STUDY ON SOLAR CELLS – FILL FACTOR AND EFFICIENCY

PROJECT REPORT

Submitted by

SREEPRIYA P

Register No: AB20PHY025

Under the guidance of

Dr. SANTHI A

Submitted to

Mahatma Gandhi University, Kottayam

In partial fulfillment of the requirement for the award of
BACHELOR'S DEGREE OF SCIENCE IN PHYSICS

ST. TERESA'S COLLEGE (AUTONOMOUS),

ERNAKULAM, KOCHI-682011

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DEPARTMENT OF PHYSICS

CERTIFICATE

This is to certify that the project report entitled "STUDY OF SOLAR CELLS - FILL FACTOR AND EFFICIENCY " is an authentic work done by SREEPRIYA P, St. Teresa's College, Ernakulam, under my supervision at the Department of Physics, St. Teresa's College for the partial requirements for the award of the degree of Bachelor of Science in Physics during the academic year 2022-23. The work presented in this dissertation has not been submitted for any degree in this or any other university.

Supervising Guide
Dr. Santhi A
Assistant Professor

Head of department
Dr. Priya Parvathi Ameena Jose
Assistant Professor

Place: Ernakulam

Date: 18/04/2023

ST.TERESA'S COLLEGE (AUTONOMOUS), ERNAKULAM

B.Sc. Physics

PROJECT REPORT

Name: Sreepriya P
Register Number: AB20PHY025
Year of work: 2022-'23

This is to certify that this project "STUDY OF SOLAR CELLS - FILL FACTOR AND EFFICIENCY" is the work done by SREEPRIYA P.

Staff member in charge
Dr. Santhi A

Head of the department
Dr. Priya Parvathi Ameena Jose

Submitted for the university examination held in St. Teresa's College, Ernakulam.

Date: 25/04/2023

Examiners: 24/04/23

St. Teresa's College * Department of Physics * Ernakulam (Autonomous)

DECLARATION

I, SREEPRIYA P final year B.Sc. Physics students, Department of Physics, St. Teresa's College, Ernakulam do hereby declare that this project work entitled "**STUDY ON SOLAR CELLS – FILL FACTOR AND EFFICIENCY** " submitted to Mahatma Gandhi University, Kottayam in partial fulfillment of the requirements for the awardof the degree of Bachelor of Science in Physics is a record of original work done by me under the supervision of Dr. SANTHI A, Assistant professor, St. Teresa's College, Ernakulam.

Place: Ernakulam

SREEPRIYA P

Date: 25/04/2023

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First and foremost I would like to thank God Almighty for showering his blessings upon us onthis endeavor.

I take this opportunity to thank our supervising guide, Dr. Santhi A, Assistant Professor, Department of Physics, St. Teresas College for the valuable guidance given for the successful completion of the project.

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I express my deep sense of gratitude to the Department of Physics, St. Teresa's College for extending the facilities and cooperation required from time to time. I take this opportunity to sincerely thank Dr. Priya Parvathi Ameena Jose, Head of the Department for her generous concern and support.

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CONTENTS

ABSTRACT

The major benefit of using solar energy is that it is a renewable source of energy. In our project, we tried to conduct a study about two solar cells, their fill factor, and their efficiencies. The solar cell characterization covered in this project addresses the electrical power-generating capabilities of the cells. Some of the characterization methods covered here help us to understand more things about solar cells and to use these in the construction of devices that can consume less energy. By the experimental methods, V-I characteristics, determination of fill factor, power, and efficiency were done.

CHAPTER 1- INTRODUCTION

1.1 Introduction

1.1.1 SOLAR CELL RELEVANCE

Energy is a fundamental need for modern life and is the function of modern economics. It is a prerequisite for improving human life and alleviating poverty. Therefore, energy conservation is our important goal. Since the world population is highly dependent on non-renewable resources of energy there is great pressure on these resources. And hence, non-renewable resources of energy are getting depleted. So, here comes the relevance of renewable energies such as solar, wind, tidal, etc. Among these, the applications of solar energy are rocketing nowadays. The earth receives an incredible supply of solar energy. For the past 4 billion years, the sun, which is a star, has been burning as a fusion reactor. Solar energy can be used directly for heating, lighting homes, generating electricity, and various industrial and commercial uses. Moreover, it is non-polluting and helps in reducing the world. Hence, recycling is more important for a country like India. There are many methods for it. REUSE, REDUCE, OR RECYCLE. Today, different kinds of solar cells are available that help us reduce e-waste. The efficiency and fill factor of such solar cells are vital factors in their performance of the same. Here, we are comparing the efficiencies and fill factors of several types of solar cells to that of silicon.

1.1.2 PHOTOVOLTAICS

Photo-voltaic solar energy is one of the renewable sources of energy. The photovoltaic solar cell is a semiconductor device that converts light energy to electrical energy. As fossil fuels are depleting at a fast pace it becomes very important to determine alternative energy sources. All renewable sources found on earth arise from the effect of solar radiation which can be directly or indirectly converted to other energies by using different technologies.

The photovoltaic effect was first observed by Alexandre-Edmond Becquerel in 1839. Subsequently, in 1946 the first modern solar cell made of silicon was invented by Russel Ohl. This crystalline silicon is one of the dominant photo-voltaic materials which is abundant, non-toxic, and low cost. It allows the fabrication of cells with high and stable conversion efficiency. Various other materials include gallium-Arsenide, cadmium-telluride, and Indium-Selenide.

A solar cell or a photo-voltaic cell is an electrical device that converts the energy of light to electricity by the photovoltaic effect. This conversion is a physical as well as chemical phenomenon. Solar cells are the building blocks of solar panels.

The operation of solar cells depends on three factors:

1. Absorption of light to generate the charge carriers, holes (p-type), and electrons(n-type)
2. Separation of charge carriers.
3. Collection of charge carriers at the respective electrodes establishing the potential difference across the p-n junction.

1.2 CLASSIFICATION OF SOLAR CELL

1.2.1 FIRST-GENERATION SOLAR CELLS –WAFER-BASED

First-generation solar cells are produced on silicon wafers. Due to high power efficiency, it is one of the oldest and most popular technologies. This is further categorized into

- Single/Mono-crystalline silicon solar cells
- Poly/Multi-crystalline silicon solar cells
- Amorphous Silicon cells
- Hybrid Silicon cells

1.2.2 SECOND-GENERATION SOLAR CELLS-THIN FILM SOLAR CELL

Most thin film solar cells like amorphous silicon and a-Si are second-generation solar cells and are more economical as compared to first-generation wafer solar cells. Silicon wafer solar cells have light-absorbing layers up to 350 micrometers thick while thin film solar cells have very thin layers generally of the order of 1-micrometer thickness. Thin films are classified into

- a-Si-Amorphous Silicon
- CdTe-Cadmium-Telluride
- CIGS-Copper Indium Gallium Diselenide

1.2.3 THIRD-GENERATION SOLAR CELL

Third-generation solar cells are the new promising technologies but have not been commercially investigated in detail. Most of the developed third-generation solar cell types are

- Nanocrystal-based solar cells
- Polymer-based solar cells
- Dye-sensitized solar cells
- Concentrated solar cells

1.3 FABRICATION OF SOLAR CELLS

To fabricate a solar cell it must obey certain conditions.

1. Band gap should be about 1.0ev to 1.8ev
2. The optical absorption and electrical conductivity must be high
3. Availability of raw materials is a vital factor
4. Price should be less

1.3.1 Raw materials required

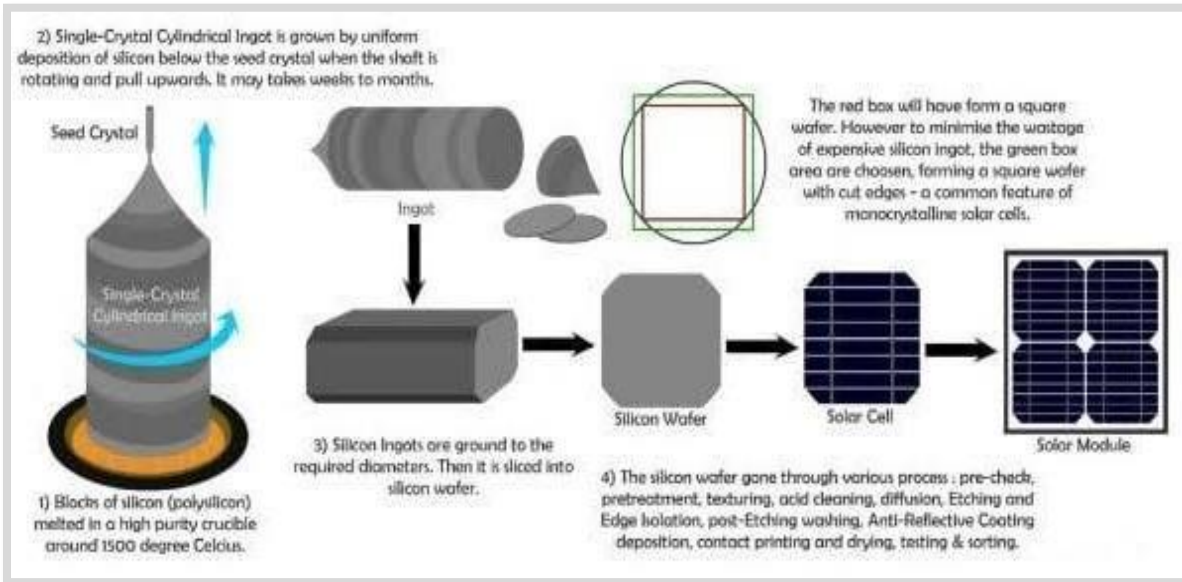
In silicon-based solar cells, the solar module consists of a silicon semiconductor. This semiconductor is surrounded by protective material in a metal frame. This frame can be steel or aluminum. Here, the silicon acts as a gum to put it all together. So, the basic component of a solar cell is silicon. Since it is not pure in its natural state, pure one can be derived from silicon dioxides such as quartzite gravel or crushed quartz. Then, we need phosphorus and boron ions to produce an excess and a deficiency of electrons to produce electricity. Moreover, titanium dioxide is used as an anti-reflective coating.

1.3.2 CONSTRUCTION OF SOLAR CELLS

To produce solar cells, we need to make silicon wafers. It is obtained by melting silicon. It should go through three major steps ingot growth, slicing, and cleaning. Next, we want to convert silicon wafers to solar cells. It involves the following steps:

1. Inside an electric furnace, the silicon dioxide of either quartzite gravel or crushed quartz is placed. A carbon arc is then applied to release oxygen and the products we get are carbon dioxide and molten silicon. This process yields silicon with one percent impurity, useful in many industries but not the solar cell industry.
2. The silicon obtained 99 percent pure silicon is purified further using the floating zone technique. When the silicon is passed through the heated zone several times, the impurities are dragged toward one end with each pass. At a point, the silicon is deemed pure and the impurity end is removed.
3. Solar cells are made of silicon boules, a polycrystalline structure that has the atomic structure of a single crystal. The most commonly used method to create a boule is the Czochralski method. In this method, a seed crystal of silicon is withdrawn and rotated, and a cylindrical ingot or boule of silicon is formed. The ingot is pure and the impurities remain in the liquid.

4. From the boule, silicon wafers are sliced one at a time using a circular saw. Rectangular or hexagonal wafers are sometimes used in solar cells because they can be fitted together perfectly, thereby utilizing all the available space on the front of the solar cell.
5. Then the wafers are polished to remove the saw marks.
6. The next step is doping. The traditional way of doping silicon wafers with boron and phosphorus is to introduce a small amount of the impurity during the Czochralski method in step 3. A more frequent way of doping silicon with phosphorus is to use a small particle accelerator to shoot phosphorus ions into the ingot.
7. Electrical contacts connect each solar cell to another and the receiver of the producer current. The contacts must be very thin so as not to block sunlight. After contacts are in place, thin strips are placed between cells. The most commonly used strips are tin-coated copper.
8. Pure silicon can reflect up to 35 percent of sunlight. To reduce sunlight loss, an anti-reflective coating is put on the silicon wafer. Then the finished solar cells are encapsulated; that is, sealed into silicon rubber or ethylene vinyl acetate.



Fig(1) - Fabrication method

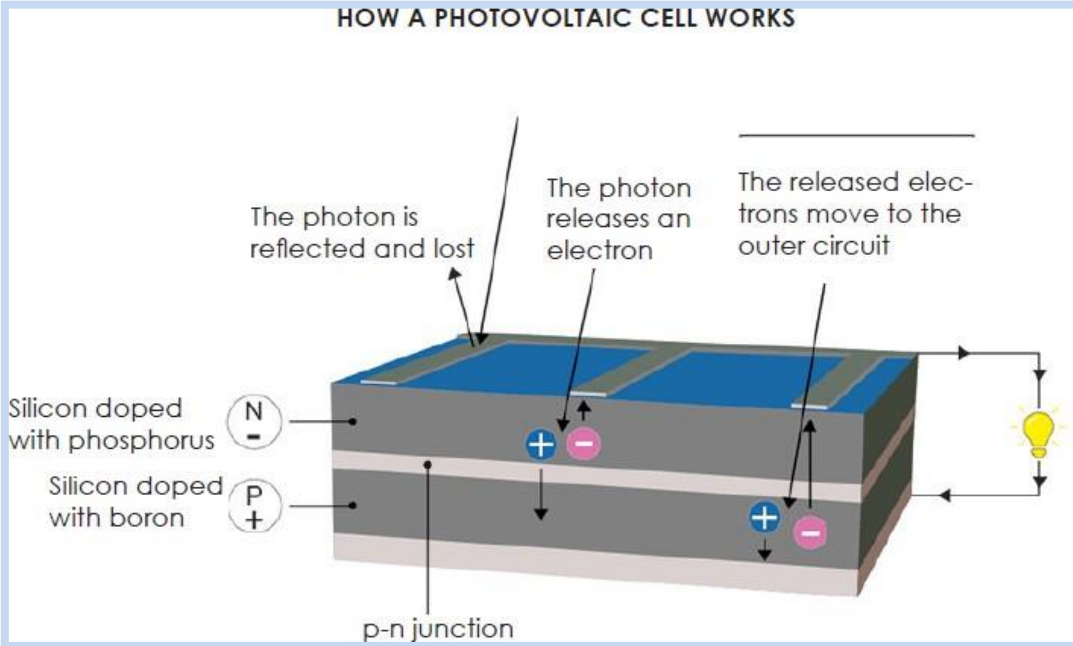
CHAPTER 2 - THEORY

The basic theory behind the working of solar cells is the photovoltaic effect.

2.1 Si-based P-N Junction

A photovoltaic device or solar cell converts incident radiation into electrical energy. Incident photons are absorbed to photo-generate charge carriers, which then pass through an external load to do electrical work. Photovoltaic devices may be p-n junctions or metal-semiconductor Schottky junctions. For example, a crystalline Si p-n junction solar cell may have a thin n-type semiconductor layer on a thick p-type substrate. The electrodes attached to the n-side must allow the light to enter the device and at the same time result in a small series resistance. Electrodes are deposited on to n-side to form an array of finger electrodes on the surface. There is a thin film antireflection coating on the surface outside the electrodes to reduce the reflection loss.

The n-side of the p-n junction is very narrow to allow most of the photons to be absorbed within the depletion region (W) and the neutral p-side and the photogeneration of electron-hole pairs occur mainly in these regions. EHP photogeneration then occurs in a volume defined by W and L_e on the p-side. The photogenerated EHPs are immediately separated by the built-in field, which drifts them apart. The electrons drift towards the n-side and holes toward the p-side, which generates a photocurrent. The excess electrons reach the neutral n-side, then drive around the external circuit, do work, and reach the p-side to recombine with the excess holes on this side. As a result, there will be a continuous external photocurrent during illumination. If the load is short-circuited, then the magnitude of the external current is simply equal to the photocurrent Iph generated by incident radiation.



Fig(2) - Working of a solar cell

Silicon has some special properties, especially in crystalline form. Due to its electronic configuration, it forms a crystalline form. The only problem is that pure crystalline silicon is a poor conductor of electricity. To overcome this issue we add impurities to it and this process is called doping. When pure silicon is given energy in the form of heat for example, it can cause a few electrons to break from their bonds leaving a hole behind. These are called free carries. They wander around the crystal looking for another hole to fall into and carrying electricity. In pure silicon, there are a few of them available. But in impure silicon is a different thing. In impure silicon (doped) the bonds are broken easily hence generating more charge carriers. So impure silicon (p-type and n-type) is more conducting than pure silicon.

Silicon remains the material of choice for photovoltaics because of its abundance, non-toxicity, high and stable cell efficiencies, the maturity of production infrastructure, and the deep and widespread level of skill available concerning silicon devices.

The upper limit of silicon solar cell efficiency is 29% but substantially higher than the best laboratory (25%) and large-area commercial (24%) cells.

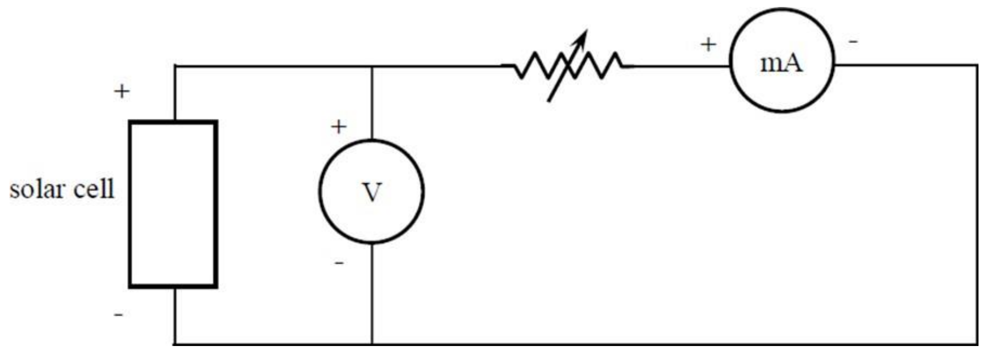
2.2 Dye-Sensitized Solar Cell

Dye-sensitized solar cells (DSSCs) belong to the group of thin-film solar cells which have been under extensive research for more than two decades due to their low cost, simple preparation methodology, low toxicity, and ease of production. The efficiency of existing DSSCs reaches up to 12%. There are two main characteristics of a substrate being used in a DSSC: Firstly, more than 80% of transparency is required by the substrate to permit the passage of optimum, sunlight to the effective area of the cell. Secondly, for efficient charge transfer and reduced energy loss in DSSCs, they should have a high electrical conductivity. The fluorine-doped tin oxide (FTO, SnO2: F) and indium-doped tin oxide (ITO, In2O3: Sn) are usually applied as conductive substrates in DSSCs. The working electrodes (WE) are prepared by depositing a thin layer of oxide semiconducting materials. Firstly, the incident light (photon) is absorbed by a photosensitizer and the electron gets excited. Now, the excited electrons with a lifetime of nanosecond range are injected into the conduction band of the nanoporous TiO2 electrode which lies below the excited state of the dye, where the TiO2 absorbs a small fraction of the solar photons from the UV region. As a result, the dye gets oxidized. These injected electrons are transported between TiO2 nanoparticles and diffuse toward the back contact. Through the external circuit, electrons reach the counter electrode. Then the dye degeneration takes place. Current flows through the circuit. It is a little different method from Si-based solar cells since dyes are used. But the efficiency is less compared to Si solar cells.

CHAPTER 3 - EXPERIMENTAL DETAILS

We aim to find the fill factor and efficiency of two solar cells and compare the results.

3.1 CIRCUIT DIAGRAM



Fig(3) -circuit diagram of working of the solar cell

The fill factor(FF), which is a figure of merit of a solar cell is defined by,

$$FF = \frac{ImVm}{Isc\ Voc}$$

The FF is a measure of closeness of the solar cell I-V curve to the rectangular shape (the ideal shape). It is advantageous to have FF as close to unity as possible, but the exponential p-n junction properties prevent this. Typically FF values are in the range of 70-85% and depend on the device structure. The standard fill factor value for Silicon solar cells is in the range of 0.7-0.82.

The efficiency of a solar cell is defined as the maximum output power from the device per unit of incident radiation power under well-defined conditions. To calculate the efficiency of the solar cell, it is necessary to know how much power the solar cell receives and how much power it produces.

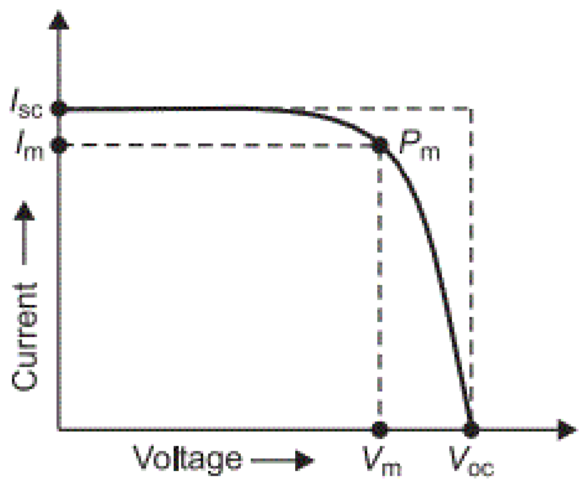
If the light source used is the sun on a cloudless day, the incoming power is approx. 1000 W/m^2. The output power, P_m, can be calculated using the known area of the solar cell.

The efficiency of a solar cell is,

$$\text{Efficiency} = \frac{P_{out}}{P_{in}}$$

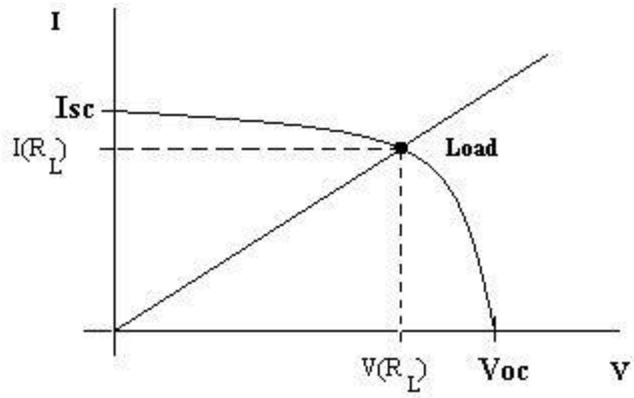
Where, P_{out} is the maximum power output from the solar cell. However, if an incandescent bulb is used as a light source, the total output from the bulb can be estimated using its input power and efficiency. Assuming the filament as a point source (reasonable approximation at a considerable distance from the filament), this total light is assumed to spread over a sphere of radius r, where r is the distance between the filament and the solar cell surface. As in the earlier case, knowing the solar cell surface area, we can calculate the total light fall on its surface. V-I characteristics of a typical Si solar cell are given in the figure.

3.2 Characterization of solar cell



Fig(4) - V-I Characteristics of a solar cell

I_{SC} is the short-circuit current corresponding to zero load resistance and Voc is the open circuit voltage corresponding to the infinite load resistance (ie; when no current is drawn from the solar cell).

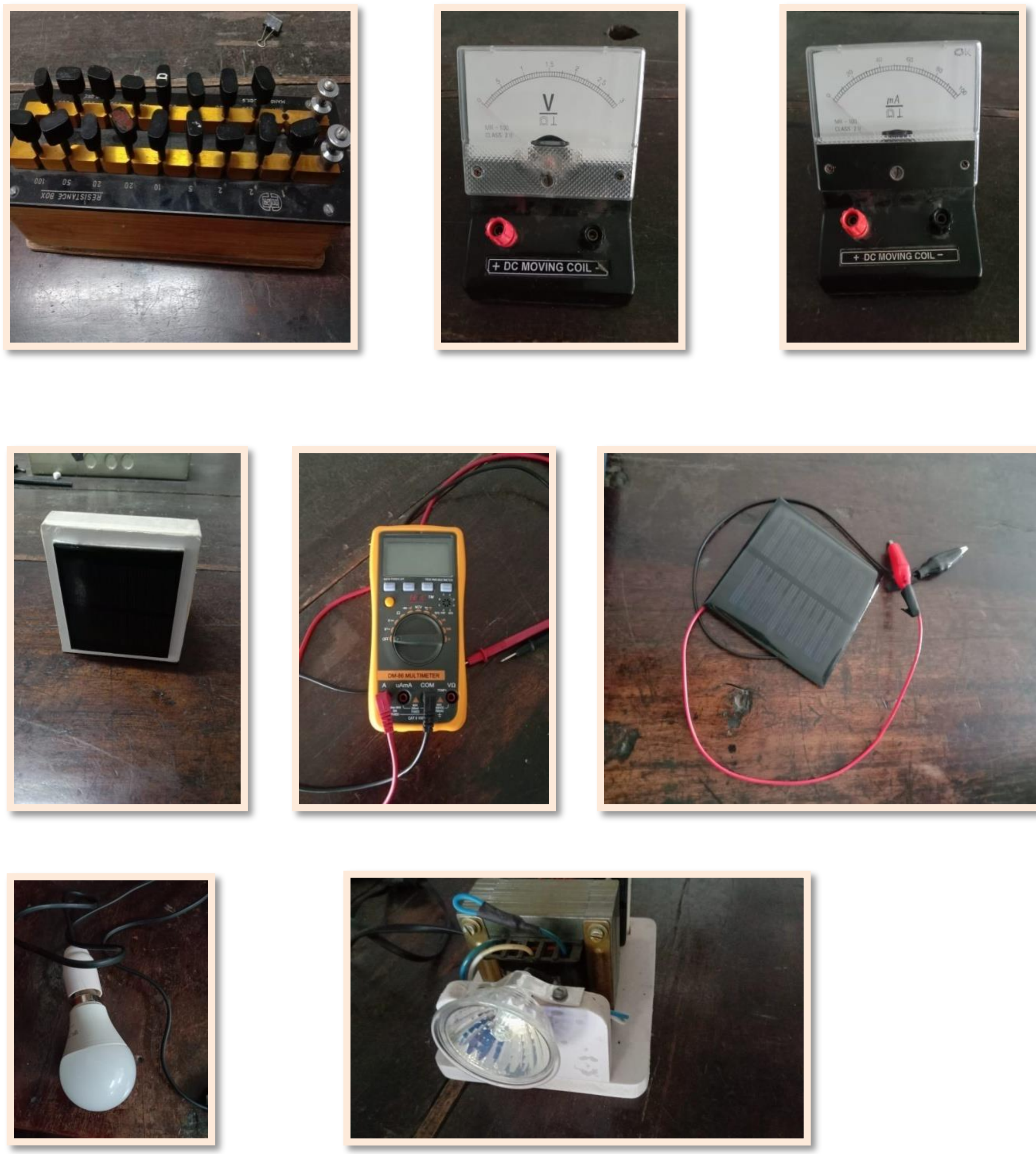


Fig(5) - Load line

A line drawn as in the figure is called a load line. It gives the current and voltage at that point.

3.3 MATERIALS REQUIRED

For our aim, solar cells(A&B), a multimeter, an ammeter (milliammeter and microammeter), a voltmeter (different ranges included), resistance box(0-10,000 Ω), a known watt bulb(10W), light source are required.



Fig(6) - Materials required

3.4 EXPERIMENTAL SETUP

To find the fill factor and efficiency of the solar cell, the setup is done as in the figure. The solar cell is connected in series with a resistance box and ammeter, and parallel with a voltmeter. At first, due to less intensity, the milliammeter did not show any deflection but the micro range ammeter did. According to the intensity, ammeters and voltmeters of different ranges are used. A digital multimeter is also used to measure voltage and current. The circuit is connected as shown in Fig (3). Both solar cells A and B were placed in source light as well as sunlight. The measurements under sunlight were taken at different times of the day.

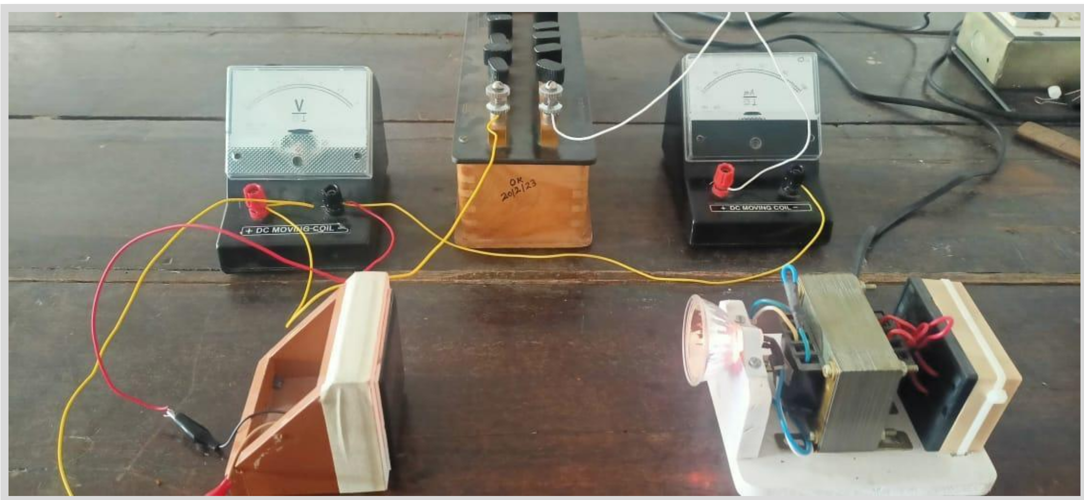


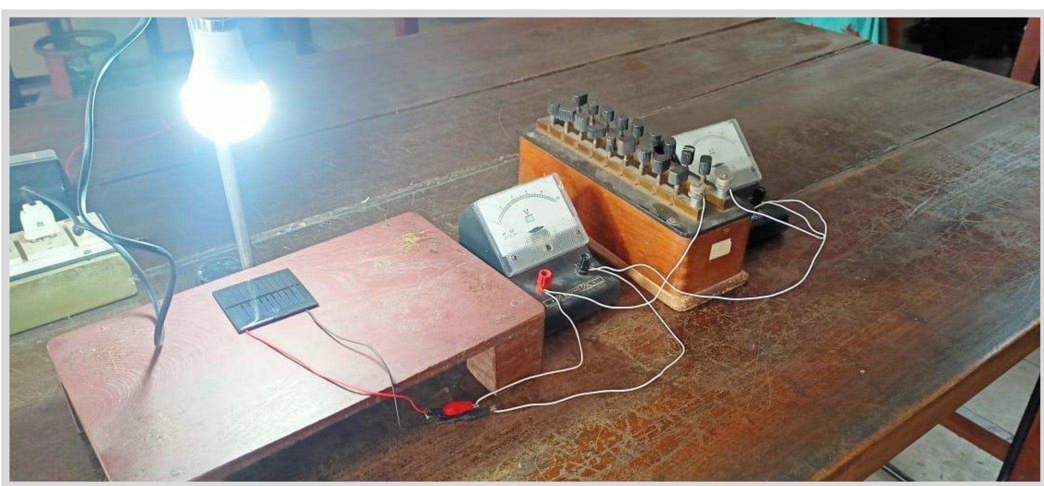
Fig (7) (a)

Fig (7) (b)

Fig(7)-(a) - Experimental setup in source light; (b) Experimental setup in sunlight.

The obtained data is used to plot the V-I characteristics. The point for maximum power is obtained and hence fill factor is calculated.

For calculating the power, another setup is done as in the figure.



Fig(8) - Experimental setup for determining input power

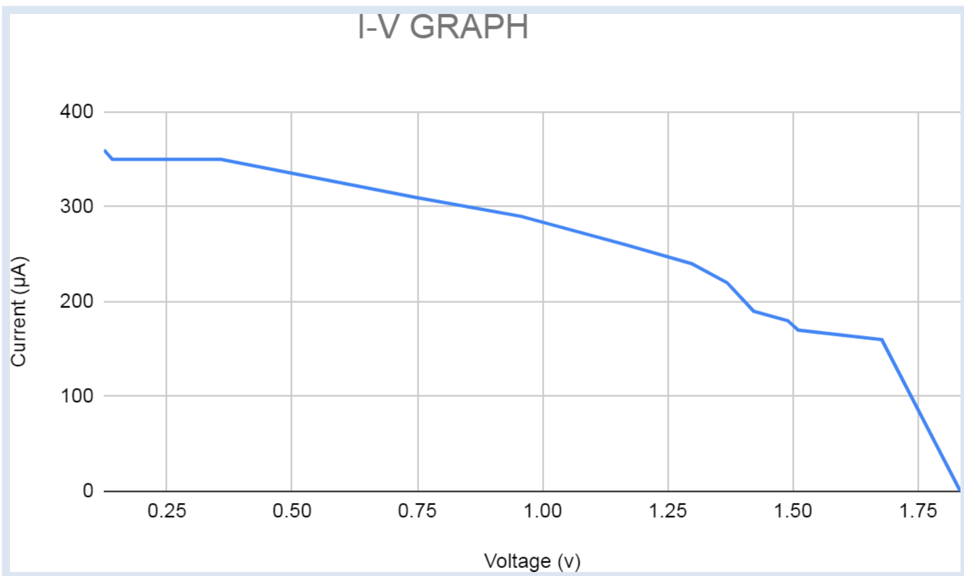
Here, the connections are made according to the same connection used to calculate the fill factor. By varying resistance, voltage and current are measured and maximum power is obtained. The total output power from the bulb is known. The total light from the bulb is assumed to spread over a sphere of radius r, where r is the distance between the filament or bulb and the solar cell surface. Knowing the solar cell's surface area, we can calculate the total light that falls on its surface. Hence we calculate the efficiency of the solar cell.

CHAPTER 4 - RESULTS AND DISCUSSION

Using 2 solar cells A and B, the V-I graphs are plotted during different times of the day using sunlight. Also using source light at different intensities the graphs are plotted.

The V-I graphs of solar cell A placed at a distance of 20 cm from the source light with different intensities are shown below.

Intensity = 51.8 LUX



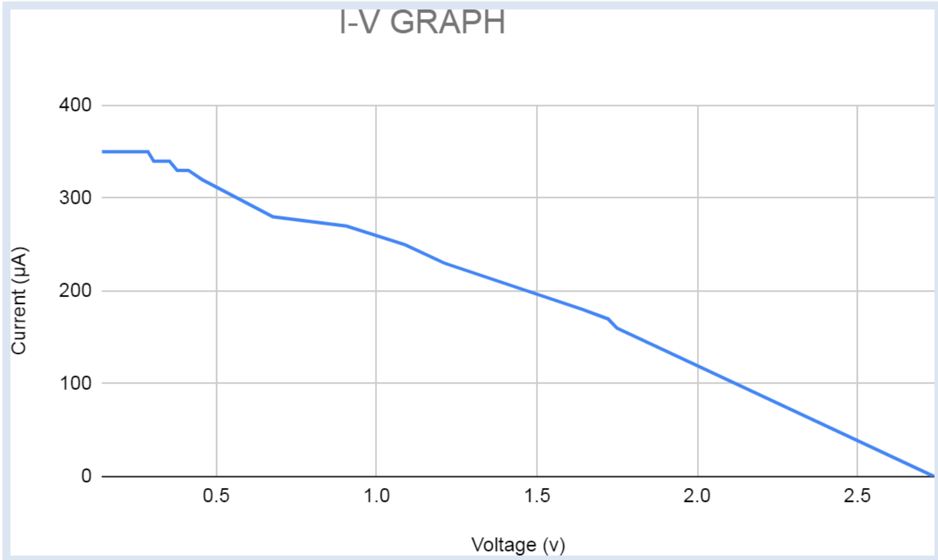
To determine the fill factor,

$$FF = \frac{ImVm}{Isc\ Voc}$$

$$= \frac{240 \times 10^{-6} \times 1.299}{390 \times 10^{-6} \times 1.835}$$

$$= 0.4356$$

Intensity= 65.6 Lux

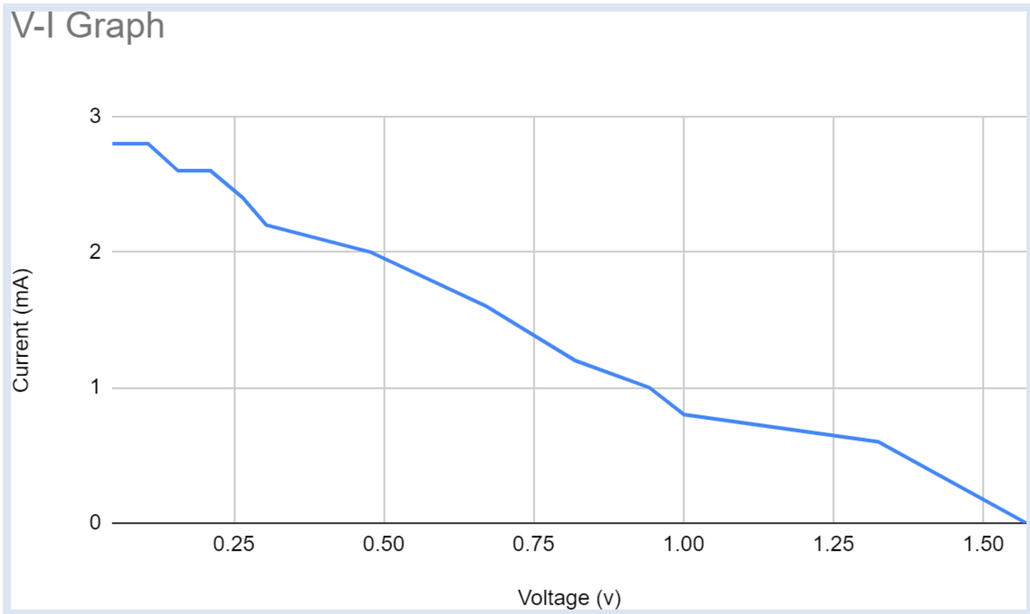


$$FF = \frac{ImVm}{Isc\ Voc}$$

$$= \frac{180 \times 10^{-6} \times 1.643}{360 \times 10^{-6} \times 2.74}$$

= 0.29981

Intensity= 1127 LUX

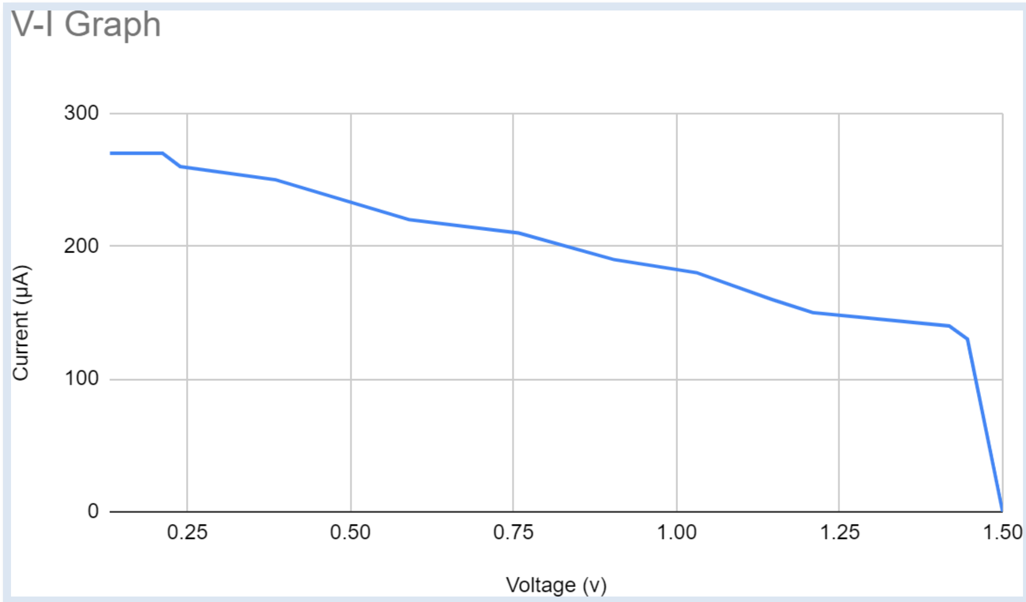


$$FF = \frac{ImVm}{Isc\ Voc}$$

$$= \frac{1.6\ x10^{-3}x0.671}{2.8\ x10^{-3}x1.572}$$

= 0.2439

Solar cell A placed in sunlight at 12:30 PM

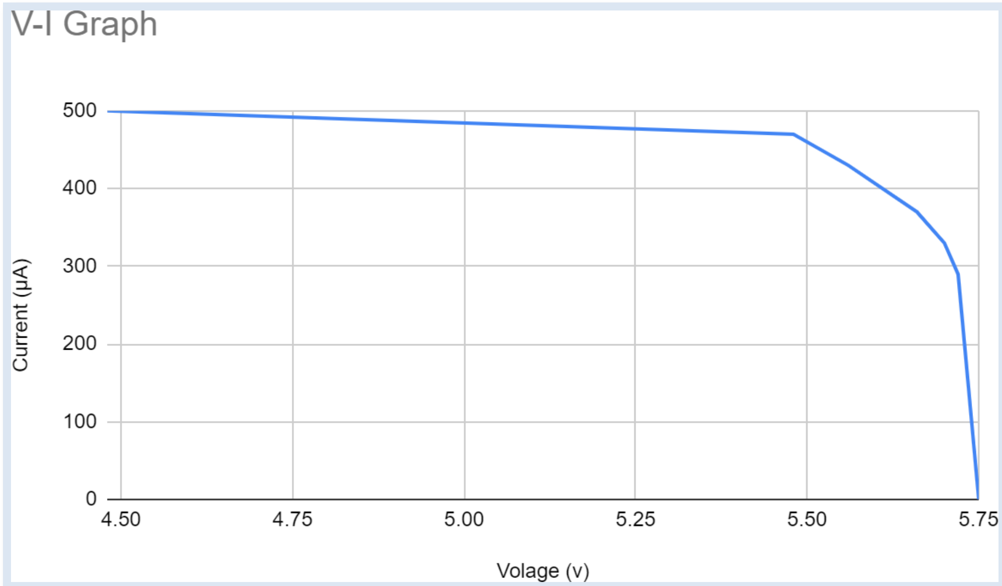


$$FF = \frac{ImVm}{Isc\ Voc}$$

$$= \frac{190 \times 10^{-6} \times 0.904}{270 \times 10^{-6} \times 1.5}$$

= 0.424

Solar cell A placed in sunlight at 3.30 PM

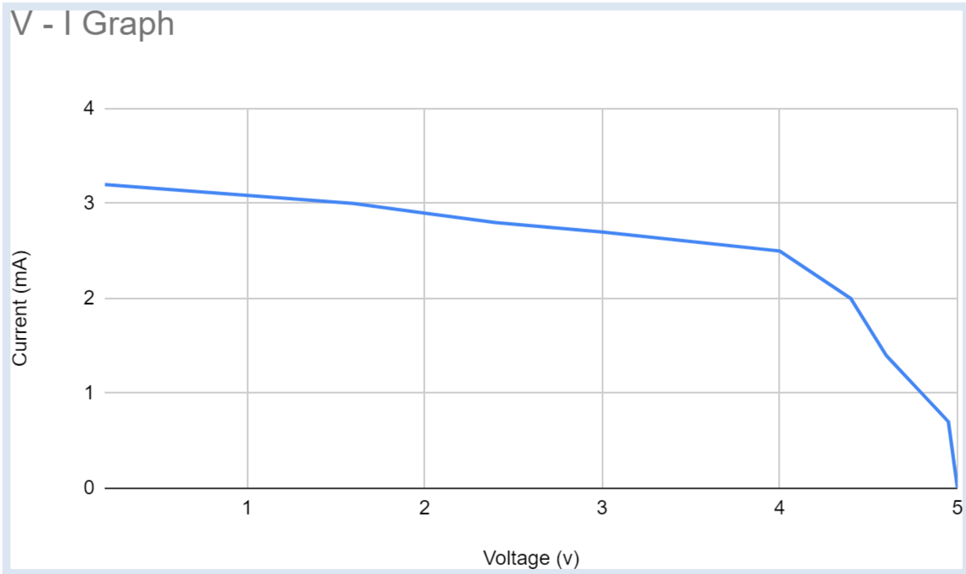


$$FF = \frac{ImVm}{Isc\ Voc}$$

$$= \frac{470\ x10^{-6}x5.48}{500x10^{-6}x5.75}$$

= 0.895

Solar cell B placed in sunlight at 3 PM



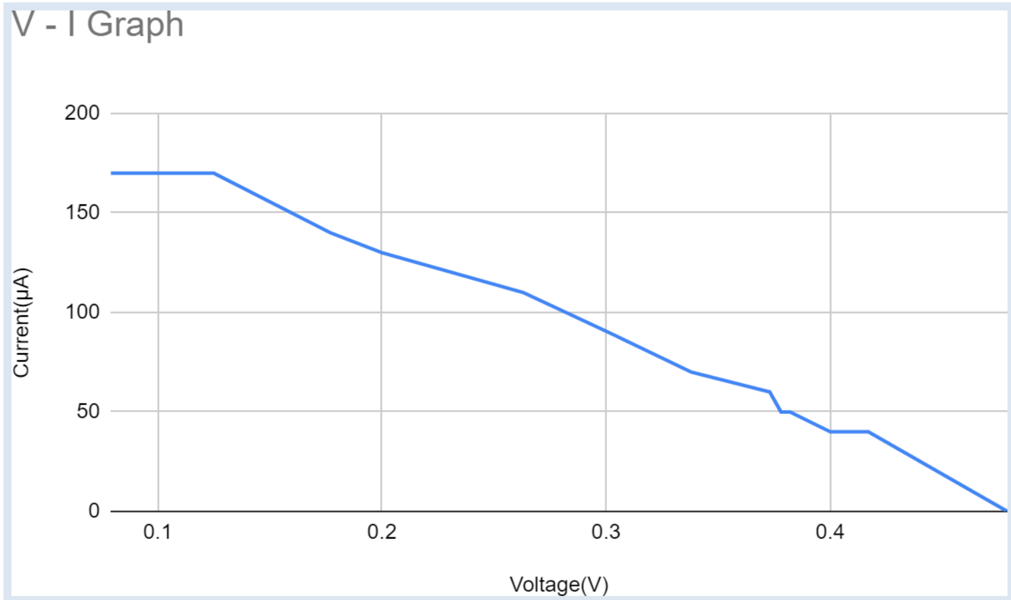
$$FF = \frac{ImVm}{Isc\ Voc}$$

$$= \frac{4.4\ x10^{-3}x2}{3.2x10^{-3}x5}$$

= 0.55

The V-I characteristics of Solar cell B placed at same distance d=23 cm and different intensities are shown below;

Intensity = 53.9 LUX

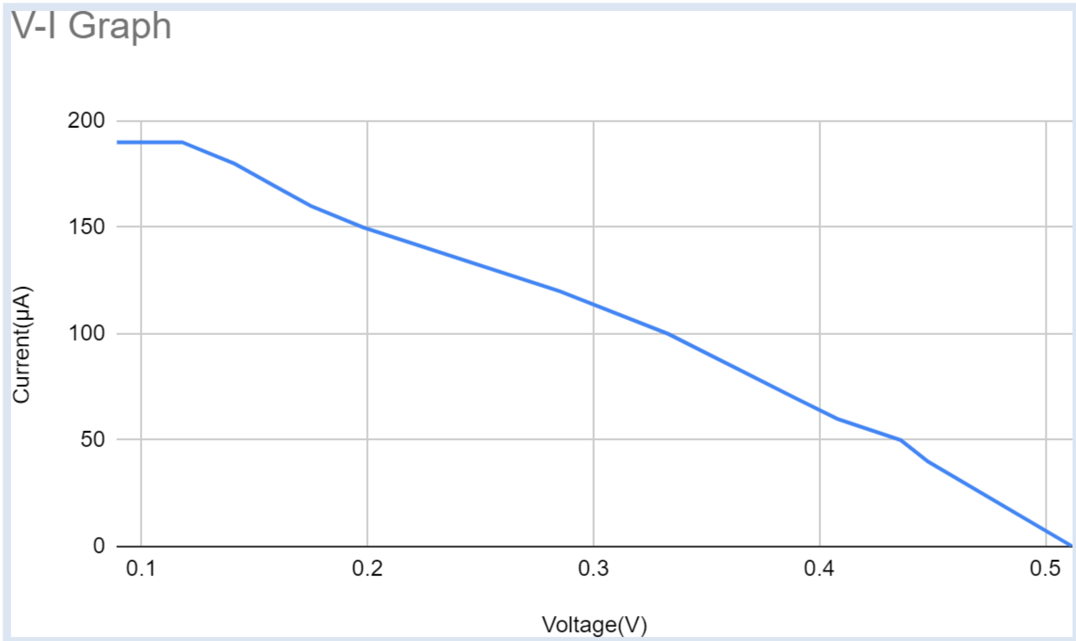


$$FF = \frac{ImVm}{Isc\ Voc}$$

$$= \frac{110 \times 10^{-6} \times 0.263}{170 \times 10^{-6} \times 0.479}$$

$$= 0.35527$$

Intensity = 68.3 LUX

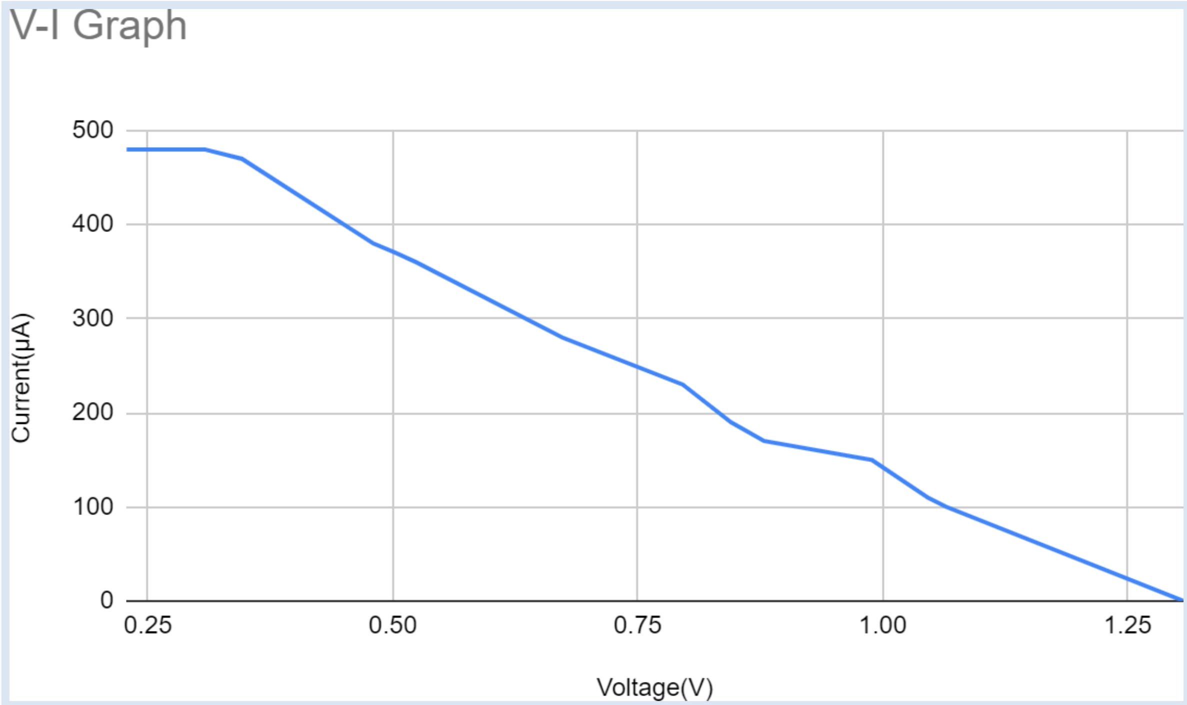


$$FF = \frac{ImVm}{Isc\ Voc}$$

$$= \frac{120x10^{-6}x0.285}{190x10^{-6}x0.512}$$

$$= 0.3515$$

Intensity = 116.7 LUX



$$FF = \frac{ImVm}{Isc\ Voc}$$

$$= \frac{360x10^{-6}x0.524}{480x10^{-6}x1.307}$$

$$= 0.3006$$

Determination of Power and Efficiency of Solar cell A

Voltage(V)	**Current(μA)**	**Power ($x10^{-5}$ W)**
0.146	712	10.395
0.294	693	20.374
0.492	671	33.013
0.73	645	47.085
1.27	589	74.803
2.31	436	100.716
2.63	360	94.68
2.74	331	90.694
2.83	302	85.466
2.89	282	81.498

Total area $= 4\pi r^2$

$= 4 \times \pi \times (20 \times 10^{-2})^2$

$= 0.5024\ m^2$

Area of solar cell $= (6.9 \times 10^{-2})^2$

$= 4.761 \times 10^{-3}\ m^2$

$$\text{Input power} = \frac{\text{Solar area}}{4\pi r^2} \times \text{Power}$$

$$= \frac{4.761 \times 10^{-3}}{0.5024} \times 10$$

$= 0.094765$ W

Output power = 100.71×10^{-5} W

$$\text{Efficiency} = \frac{P_{out}}{P_{in}}$$

$$= \frac{100.716 \times 10^{-5}}{0.094765} \times 100\%$$

$$= 1.0625\ \%$$

Determination of Power and Efficiency of Solar cell B

Voltage (V)	**Current(μA)**	**Power ($\times 10^{-4}$ W)**
0.557	500	2.785
0.675	490	3.308
1.489	420	6.254
1.782	390	6.949
2.05	370	7.585
2.41	310	7.471
2.54	290	7.366
2.89	250	7.225

Total area $= 4\pi r^2$

$= 4 \times \pi \times (20 \times 10^{-2})^2$

$= 0.5024\ m^2$

Area of solar cell = $(6.9 \times 10^{-2})^2$

$= 4.761 \times 10^{-3}\ m^2$

$$\text{Input power} = \frac{\text{Solar area}}{4\pi r^2} \times \text{Power}$$

$$= \frac{4.761\times10^{-3}}{0.5024} \times 10$$

$= 0.094765$ W

Output power $= 7.585 \times 10^{-4}$ W

$$\text{Efficiency} = \frac{P_{out}}{P_{in}}$$

$$= \frac{7.585\times10^{-4}}{0.094765} \times 100\%$$

$= 0.8004$ %

CHAPTER 5 - CONCLUSION AND FUTURE

The use of solar cells in our daily lives is a small step towards a big change. A change that could leads us in conserving more energy. What we have done so far is just a small step in using renewable energy. We look forward to more research to make more modifications to this project for better precision and efficiency. The calculation of efficiency and fill factor of solar cells help us in finding more suitable solar cells in the construction of devices which will help us conserve more energy. We can look forward to a world that would promote more innovative thoughts in young minds through experimental techniques.

During the last decade lead, halide perovskites have shown great potential for photovoltaic applications. However, the stability of perovskite solar cells still restricts commercialization, and the lack of properly implemented unified stability testing and disseminating standards makes it difficult to compare historical stability data for evaluating promising routes toward better device stability. Perovskite-based tandem solar cells are a promising photovoltaic technology to enter the market at a low cost due to their higher power conversion efficiency (PCE) potential. In recent research results, perovskite/CIGS tandem solar cells of high PCEs are realized.

Solar power generation is a promising fields where there are many things to explore. Solar cells are used in many devices such as solar cookers, mobile chargers, etc. Previously, the average efficiency of solar cells was 5%. But photovoltaic technologies have advanced and now the efficiency is between 15-22%. But they have drawbacks as well. Some of the monocrystalline panel brands are LG, Panasonic, and SunPower.Polycrystalline solar panels can overcome some drawbacks. Still, they are less efficient. Some polycrystalline solar panel brands are TrinaSolar and YingliSolar.In the future with less amount of fuel, solar energy can be used to improve the quality of life.

Solar power generation has been developed as one of the most demanding renewable sources of electricity. It has several more advantages than any other form of energy production. It is also a promising field where there are many more things to explore.

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