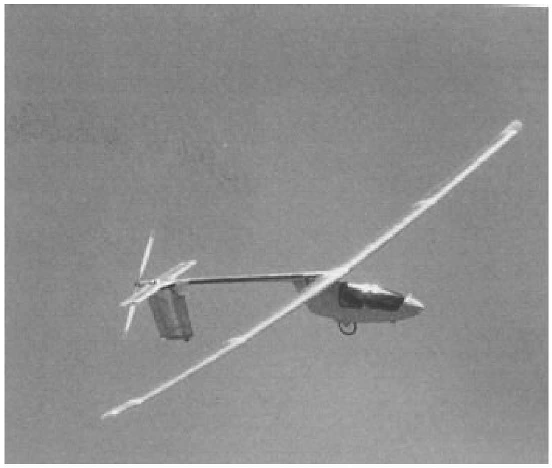
SOLAR CELLS

LECTURE 3

Prof. John David



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Lecture notes :
Either at http://www.shef.ac.uk/webct/ or http://hercules.shef.ac.uk/eee/teach/resources/MEC316/MEC316.html

I-V Characteristics under Illumination

1) Open Circuit Conditions

It has been previously shown that the I-V characteristic of an illuminated solar cell is given by the equation

$$I = I_o\,[\exp(eV_{app}/kT) - 1] - I_L$$

If the solar cell has no load connected across it, then no current can flow as no external circuit is present.

Under these conditions $I = 0$, so

$$0 = I_o\,[\exp(eV_{app}/kT) - 1] - I_L$$

So $$(I_L + I_o) / I_o = \exp(eV_{OC}/kT)$$

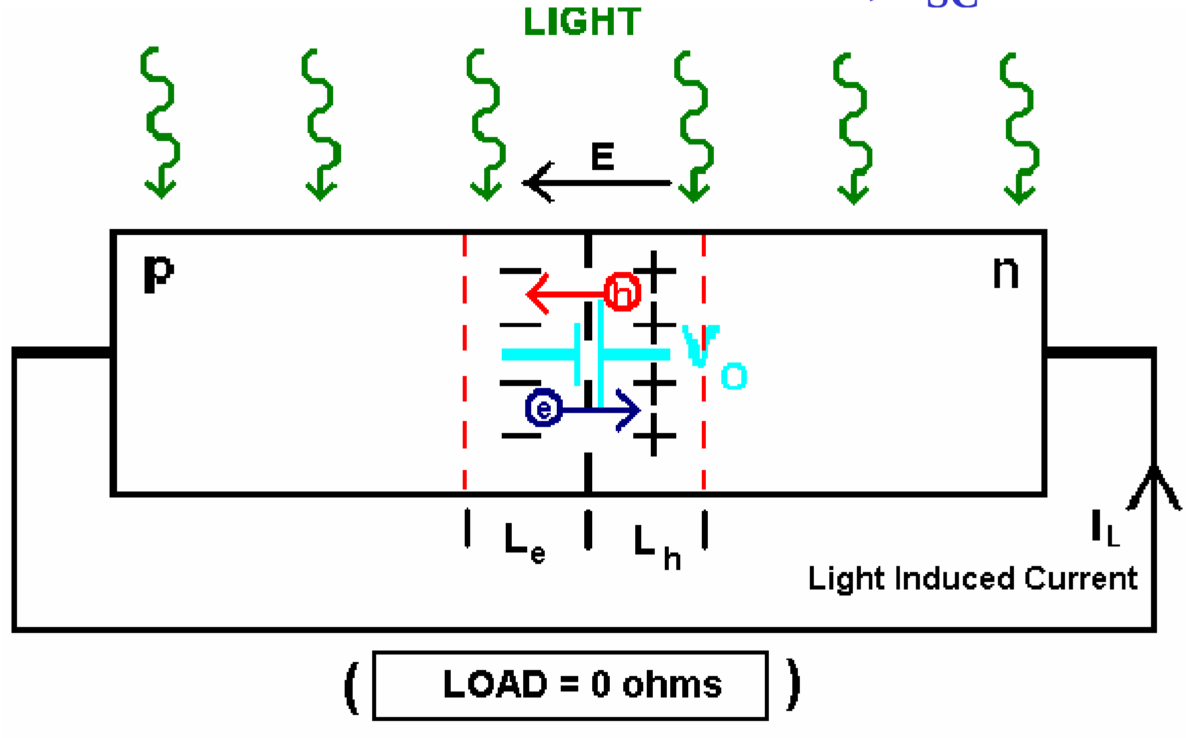
or $$V_{OC} = (kT/e)\ \ln\,[(I_L + I_o) / I_o] \sim 0.5\,V$$

(ln = Natural logarithm)

I-V Characteristics under Illumination

2) Short Circuit Conditions

If the solar cell has a short circuit across it (a load of 0 ohms), then the current flowing through the cell is the short circuit current, I_{SC}.



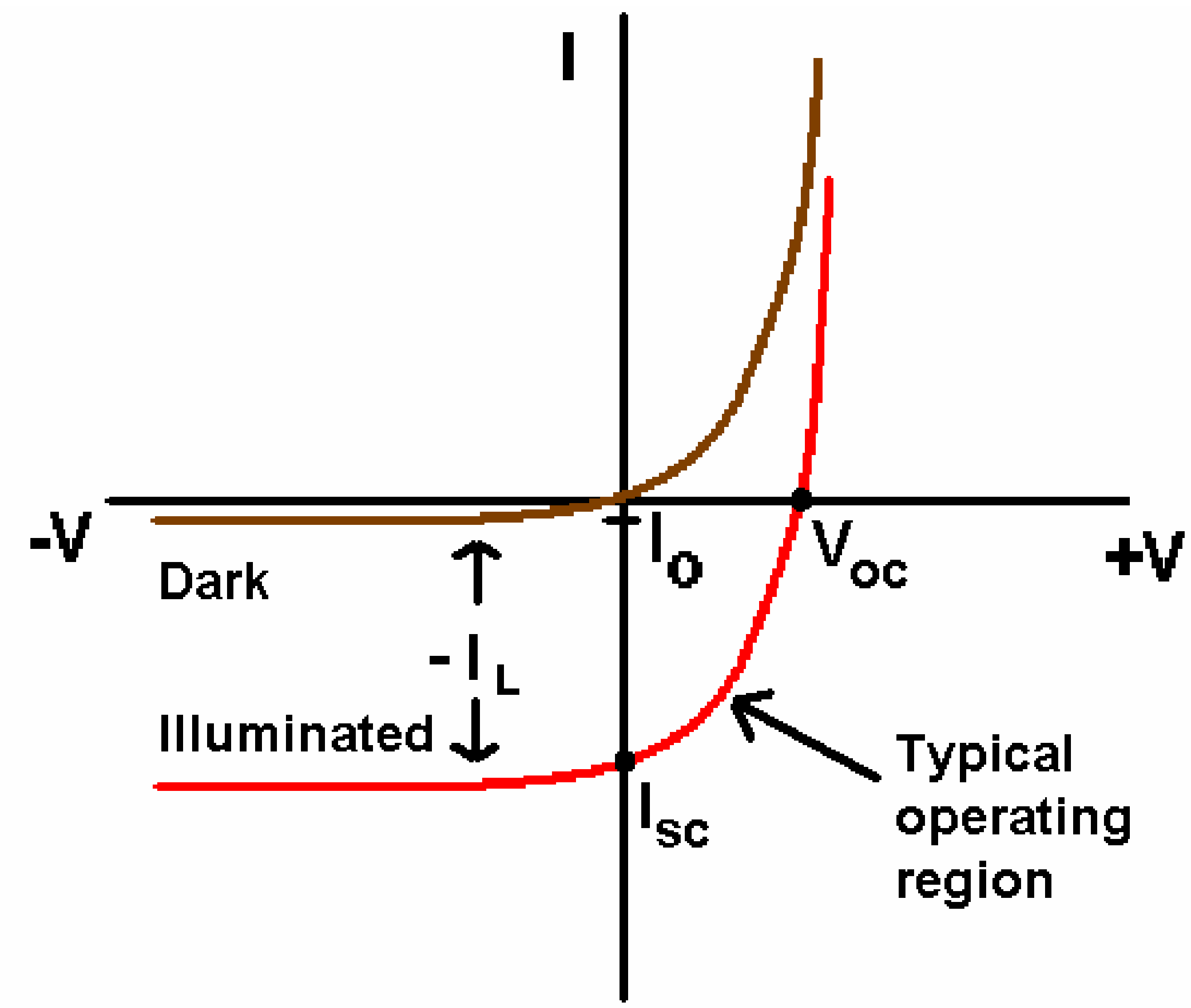
The voltage across the cell must be zero, since it is equal to the voltage across the load

$$I_{SC} = I_o\,[\exp(0) - 1] - I_L$$

so, $$I_{SC} = -\ I_L$$

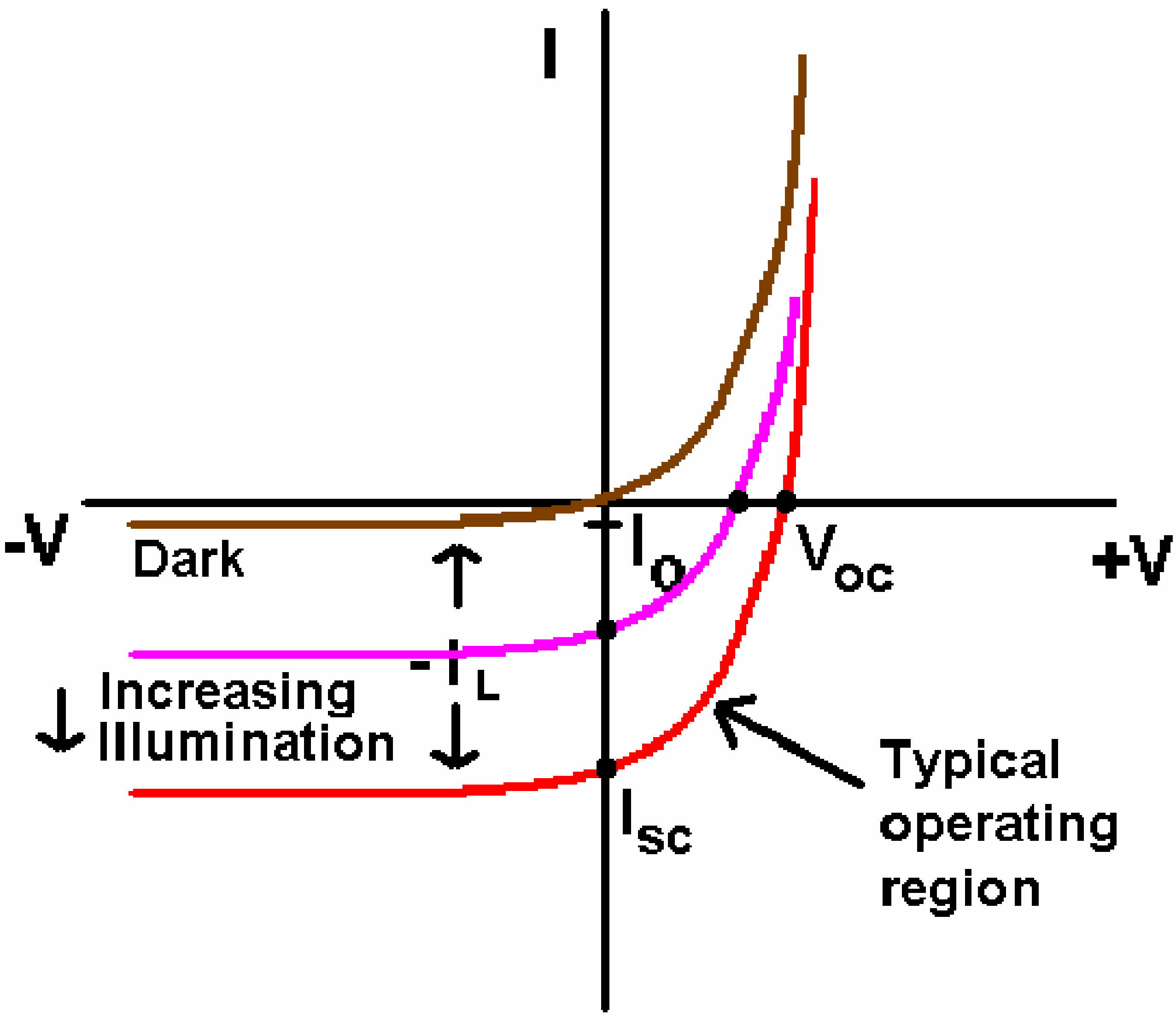
I-V Characteristics under Illumination

Usually, however, a load, R_L, is present across the solar cell, so $I < I_{SC}$ and $V < V_{OC}$.
The I-V curve for a solar cell under illumination can then be obtained.



I-V Characteristics under Illumination

The magnitude of I_L depends on the intensity of the illumination.
As the illumination is increased, the I-V curve is shifted further down.



Maximum Power Output

To operate under the most efficient conditions, we need to find the operating point for the maximum power output.

The power delivered to the load is given by -

$$P = IV$$

This is a maximum when

$$\frac{dP}{dI} = 0 = V + I\frac{dV}{dI}$$

or when

$$-\frac{V}{I} = \frac{dV}{dI}$$

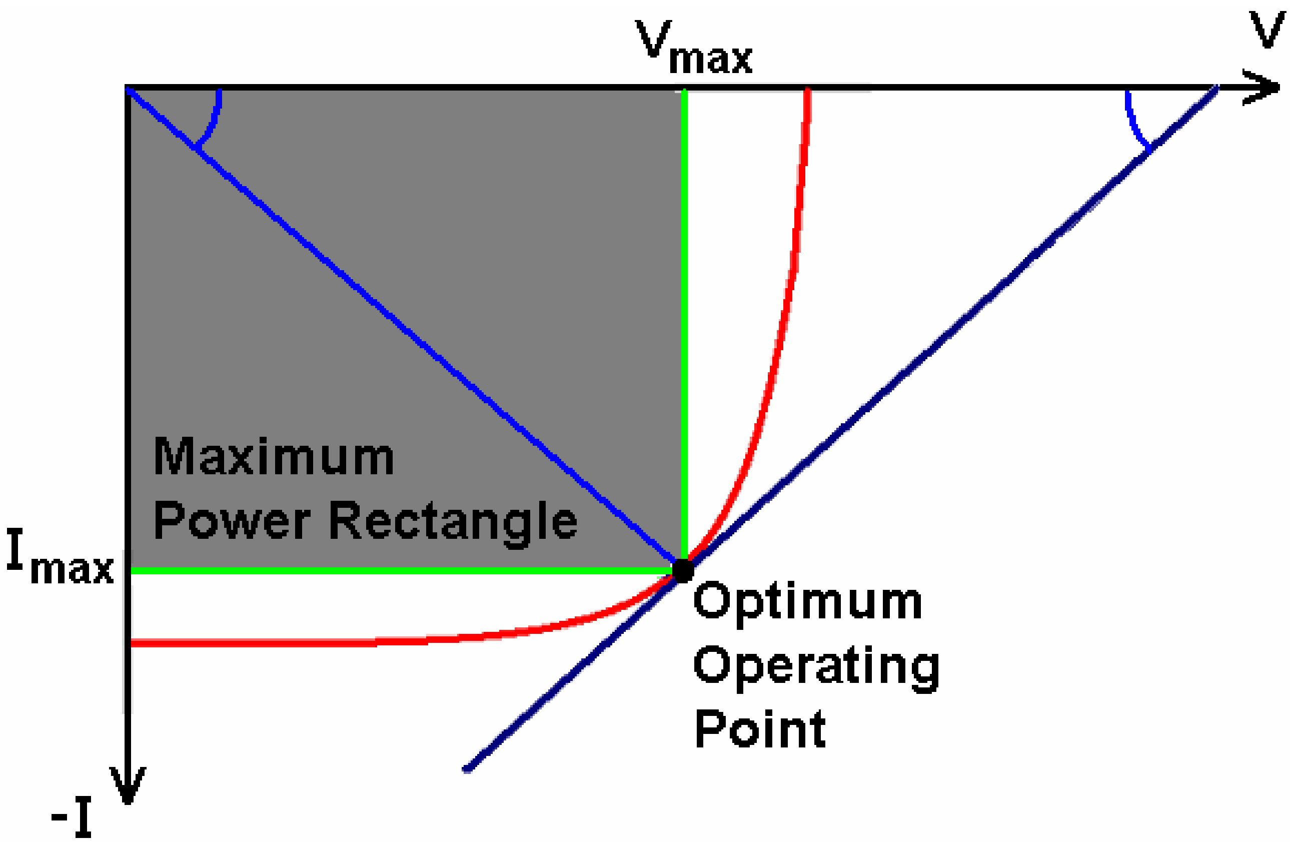
This corresponds to the condition when the slope of the line from the origin to the optimum point on the curve equals the negative slope of the I-V curve at the same point.

Maximum Power Output

Let us try to clarify the statement made at the bottom of the last slide-
The power delivered to the load is a maximum when

$$-\frac{V}{I} = \frac{dV}{dI}$$

This corresponds to the condition when the slope of the line from the origin to the optimum point on the curve equals the negative slope of the I-V curve at the same point.

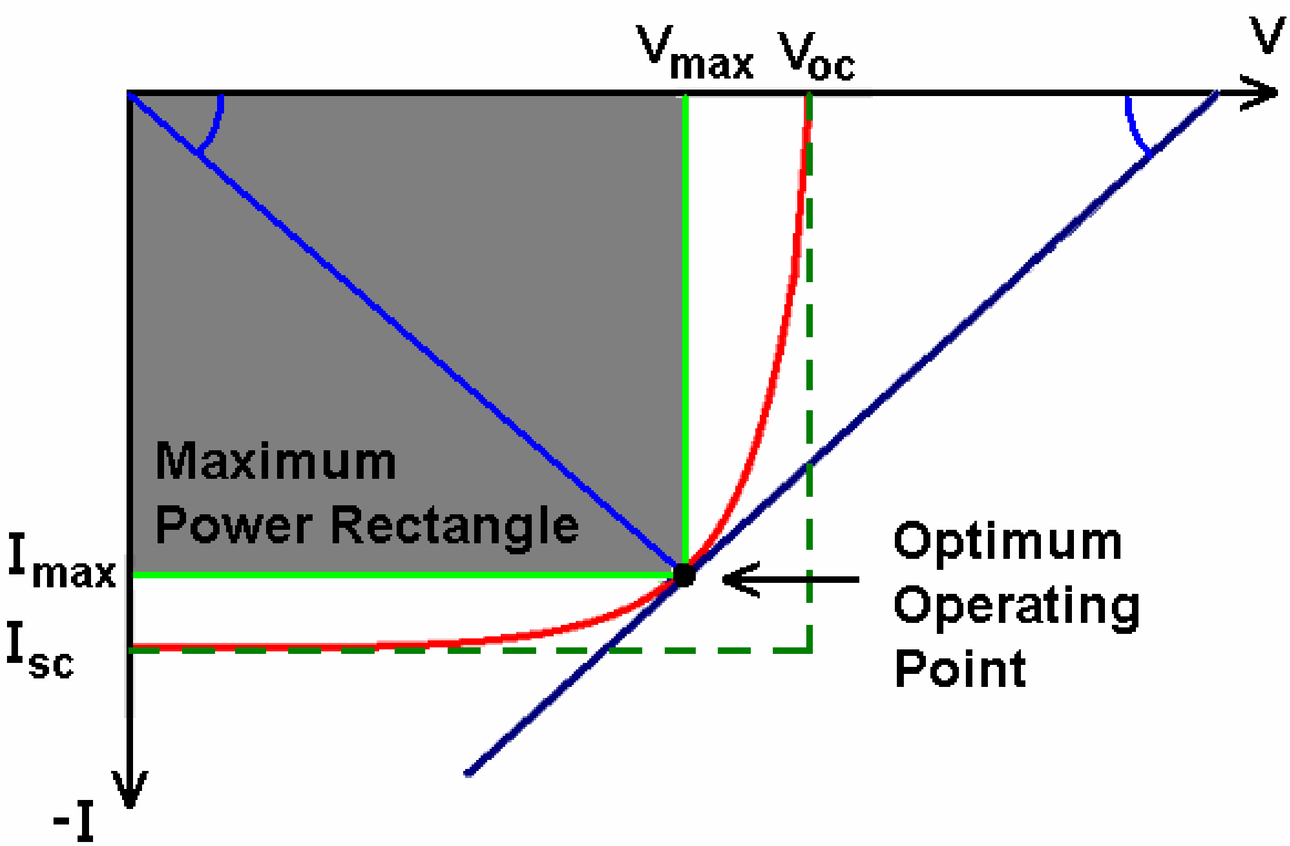


Maximum Power Output

For an efficient solar cell we would like V_{max} to be as close to V_{oc} as possible, and I_{max} to be as close to I_{sc} as possible.
A measure of how well this has been achieved is the fill factor, which is defined as -

$$\text{Fill factor} = \frac{V_{max} \times I_{max}}{V_{oc} \times I_{sc}}$$

The fill factor is typically between 0.6 and 0.7



Maximum Power Output

Alternatively, we can differentiate the expression for power output with respect to V rather than I

$$\text{Power Output} = P = V\,I = V\,I_o\left(e^{\left(\frac{eV}{kT}\right)} - 1\right) - V\,I_L$$

P is a maximum when $\frac{dP}{dV} = 0$

$$0 = V_m I_o \frac{e}{kT}\, e^{\left(\frac{eV_m}{kT}\right)} + I_o\left(e^{\left(\frac{eV_m}{kT}\right)} - 1\right) - I_L$$

where V_m is the voltage for maximun power output

Re-arranging

$$I_o + I_L = I_o\left(1 + \frac{eV_m}{kT}\right) e^{\left(\frac{eV_m}{kT}\right)}$$

$$1 + \frac{I_L}{I_o} = \left(1 + \frac{eV_m}{kT}\right) e^{\left(\frac{eV_m}{kT}\right)}$$

or, since $I_L = I_{SC}$

$$\left(1 + \frac{eV_m}{kT}\right) e^{\left(\frac{eV_m}{kT}\right)} = 1 + \frac{I_{SC}}{I_o}$$

Maximum Power Output

If $I_{SC} \gg I_o$ and $V_m \gg \frac{e}{kT}$

Then

$$\left(\frac{eV_m}{kT}\right) e^{\left(\frac{eV_m}{kT}\right)} = \frac{I_{SC}}{I_o}$$

$$\left(\frac{eV_m}{kT}\right)\left(\frac{I_o}{I_{SC}}\right) = e^{\left(\frac{-eV_m}{kT}\right)}$$

$$\ln\left(\frac{eV_m}{kT}\right) + \ln\left(\frac{I_o}{I_{SC}}\right) = \frac{-eV_m}{kT}$$

This can then be used to solve for V_m iteratively

Solar Cell Efficiency

The efficiency, η, of the solar cell is defined as

$$\text{Efficiency} = \frac{\text{Output Power}}{\text{Input Power}} = \frac{I_{max} \text{ x } V_{max}}{P_{in(solar)}}$$

Alternatively, this can be written as

$$\text{Efficiency} = \frac{I_{sc} \text{ x } V_{oc} \text{ x ff}}{P_{in(solar)}}$$

Where ff is the fill factor.
On a clear day P_{in} is typically $1kW/m^2$.

The theoretical maximum efficiencies for solar cells are 28% (silicon) and 31% (gallium arsenide).

However, for a good practical solar cell, an efficiency of 15% is acceptable.

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END OF LECTURE 3

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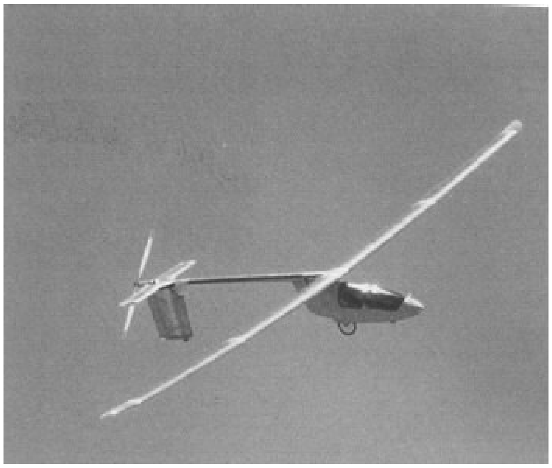

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Lecture notes :
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