Math and Science for Sub-Saharan Africa (MS4SSA)

Project-Based Learning: Introduction to Photovoltaics

M.G. Zebaze Kana
Visiting Scholar, Worcester Polytechnic Institute

Section A: Background and introduction

Section B: Introduction to electricity

Section C: Introduction to photovoltaics

Section D: Summary and concluding remarks

Background and Introduction

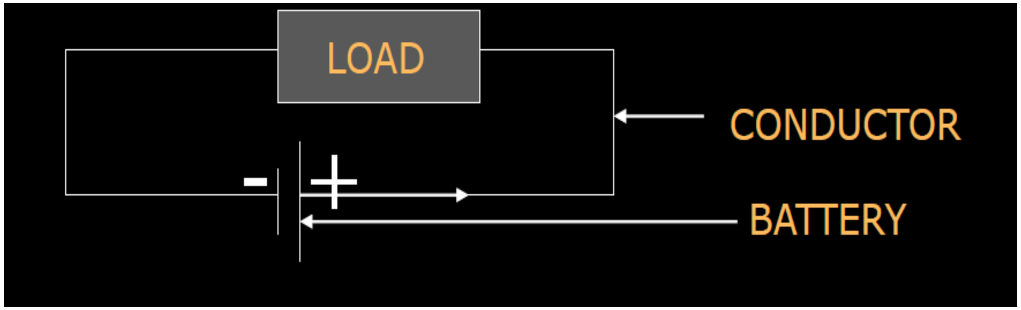
- Electricity is generally considered by many people as a sign of development and modernization…
- Access to cheap and reliable electric power is also a requirement for improved quality of life and industrial development
- However, most people in Africa do not have adequate access to electricity
- This class presents the basic ideas behind electricity and an introduction to photovoltaics

Some Sources of Electricity

- Fossil Fuels
- Nuclear Power
- Renewable Energy (Solar, Biomass, Hydro, geothermal, wind, …)
  - Solar cells – Generate electricity from the sun
  - Wind and hydro – Generate electricity from moving fluids (wind and water)
  - Dynamos and generators – Generate electricity from electromagnetic interactions, e.g., where coils (conductors) move in magnetic fields e.g., bicycle dynamo, generators etc.
- The energy generated can be stored temporally in batteries

Introduction to Electrical Circuits

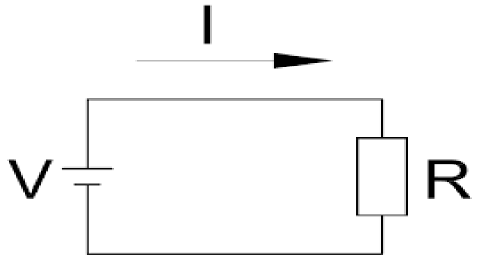
- An electrical circuit comprises the source, electrical conductor, and a load



- Electrons flow from the negative electrode of the battery towards the load and then to the positive electrode.
- Holes flow in the opposite direction, from the positive electrode to the load, and then to the negative electrode.
- By convention the electric current I flows in the same direction with the holes
- The battery is a 'reservoir' of charges

Ohm's Law

- If one applies a voltage (V) across a conductor, there will be a flow of current (*I*) through the conductor in such a way that ***I*** and **V** are proportional
- This linear relationship between the Current (I) and the Voltage (V) is referred to as Ohm's law $V = I\,R$



- The unit of voltage is Volt (**V**) while that of the current is *Ampere* (**A**)
- The unit of the resistance is *Ohm* (**Ω**)
- The reciprocal of the resistance is called ***Conductance (G)*** and its unit is ***Siemens (S)***

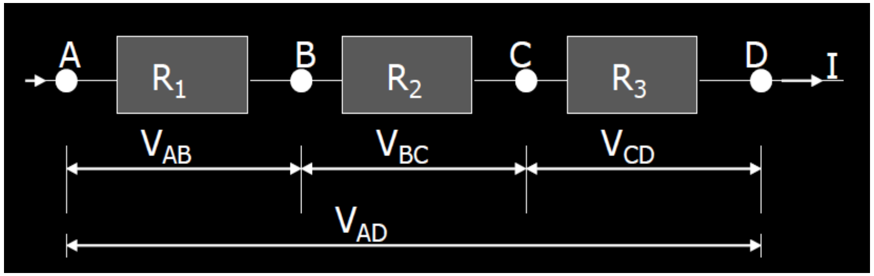
$$G = \frac{1}{R}$$

Units

- The potential difference (V) is measured in volts (V), whereas the current (I) is measured in Amperes (Amps)
- The unit of resistance is Ohms and is designated by
- Note that depending on the magnitudes of potential difference (p.d.), current or resistance, smaller or larger units that are multiples of the above units may be used, e.g., milli-volts (mV), kilo-volts (kV), milli-Amps (mA), mega-Ohms (MΩ) etc.

Resistances in Series

- Loads (or resistances) can be connected either in series or in parallel . Shown below is the series connection.



- The overall resistance or **equivalent resistance** (R) is given by:

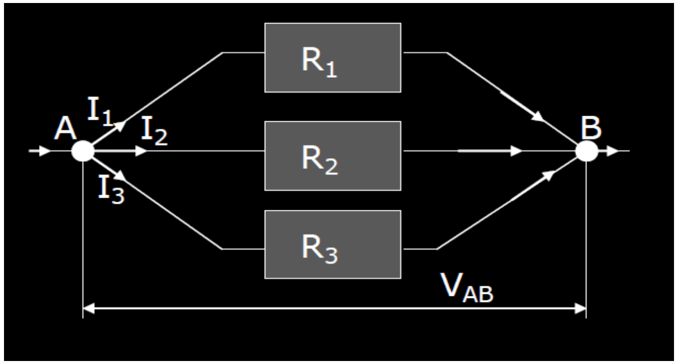
$$\mathbf{R = R_1 + R_2 + R_3}$$

- Take note that the same current I flows through each Resistance, but the applied voltage V is shared proportionally among the 3 loads (resistances).
- The above equation can be generalized for a series of ***n*** resistances R_1 , R_2 , $R_{3,}$ . .. R_n connected in series. The equivalent resistance R is

$$\mathbf{R = R_1 + R_2 + R_3 +. .. + R_n}$$

Resistances in Parallel

- In the parallel connection shown below,



the Equivalent resistance (R) is such that

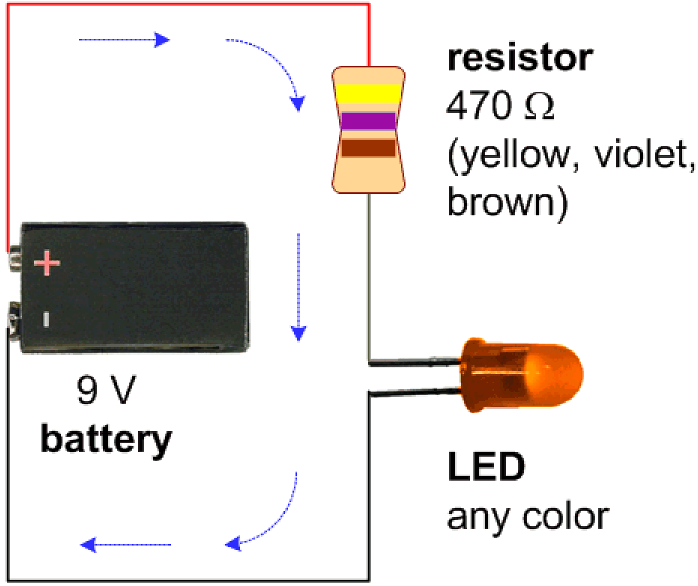
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

- Notice same voltage across the loads, different currents flow through each load.
- Similarly for a set of *n* resistances R_1 , R_2 , R_3, . .. R_n connected in parallel, the equivalent resistance R is such that

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$$

Example 1

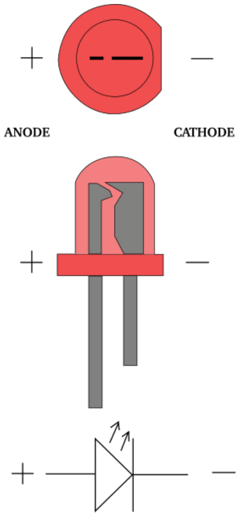
- Let us have a very simple circuit having 1Watt LED (lamp), A 6V battery and measure the current flowing through the load, the p.d. across the load and estimate the power
- *If this system is ON for 1Hr, how much energy will be consumed?*



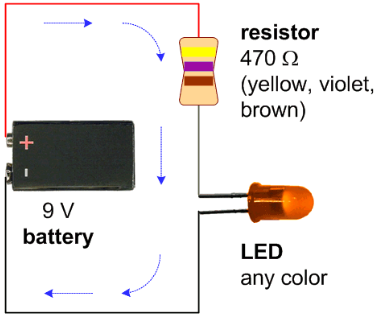
Light Emitting Diode (LED)

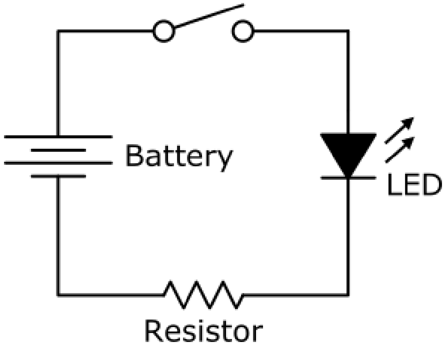
MS4SSA

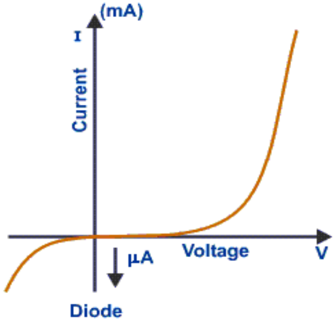
Math and Science for Sub-Saharan Africa



Used as white light-emitting alternatives to light-bulbs
Commonly used in electronics, devices such as cell phones, computers, TVs







Introduction to Photovoltaic

- A solar cell converts incident sunlight (photons) directly into electricity
- Materials suitable for converting sunlight into electricity are the semiconductors
- Solar cells can either be:
  - Inorganic (stable, high efficiency, but a bit expensive and relatively difficult to fabricate)
  - Organic (easy to fabricate, but unstable)
  - Hybrid Inorganic-organic
- Recall that an atom comprises the nucleus and electrons arranged in shells (allowed orbits) around the nucleus

Solar Cell Terms

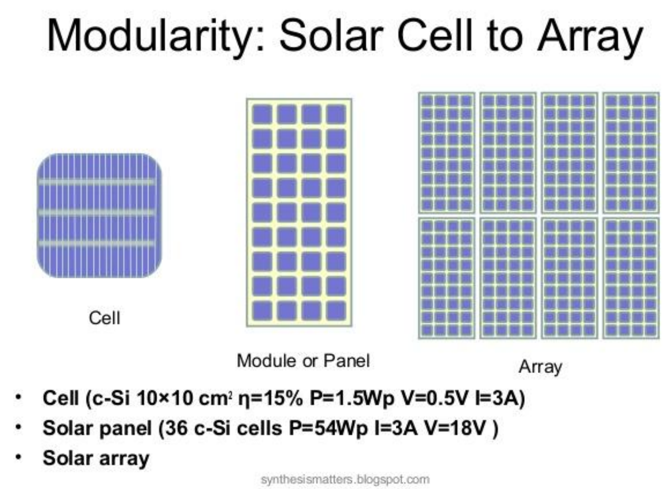
- A set of cells assembled together constitute a Module
- Modules are connected together to form an Array

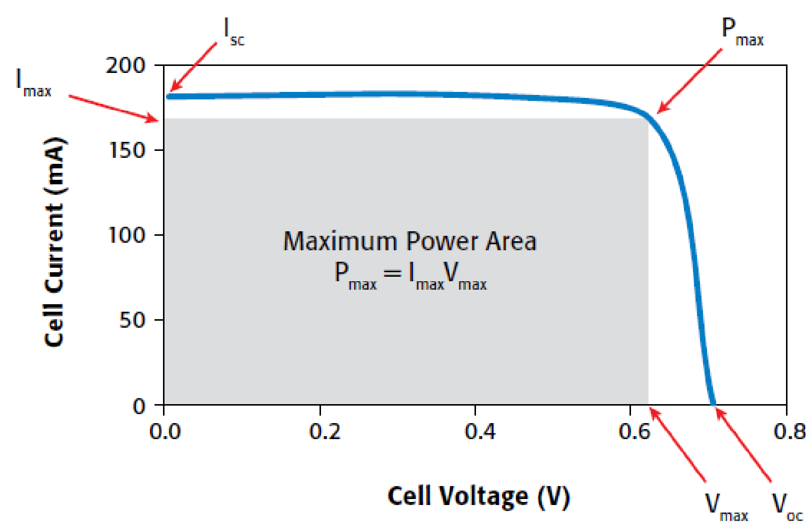
- V_{oc} =Open circuit voltage
- I_{sc} = Short circuit current
- P_{max}= Maximum Power
- η = Conversion efficiency

$$\eta = \frac{P_{max}}{P_{in}}$$

- **FF** = Fill Factor

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





Practical Solar Cells

- We now have a rough understanding of the principles of a solar cell
- Remember that to minimize unnecessary recombination of the electron-hole pairs, materials of high purity are required
- Also to enhance absorption, antireflection coatings or thin films are recommended
- Sunlight is intermittent, hence the need for storage (batteries) of the charge generated

Problem 1

1. Let us use the solar panel to replace the battery in the previous example.
2. Measure current, voltage and estimate P = IxV
3. What are some possible issues in this approach?

Energy Requirements

- The total energy requirements (E), can be determined as follows:

$$E = Total\ \ Watts\ \ of\ \ Loads \times Hrs\ in\ operation$$

$$= Watt\ \ Hrs$$

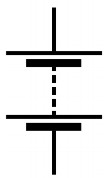
- Number & size of panels required can be determined

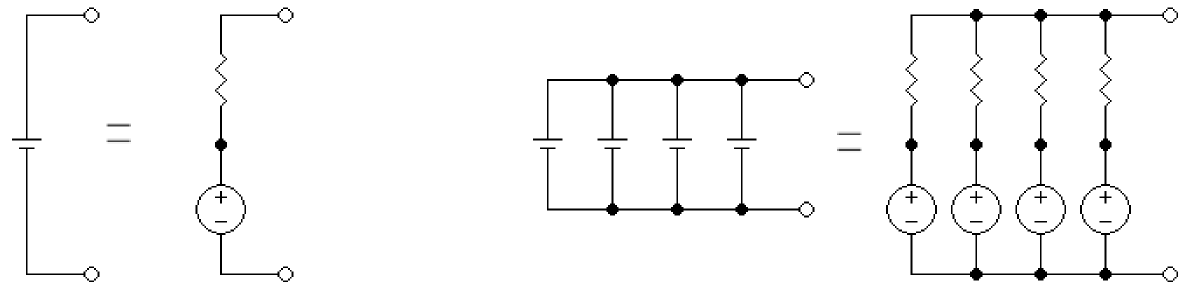
$$Watts\ \ \mathrm{Re}quired\left(solar\ \ panels\right) = \frac{Total\ \ energy\ \ required}{system\ voltage}$$

Introduction to Batteries

- Energy generated can be temporally stored in a batteries
- A battery is an electrochemical cell (or device) capable of generating energy from a chemical reaction
- A standard cell is one whose e.m.f. is almost time and temperature invariant
- The amount of electricity an accumulator can store is referred to as the capacity of the cell
- Cells can be connected either in Series to increase the Voltage or in Parallel to increase the Current

Battery Capacity





Each cell is a voltage source with a source resistance.

- The capacity of a cell may be considered as the amount of charge stored (Q=It)
- For example, if an accumulator can supply 4A for 20 hours (C20 rating), the capacity for this accumulator is 80 Amp-hours (80-AH)
-

Quiz

This 12V, 4.5AH battery when fully charged can supply:

- A: A load of 54W for 20 hours
- B: A load of 20A for 4.5 hours
- C: A load of 12A for 4.5 hours
- D: 54WHr irrespective of the wattage

Problem 2

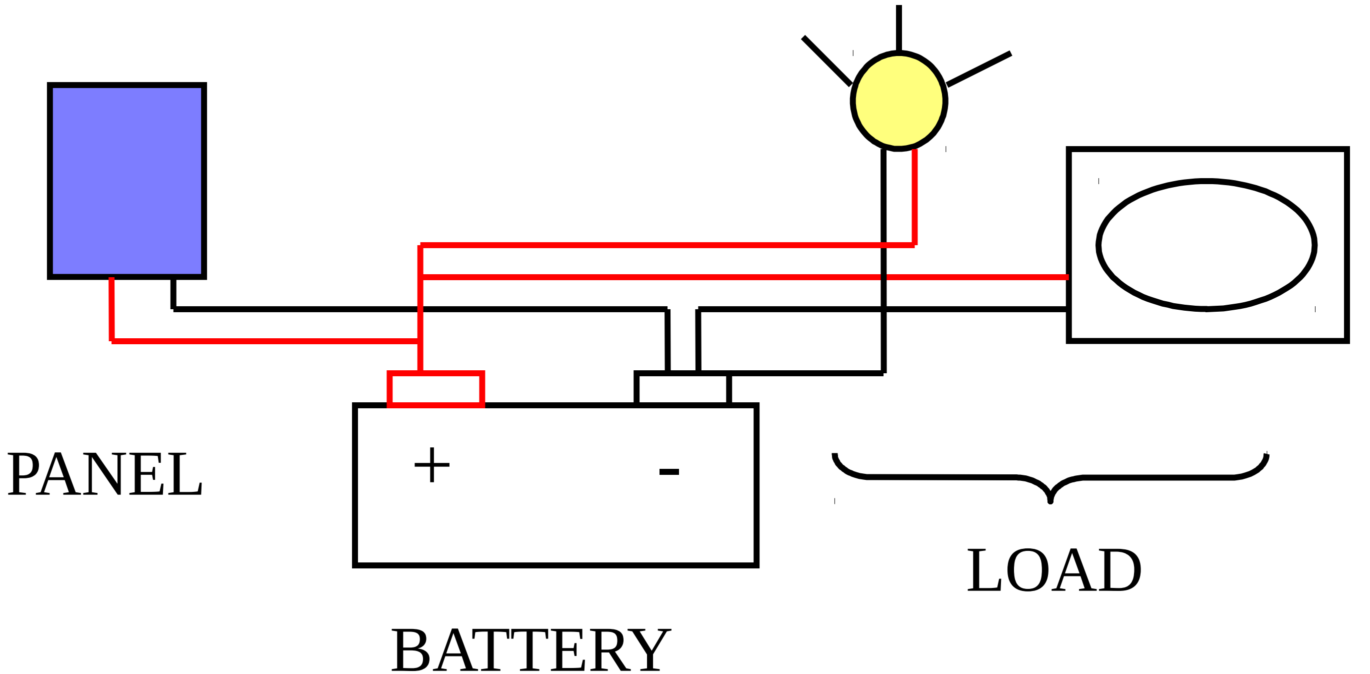
1. From the provided bulb, PV and battery, Design a small PV system and estimate its autonomy

2. Design a PV system to take care of your basic needs in a remote house

Practical Connection Modes

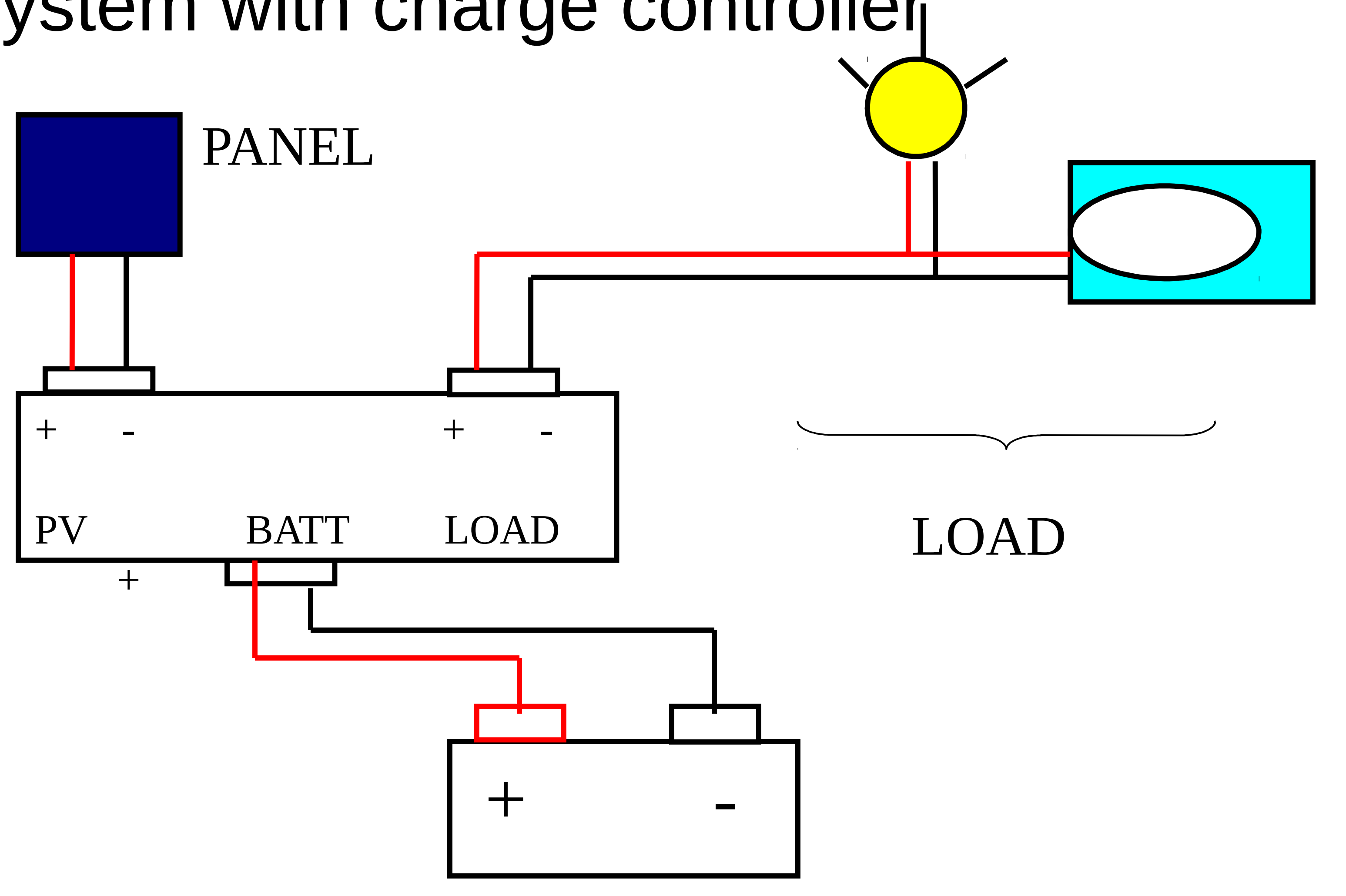
- *Case 1: One Battery: One Panel System*

a) System without charge controller



Practical connection Modes

(b) System with charge controller



Summary and Concluding Remarks

- This class presents an introduction to electricity and photovoltaics
- Basic principles of Ohmic and non-Ohmic conduction were introduced
- Quantum mechanics fundamentals were then elucidated before using the band gap concept to distinguish between insulators, semi-conductors and holes
- It is our hope in our next hands-on session, we will be able to now construct simple systems to take care of our energy need