OSAW

Study of solar cell characteristics

Experiment: - To study the photovoltaic cell characteristics as:

1. V-I characteristics of photovoltaic cell.
2. Spectral characteristics of photovoltaic cell.
3. Areal Characteristics of photovoltaic cell.

Apparatus required:-

1. Light source Tungsten Bulb (60W/100W) mounted in the specially designed metallic mount.
2. Solar cell (6Volt/100mA).
3. Solar cell stand.
4. Experimental module kit
5. Chopper Plates
6. A set of Eight Colour Filters
7. Wooden bench with 100cm. scale.

Main features of the experimental apparatus as given below:

1. Two analog dual range meters are given on the front panel as given below:
   Voltmeter - (1Volt. /10 Volt.).
   Ammeter – (10mA. / 100mA).
   And connections are brought out on the 4mm sockets for input and output connections.
2. Three nos. of variable resistances as mounted on the band switch given on the front panel in series.
   1×1000Ω, 1×100 Ω, 1×10 Ω and connections brought out on the 4mm. sockets.
3. Two pair of sockets also given on the front panel to connect the solar cell.
4. 8 nos. of color filters also provided with the apparatus.
5. Chopper plates with different window size given with this experiment.

Theory:-

A photo voltaic cell is much more sensitive than even a gas filled photoemssive cell and is used as a solar cell.
In such a cell the current is generated due to the photoelectric e.m.f. which is proportional to the intensity of incident light only when the electrodes are short circuited i.e. there is no external resistance.

The emf is generated by the photo-voltaic cell in open circuit, when no current is drawn from it is V_{OC} (V open circuit).

There is the maximum value of emf when a high resistance is introduced in the external circuit a small current is flows through it and the voltage decreases. The voltage is goes on falling and the current is goes on increasing as the resistance in the external circuit is reduced. When the resistance is reduced to zero the current rises to its maximum value known as saturation current and is denoted as **Isc** the voltage becomes zero an I-V characteristics of a photo voltaic cell as shown in fig.2.

Background:

A solar cell is a semiconductor PN junction diode as shown in figure 1. The large surface area indicated in light blue is exposed to incident light energy. Solar cells are usually coated with anti-reflective materials so that they absorb the maximum amount of light energy. Normally no external bias is applied to the cell. When a photon of light is absorbed near the PN junction a hole / electron pair is produced. This occurs when the energy of the photon is higher than the energy band-gap of the semiconductor. The built in electric field of the junction cause the pair to separate and head toward the respective +ve and -ve terminals. The energy from the light causes a current to flow in an external load when the cell is illuminated.

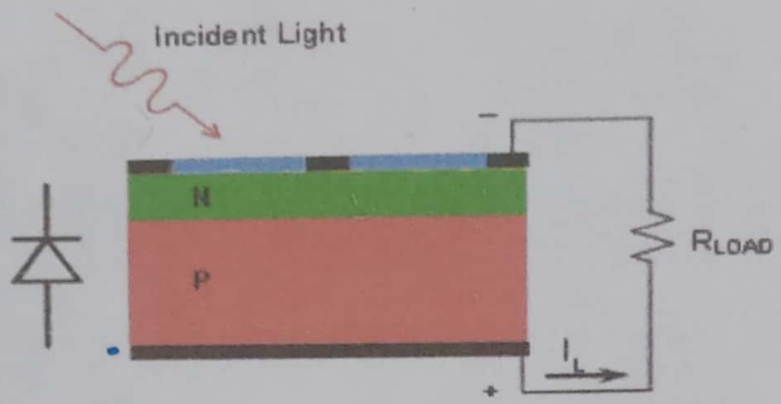


Figure 1 Structure of a basic solar cell.

A typical voltage vs. current characteristic, known as an I/V curve, of a PN diode without illumination is shown in green in figure 2. The applied voltage is in the forward bias direction. The curve shows the turn-on and the buildup of the forward bias current in the diode. Without illumination, no current flows through the diode unless there is external potential applied. With incident sunlight, the I/V curve shifts up showing that there is external current flow from the solar cell to a resistive load as shown with the red curve.

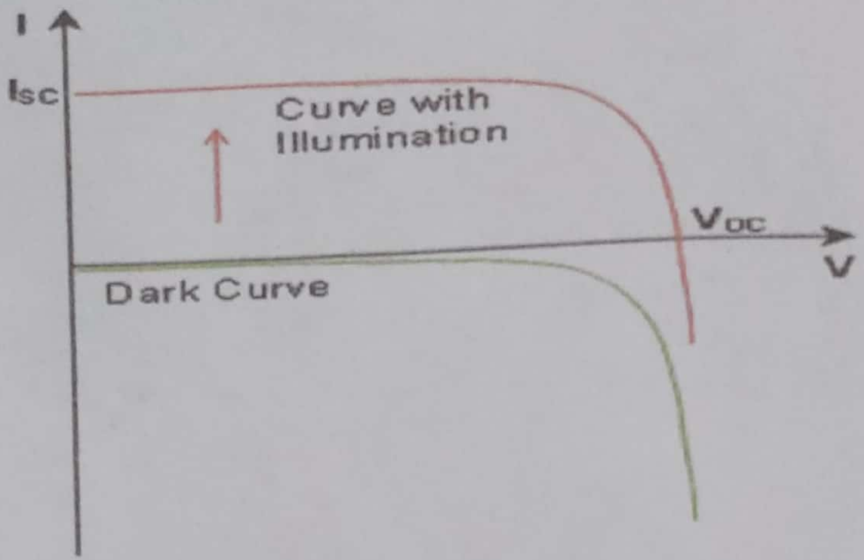


Figure 2 Shift of the solar cell I/V curve with increasing incident light.

Short circuit current, I_{SC}, flows when the external resistance is zero ($V = 0$) and is the maximum current delivered by the solar cell at a given illumination level. The short circuit current is a function of the PN junction area collecting the light. Similarly, the open circuit voltage, V_{OC}, is the potential that develops across the terminals of the solar cell when the external load resistance is very large, $R_{LOAD} = \infty$. For silicon based cells a single PN junction produces a voltage near 0.5V. Multiple PN junctions are connected in series in a larger solar panel to produce higher voltages. Photovoltaic cells can be arranged in a series configuration to form small modules, and modules can then be connected in parallel-series configurations to form larger arrays. When connecting cells or modules in series to produce higher output voltages, they must have the same current rating (if not the cell with the lowest current specification will limit the ultimate current of the module), and similarly, modules must have the same voltage specification when connected in parallel to generate larger currents. The power delivered to the load is of course zero at both extremes of the I/V curve and reaches a maximum (P_{MAX}) at a single load resistance value. In figure 3, P_{MAX} is shown as the area of the shaded rectangle.

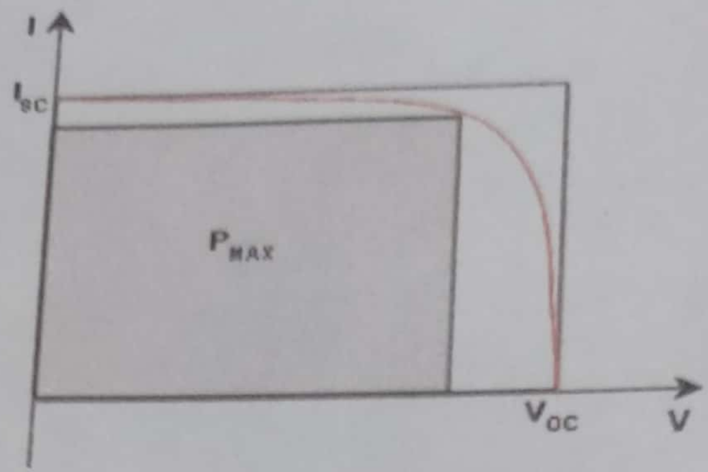


Figure 3 the maximum power delivered by a solar cell, P_{MAX}, is the area of the largest rectangle under the I/V curve.

A commonly used parameter that characterizes a solar cell is the fill factor, FF, which is defined as the ratio of P_{MAX} to the area of the rectangle formed by V_{OC} and I_{SC}.

$$FF = \frac{P_{MAX}}{V_{OC} I_{SC}}$$

The efficiency of a solar cell is the ratio of the electrical power it delivers to the load, to the optical power inType equation here.cident on the cell. Maximum efficiency is when power delivered to the load is P_{MAX}. Incident optical power is normally specified as the power from sunlight on the surface of the earth which is approximately 1mW/mm^2. Spectral distribution of sunlight is close to a blackbody spectrum at 6000° C minus the atmospheric absorption spectrum. The maximum efficiency ?$_{MAX}$ may be written as:

$$\eta_{MAX} = \frac{P_{MAX}}{P_{IN}} = \frac{V_{OC} I_{SC} FF}{P_{IN}}$$

For a cell of a certain size, I_{SC} is directly proportional to the incident optical power P_{IN}. However, V_{OC} increases logarithmically with the incident power. So, we would expect the overall efficiency of the solar cell to also increase logarithmically with incident power. However, thermal effects at high sunlight concentrations and electrical losses in the series resistance of the solar cell limit the enhancement in efficiency that can be achieved. So the efficiency of practical solar cells peaks at some finite light concentration level.

Shunt Resistance and Series Resistance

Photovoltaic cells can be modeled as a current source in parallel with a diode as depicted in figure 4. When there is no light present to generate any current, the cell behaves like a diode. As the intensity of incident light increases, current is generated by the PV cell.

In an ideal cell, where R_{SH} is infinite and R_S is zero, the load current I is equal to the current I_l generated by the photoelectric effect minus the diode current I_D, according to the equation:

$$I = I_\ell - I_D = I_\ell - I_S\left(e^{qV/kT} - 1\right)$$

Where I_S is the saturation current of the diode, q is the charge on an electron, 1.6×10^{19} Coulombs, k is Boltzmann's constant, 1.38×10^{23} J/K, T is the cell temperature in degrees Kelvin, and V is the measured cell voltage that is either produced (power quadrant) or applied (voltage bias). A more accurate model would include two diode terms, however, we will limit the model to a single diode for this discussion.

Expanding the equation gives the simplified circuit model shown below and the following associated equation, where n is the diode ideality factor (typically between 1 and 2), and R_S and R_{SH} represents the series and shunt resistances.

$$I = I_\ell - I_S\left(e^{q(V+IR_S)/nkT} - 1\right) - \frac{V + IR_S}{R_{SH}}$$

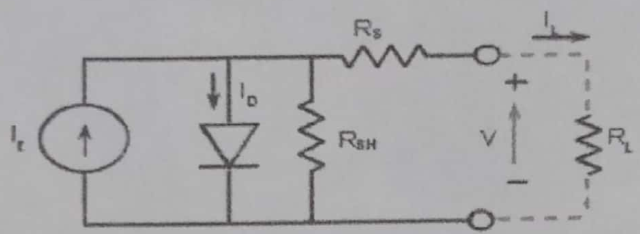
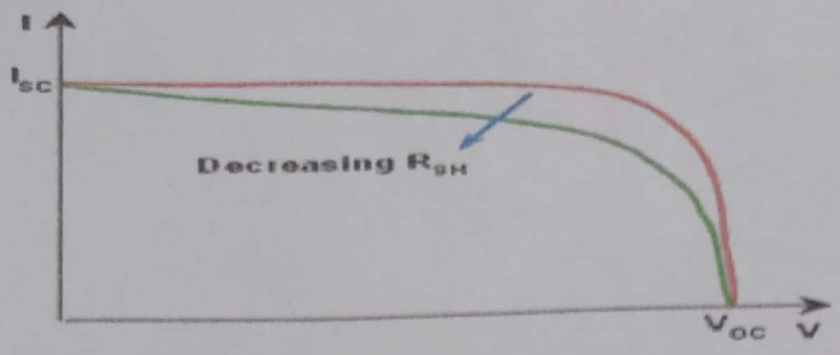


Figure (4) Electrical model of solar cell

During operation, the efficiency of solar cells is reduced by the dissipation of power across internal resistances. These parasitic resistances can be modeled as a parallel shunt resistance (R_{SH}) and series resistance (R_S). For an ideal cell, R_{SH} would be infinite and would not provide an alternate path for current to flow, while R_S would be zero, resulting in no voltage drop and power loss before the load. Decreasing R_{SH} and increasing R_s will decrease the fill factor (FF) and P_{MAX} as shown in figure 5.

If R_{SH} is decreased too much, V_{OC} will drop, while increasing R_S excessively can cause I_{SC} to drop instead.



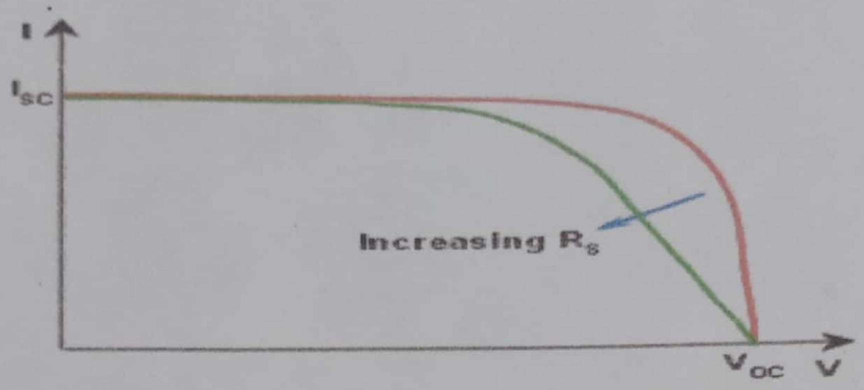


Figure 5 - Effect of changing R_{SH} & R_S from ideality

It is possible to approximate the series and shunt resistances, R_S and R_{SH}, from the slopes of the I/V curve at V_{OC} and I_{SC}, respectively. The resistance at V_{OC}, however, is at best proportional to the series resistance but it is larger than the series resistance. R_{SH} is represented by the slope at I_{SC}. Typically, the resistances at I_{SC} and at V_{OC} will be measured and noted, as shown in figure 6.

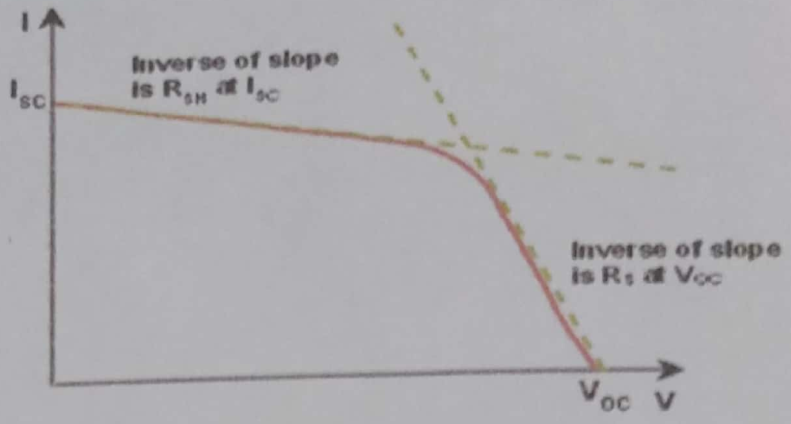


Figure 6 - Obtaining values for R_S and R_{SH} from the I/V curve

I-V Curves for Modules:

For a module or array of solar cells, the shape of the I/V curve does not change. However, it is scaled based on the number of cells connected in series and in parallel. If n is the number of cells connected in series and m is the number of cells connected in parallel and I_{SC} and V_{OC} are values for individual cells, then the short circuit current for the array is nI_{SC} and the open circuit voltage is mV_{OC}. An example I/V curve is shown in figure 8 with an overall I_{SC} of about 80mA and a V_{OC} of about 4.2V and P_{MAX} is slightly higher than 160mW.

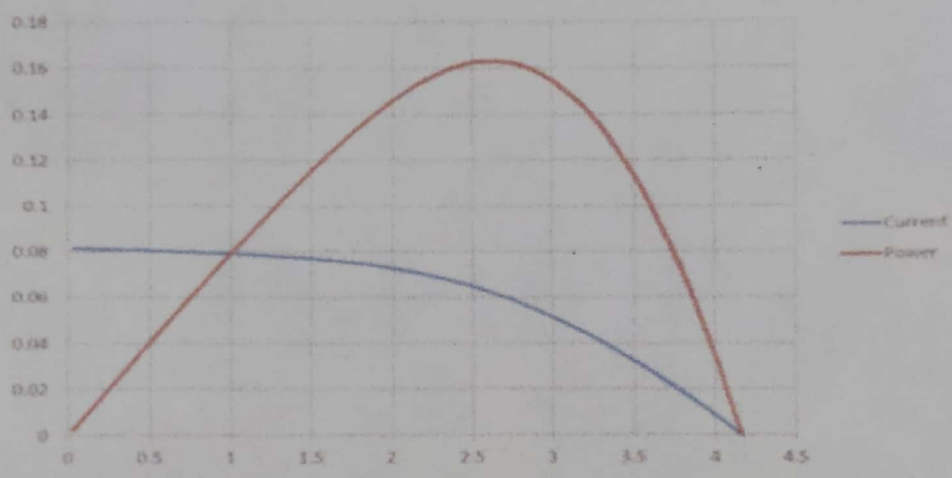


Figure (7) Example solar panel I/V and power curves.

Connection diagram:-

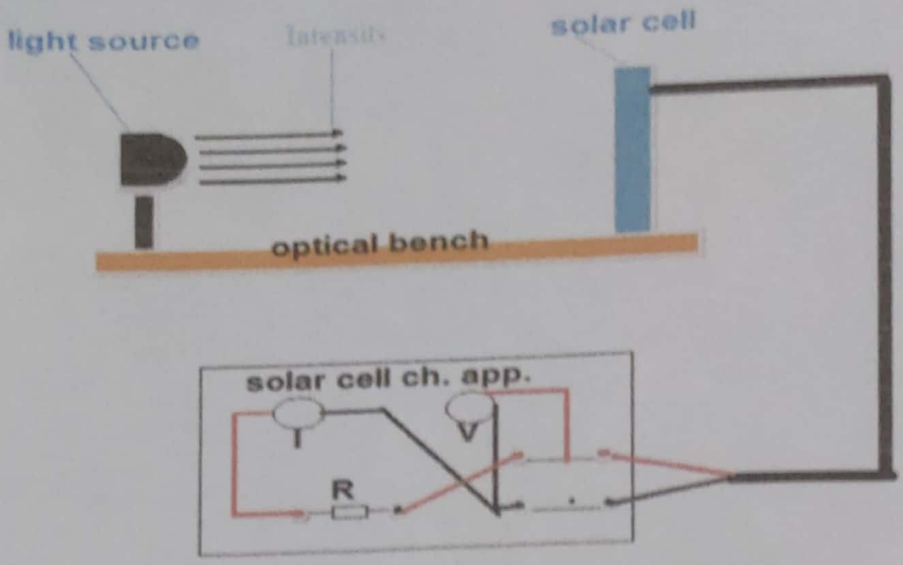


fig.6 -connection digram

Experimental Procedure:

(A) V - I CHARACTERISTICS OF SOLAR CELL:-

1. Place the light source mount on the one end of the optical wooden bench and solar cell mount on the other end of the wooden bench in front of the light source.
2. Connect the solar cell connecting lead having banana plug to the solar cell kit terminals as given on the front panel red to red and black to black terminals respectively as shown in fig.6.
3. Now connect the voltmeter in parallel and current meter in series with load resistance as provided on the front panel in fig 6.
4. Switch ON the light source and adjust the distance between the light source and solar cell for maximum voltage (open circuit voltage V_{OC}) note from the current meter fig.6.
5. Similarly note down the maximum current Or (short circuit current I_{sc}) fig.6.
6. Now vary the load resistance step by step with the help of band switch given on the front panel.
7. Note the reading of voltage and current from the meters at every step of resistance and make the observation table and calculate the power in mW as shown in observation table 1.

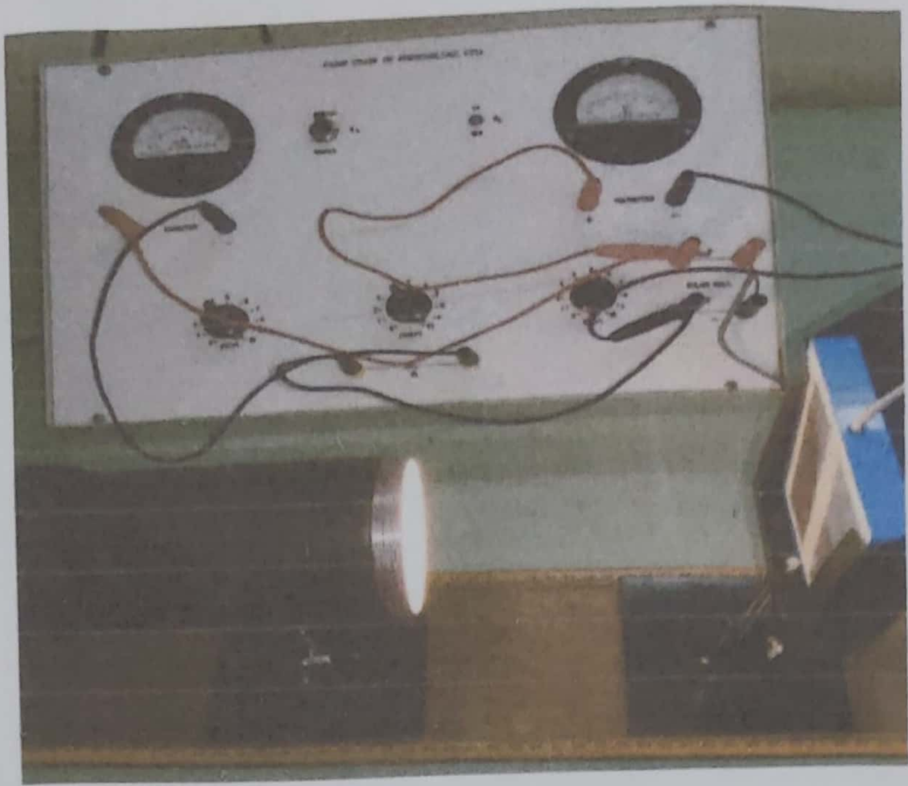


Figure 9 – Setup for V & I Characterstics and Power(P) & Load Resistance(R_L) Characterstics

Observation Table 1.

Sr. no.	Load Resistance(R_L) (Ω)	Voltage(V) (Volts)	Current(I) (milli-Amperes)	Power(P) (milli-Watt)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Maximum Power(P_{max})= ______________ milli-Watt
Load Resistance(R_L) at P_{max} = ______________ Ohm

Draw the graph between : (1)Voltage (V) & Current(I)
(2) Power(P) & Load Resistance(R_L)

(B)- Spectral characteristics:-

To study the spectral response of the solar cell, adjust distance between the light source and solar cell for maximum intensity or maximum short circuit current I_{SC}.

1. Minimize the load resistance with the help of band switches to make the short circuit for maximum Current.
2. Now insert the any color filter(say red or green) in the solar cell mount to cover the face of the solar cell and note down the current and voltage from the voltmeter and current meter.
3. Repeat the same process by inserting the other seven color filters one by one in the solar cell mount and note down the voltage and current every time in the observation table 2 as shown below.
4. Plot the graph between color (different wavelengths) and power calculated from table.

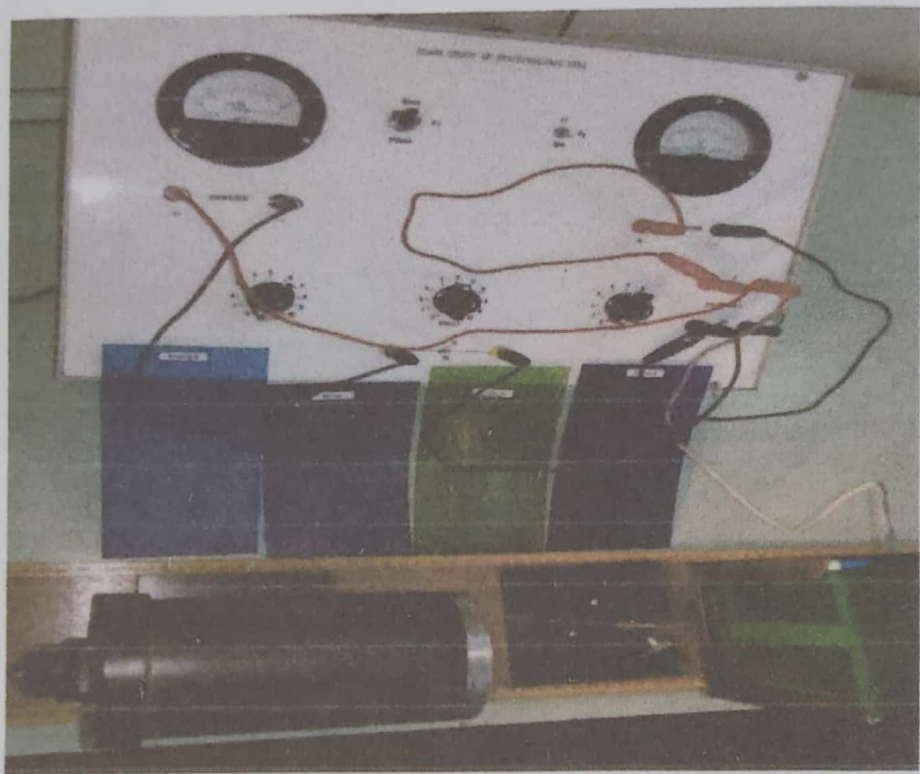


Figure 10 – Setup for Spectral Characterstics of a Solar Cell

Observation Table 2 :

Sr. no.	Color Filter	Voltage(V) (Volts)	Current(I) (milli-Ampere)	Power(P) (milli-Watt)
1	White			
2	Voilet			
3	Indigo			
4	Blue			
5	Green			
6	Yellow			
7	Orange			
8	Red			

(C)- Areal characteristics:-

1. To study the areal characteristic of the solar cell adjust the light source and solar cell for maximum current or voltage.
2. Insert the chopper plates of different window area between the solar cell and light source as shown in figure 11 below.
3. Current and voltage will be varying at every chopper plate.
4. Note down the voltage and current and calculate the power every time. And make the observation table.
5. And plot the graph between Area in cms. and Power in mW.

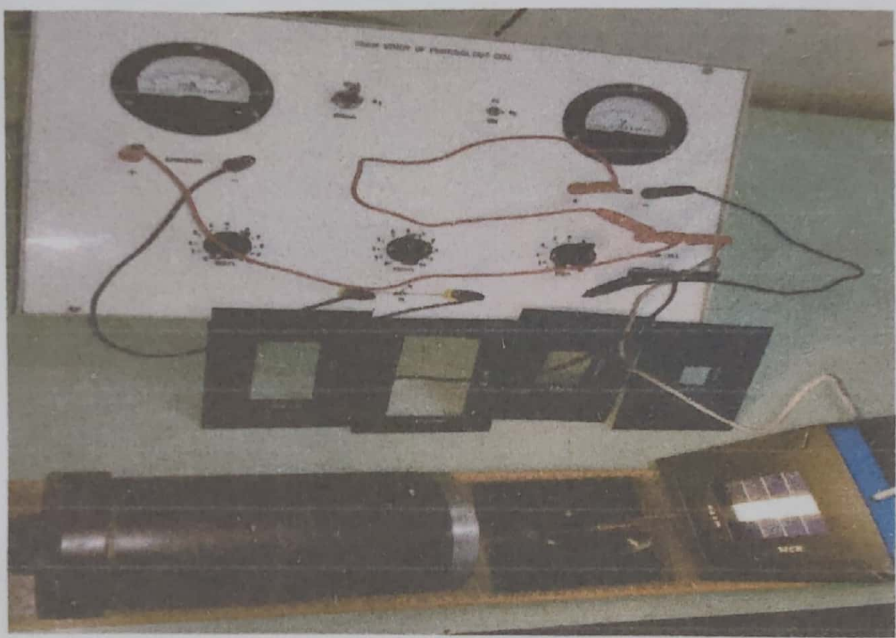


Figure 11 – Setup for Areal Characterstics of a Solar Cell

Observation Table 3 :

Sr. no.	Plate No.	Area(A) (cm^2)	Voltage(V) (Volts)	Current(I) (milli-Ampere)	Power(P=V×I) (milli-Watt)
1	CP-1				
2	CP-2				
3	CP-3				
4	CP-4				
5	CP-5				

Plot the graph between Power(P) and Area(A) using the reading of above table.

Result :-

1. Fill factor:-

$$FF = \frac{P_{MAX}}{V_{OC} I_{SC}}$$

2. Efficiency

$$\eta_{MAX} = \frac{P_{MAX}}{P_{IN}} = \frac{V_{OC} I_{SC} FF}{P_{IN}}$$

3. Plot the graph between I and V, R_L and P , Area(A) and P , Color (wavelength) and power (P).
