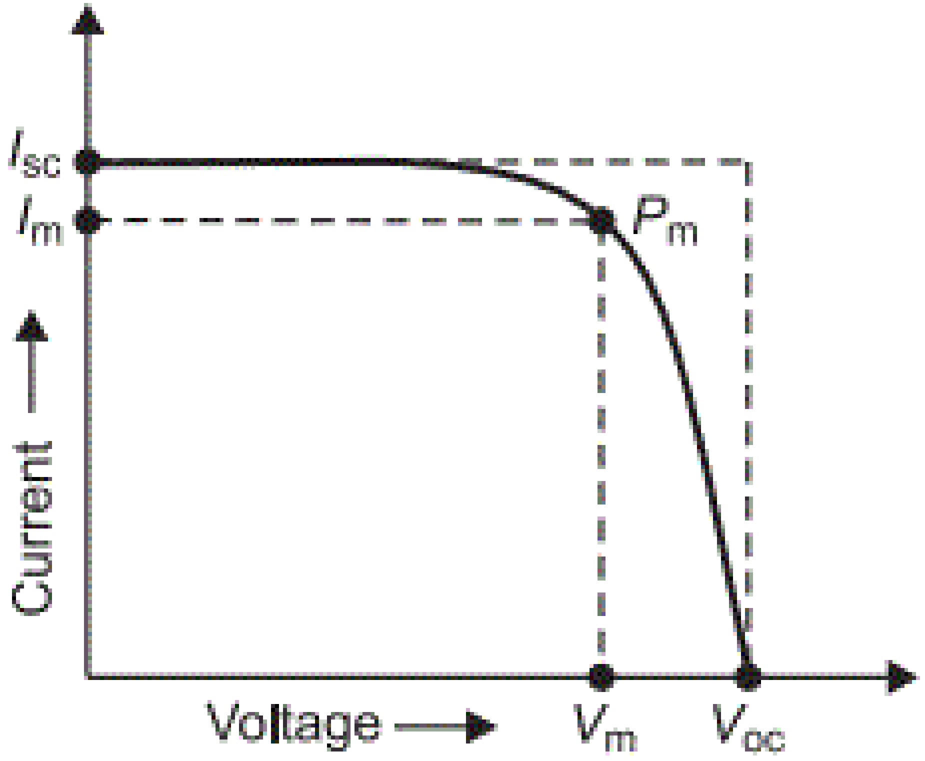
I_0 = Reverse saturation current of the diode (A)

q = Charge of an electron (1.602×10^{-19} C)

V = Voltage across the cell (V)

k = Boltzmann constant (1.381×10^{-23} J/K)

T = Absolute temperature (K)



Open-Circuit Voltage (V_{oc}):

The open-circuit voltage Voc is *<u>the maximum voltage</u>* available from a solar cell when there is *<u>no external load connected</u>* (i.e., when the circuit is open). At this point, *<u>no current flows through the cell</u>*, and Voc is measured across the terminals.

Short-Circuit Current (I_{sc}):

The short-circuit current Isc is the *<u>maximum current</u>* that flows through the solar cell *<u>when its terminals are shorted</u>* (i.e., the *<u>output voltage is zero</u>*).

Maximum Power Point (MPP):

The maximum power $Pmax$ output by the cell occurs at the maximum power point, *where both voltage V_{mp} and current I_{mp} are optimized*.

$$P_{max} = V_{mp} \cdot I_{mp}$$

Fill Factor (FF):

The fill factor is a *measure of the cell's efficiency* in *converting solar energy to electrical energy*. It's defined as the ratio of maximum power to the product of open-circuit voltage Voc and short-circuit current Isc.

$$FF = \frac{V_{mp} \cdot I_{mp}}{V_{oc} \cdot I_{sc}}$$

Efficiency:

The overall efficiency η of a solar cell is the ratio of output electrical power to input light power.

$$\eta = \frac{P_{max}}{E \cdot A} \times 100\%$$

η = Efficiency (%)

E = Incident light intensity (W/m^2)

A = Surface area of the solar cell (m^2)

Problem:

A solar cell is tested under standard conditions (light intensity $E = 1000\ \mathrm{W/m^2}$) with the following parameters:

- **Short-circuit current** $I_{sc} = 5\ \mathrm{A}$
- **Open-circuit voltage** $V_{oc} = 0.6\ \mathrm{V}$
- **Maximum power point (MPP)**:
  - **Voltage at MPP** $V_{mp} = 0.5\ \mathrm{V}$
  - **Current at MPP** $I_{mp} = 4.5\ \mathrm{A}$
- **Surface area** of the solar cell $A = 0.01\ \mathrm{m}^2$

1. The **maximum power** P_{max}.
2. The **fill factor** FF.
3. The **efficiency** η of the solar cell.

Calculate Maximum Power (P_{max}): The maximum power P_{max} is found at the MPP, using V_{mp} and I_{mp}:

$$P_{max} = V_{mp} \times I_{mp}$$

$$P_{max} = 0.5\ \mathrm{V} \times 4.5\ \mathrm{A} = 2.25\ \mathrm{W}$$

Calculate Fill Factor (FF): The fill factor FF is the ratio of P_{max} to the product of V_{oc} and I_{sc}:

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}}$$

$$FF = \frac{2.25\ \mathrm{W}}{0.6\ \mathrm{V} \times 5\ \mathrm{A}} = \frac{2.25}{3} = 0.75$$

Calculate Efficiency (η): The efficiency η is the ratio of the maximum power output to the power of the incident light on the solar cell:

$$\eta = \frac{P_{max}}{E \times A} \times 100\%$$

$$\eta = \frac{2.25 \text{ W}}{1000 \text{ W/m}^2 \times 0.01 \text{ m}^2} \times 100\%$$

$$\eta = \frac{2.25}{10} \times 100\% = 22.5\%$$