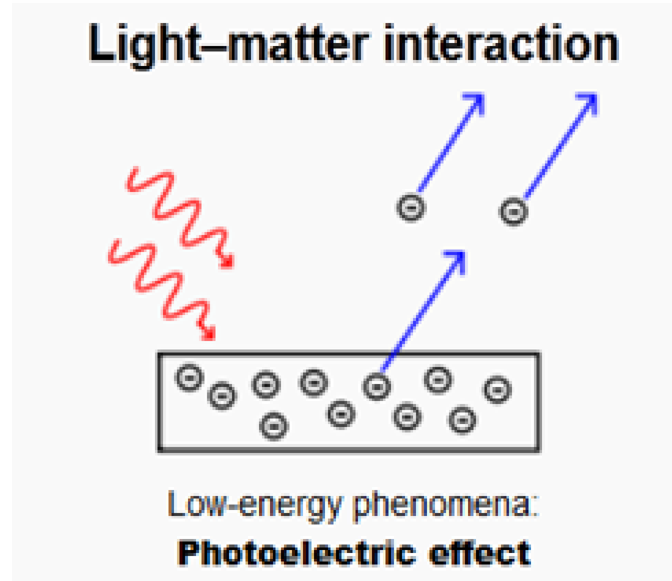
Chapter 8
Photovoltaic (PV) Materials and Electrical Characteristics



⌘ **Photoelectric Effect**:

⌘ Silicon wafer

⌘ 1887, Heinrich Hertz

⌘ 1905 Albert Einstein

Photovoltaic (PV)

Solar Energy: "The surface of the earth receives 6000 times as much solar energy as our total energy demand"

- Photovoltaic (PV):

  - PV History

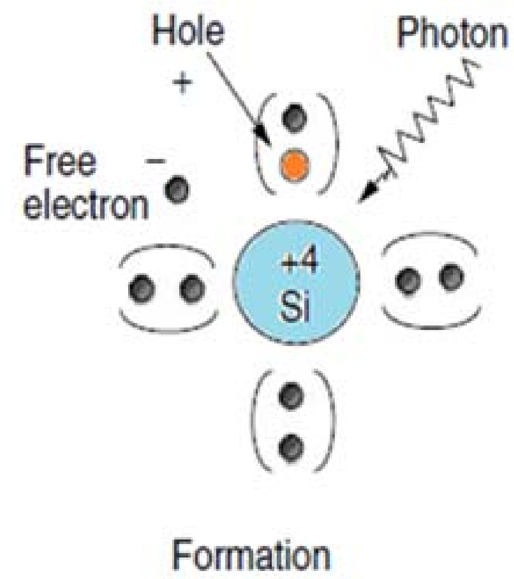
Solar Cell Semiconductor Physics

⌘ Solar Cell Types

The Portion of the Periodic Table of Greatest Importance for Photovoltaics Includes the Elements Silicon, Boron, Phosphorus, Gallium, Arsenic, Cadmium, and Tellurium

I	II	III	IV	V	VI
		5 B	6 C	7 N	8 O
		13 Al	**14 Si**	**15 P**	16 S
29 Cu	30 Zn	**31 Ga**	32 Ge	**33 As**	34 Se
47 Ag	**48 Cd**	49 In	50 Sn	51 Sb	**52 Te**

Band Gap Energy

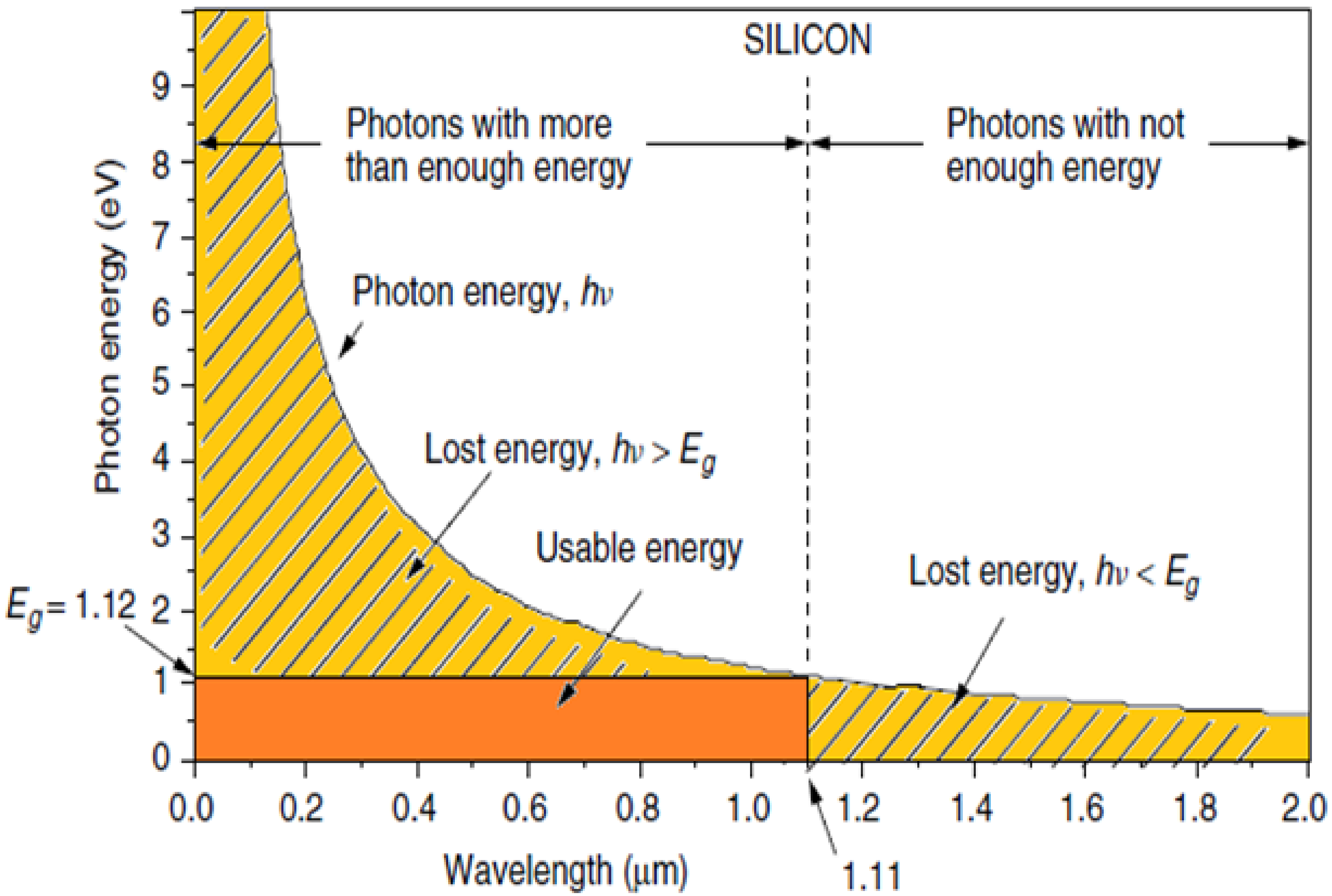


Energy of a photon

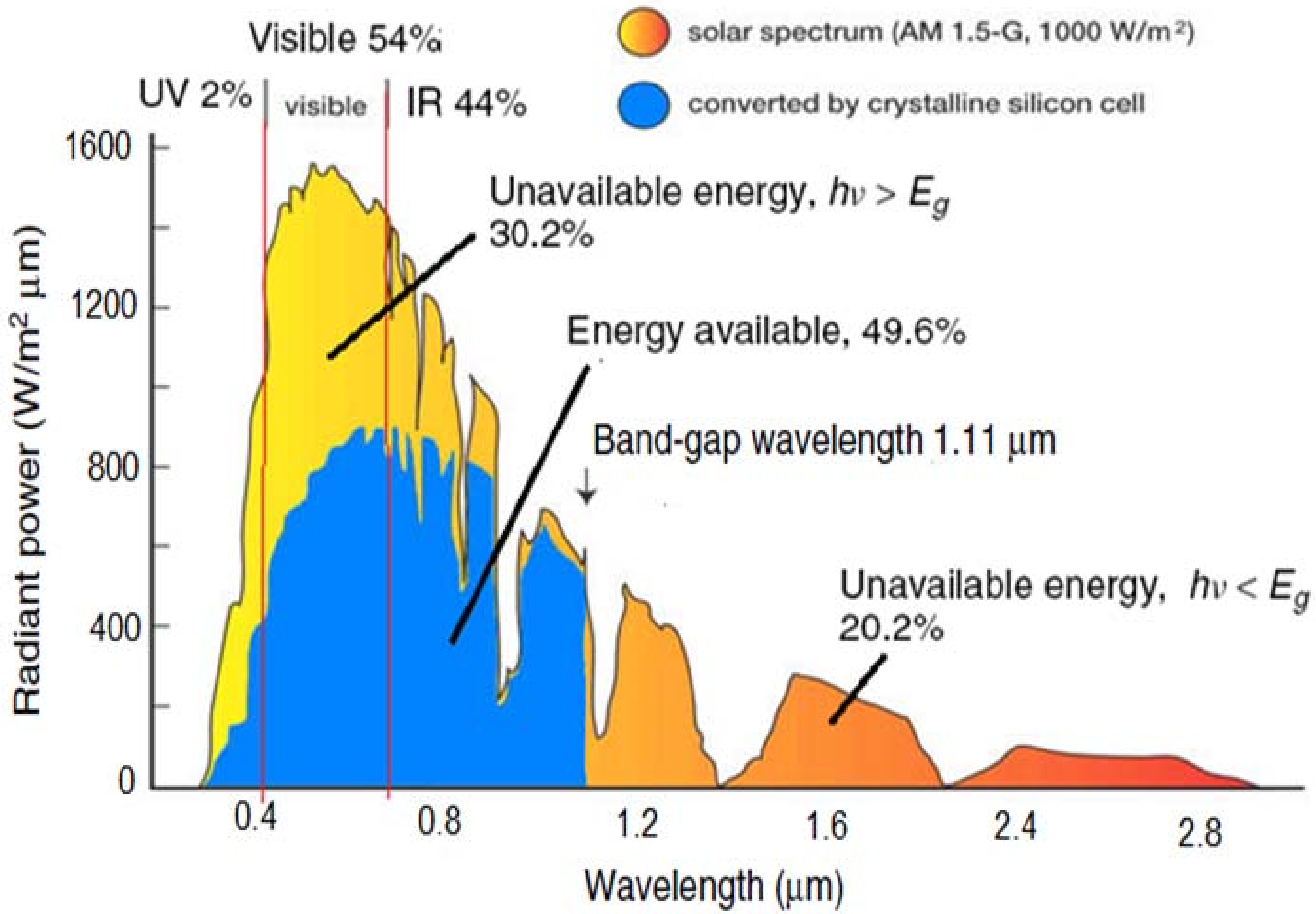
$$E = h\nu = \frac{hc}{\lambda}$$	E energy of a photon (J)
	c speed of light (3×10^8 m/s)
	ν frequency (hertz),
	h Planck's constant (6.626×10^{-34} J-s)
	λ wavelength (m)

- **Sample Calculation**: Silicon has a band gap of 1.12 eV and 1 eV = 1.6 x 10^{-19} [J] (a) What maximum wavelength can a photon have to create hole-electron pairs in silicon? (b) What minimum frequency is that?

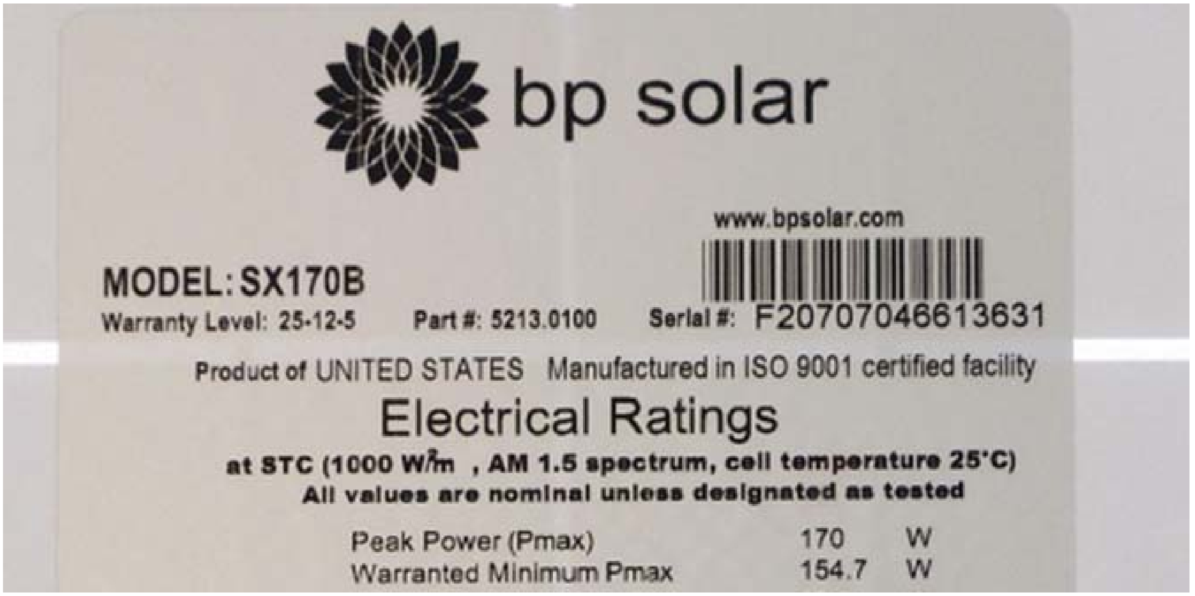
Band Gap Energy for Si and Photon Energy

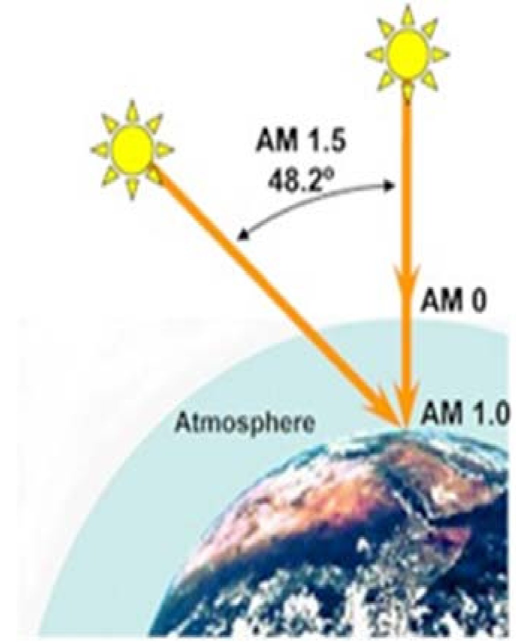


Solar Spectrum and Band-Gap



AM Ratio and PV plate





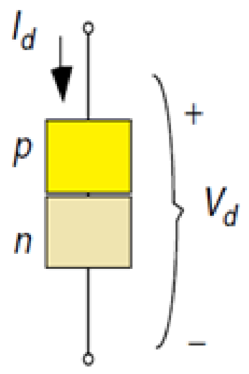
Band Gap Energy for Solar Cell Material

- Band-Gap and Cut-Off Wavelength for Electron Excitation

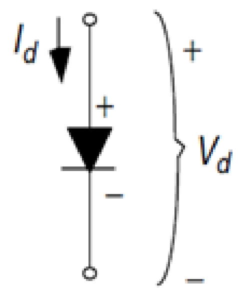
PV Material	Silicon (Si)	Gallium Arsenide (GaAs)	Cadmium Telluride (CdTe)	Indium Phosphide (InP)
Band Gap [eV]	1.12	1.42	1.5	1.35
Cut-off wavelength [μm]	1.11	0.87	0.83	0.92

p-n Junction Diode

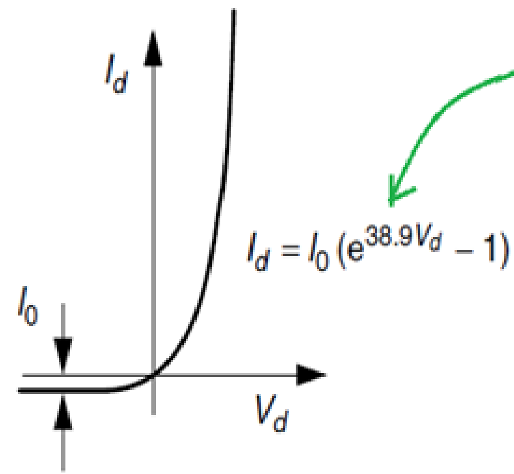
Shockley diode equation: $I_d = I_0(e^{qV_d/kT} - 1)$



p–n junction diode



Symbol for real diode



Diode characteristic curve

$$\frac{q}{kT} = 38.9$$

at junction temperature of 25°C → standard

I_0 reverse saturation current (A)
reverse saturation current is the result of thermally generated carriers with the holes being swept into the *p*-side and the electrons into the *n*-side.

I_d the diode current in the direction of the arrow (A)

V_d the voltage across the diode terminals from the *p*-side to the *n*-side (V).

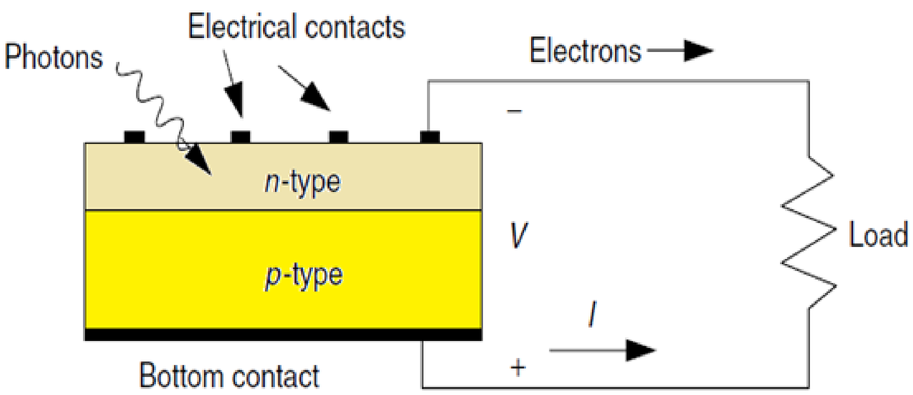
q the electron charge (1.602×10^{-19}C)

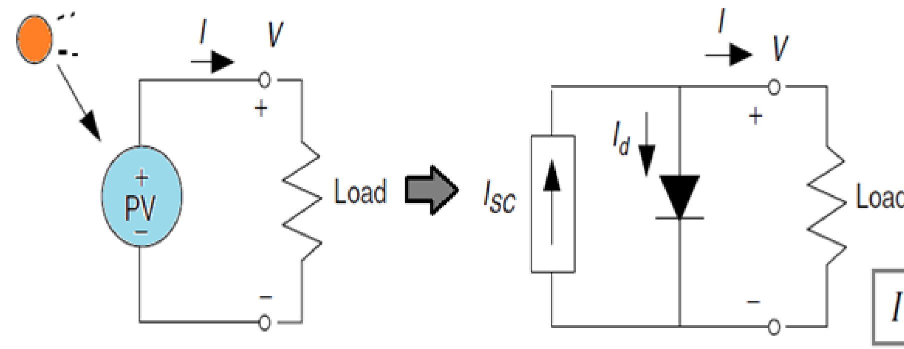
k Boltzmann's constant (1.381×10^{-23} J/K)

T the junction temperature (K).

PV Cell Equivalent Circuit

$$I_d = I_0(e^{qV_d/kT} - 1)$$

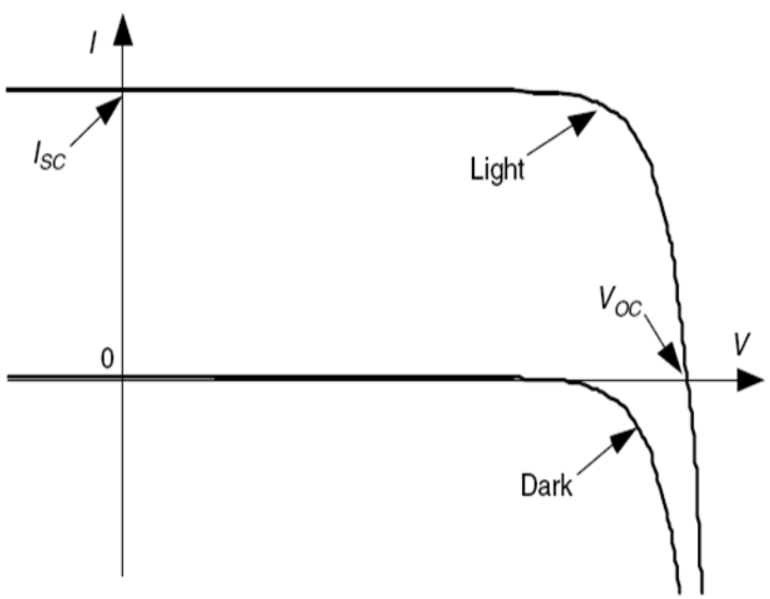




$$I = I_{SC} - I_d$$

I_{SC} short-circuit current

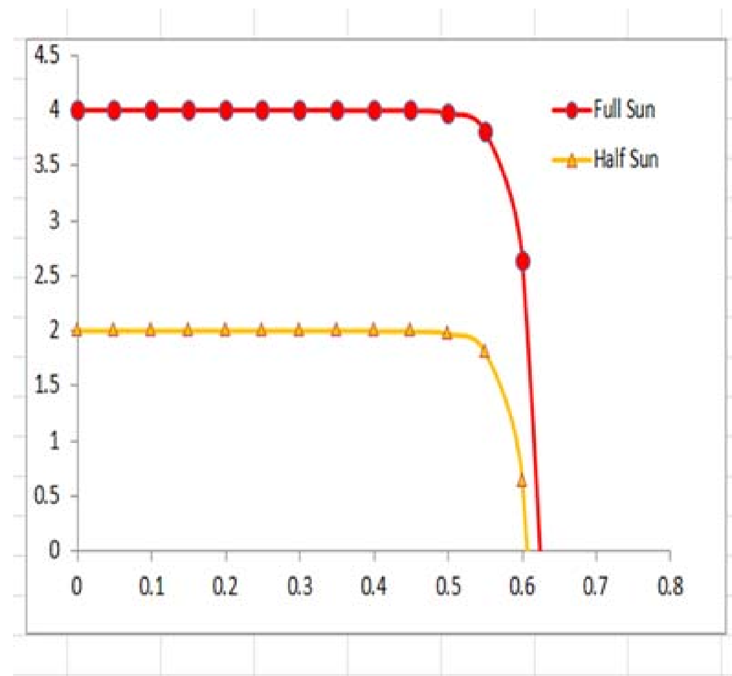
I-V Curve



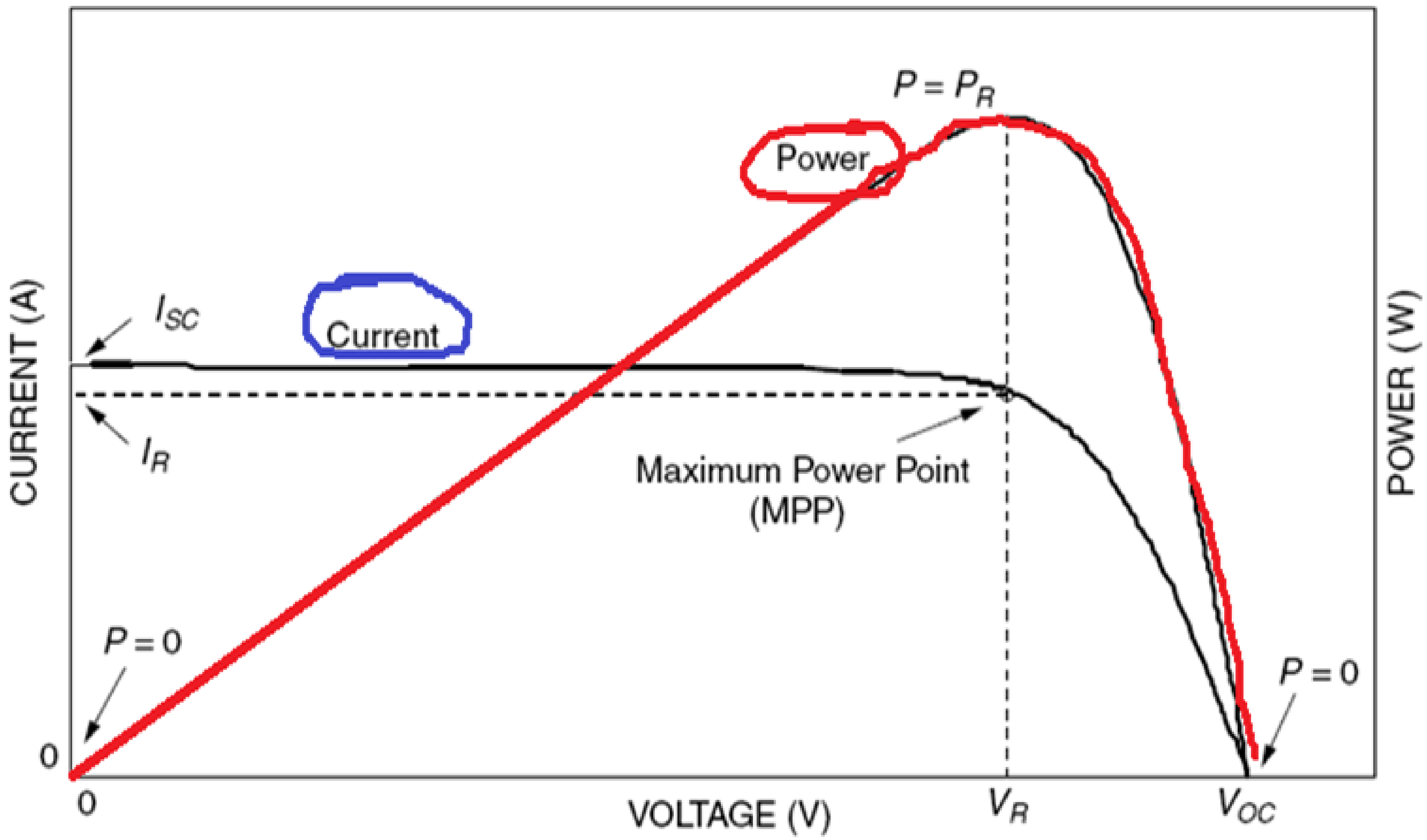
I-V Curve Example

Example: Consider a 100 cm^2 PV cell with reverse saturation current density 10^{-12} A/cm^2. In the full sun ("peak sun"), it produces a short-circuit current density of 40 mA/cm^2 at 25 °C. Find the open-circuit voltage at full sun and again for 50% sunlight. Plot I-V curve.

Ex8.3.xlsx

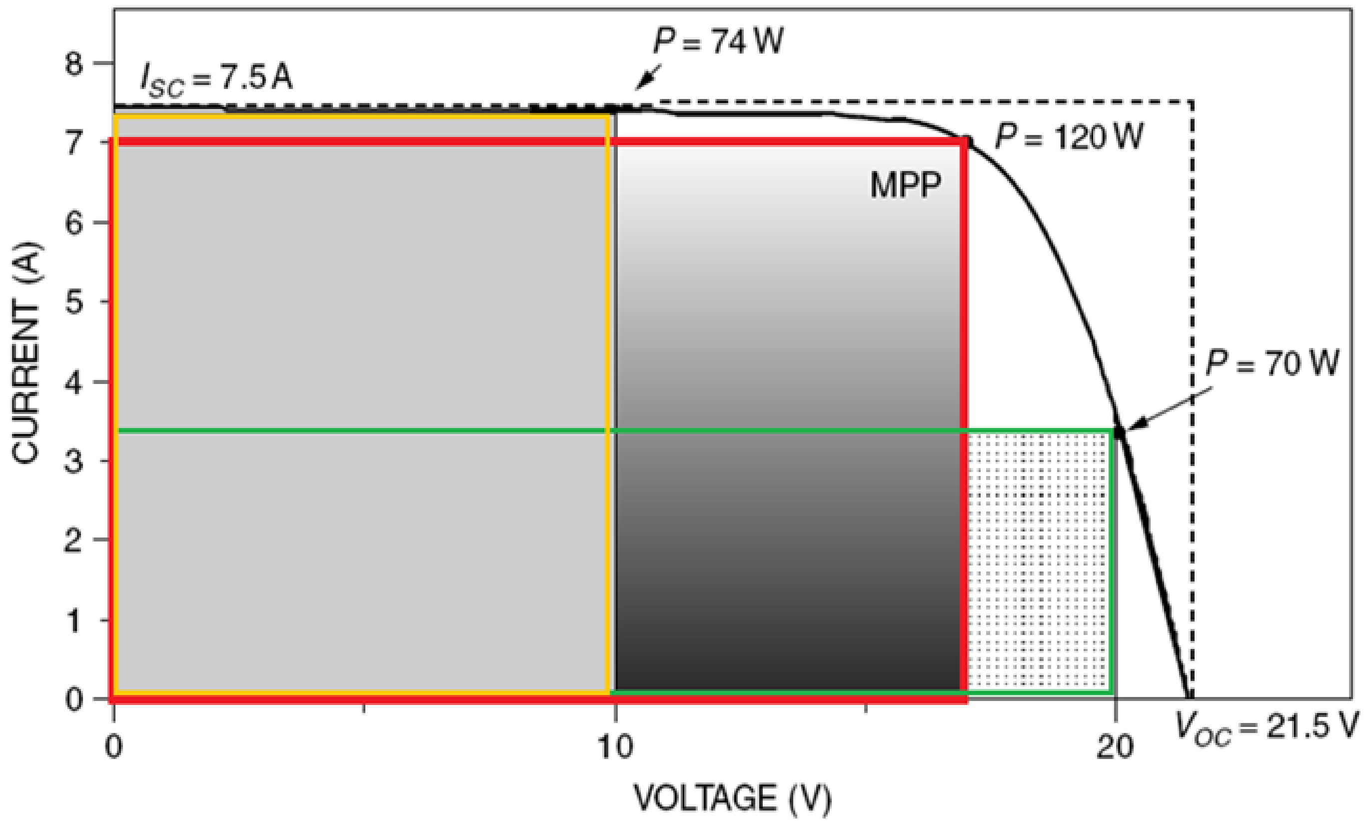


I-V Curve and Power Output

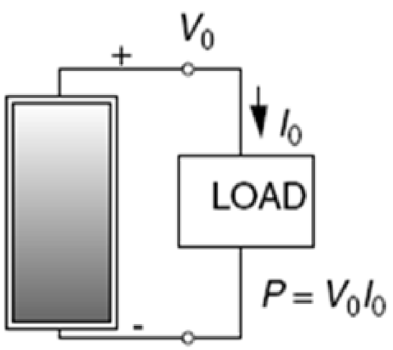


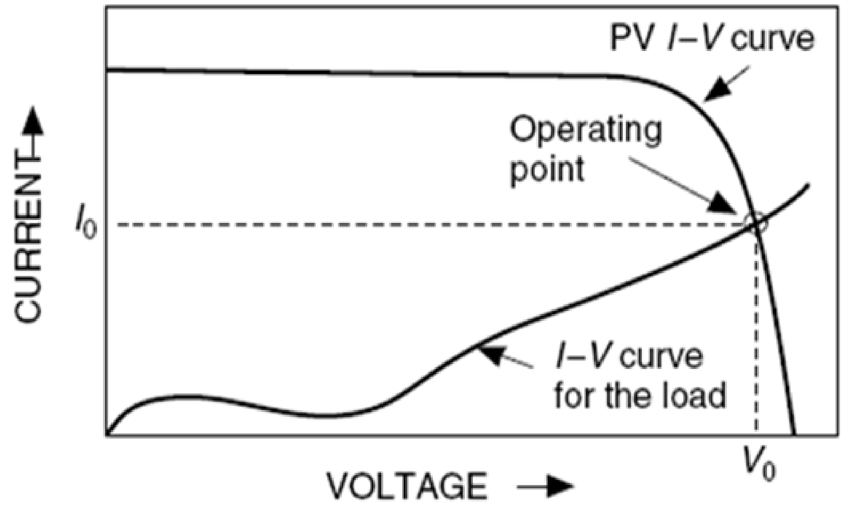
MPP and FF (Fill Factor)

- Fill Factor (FF): performance measure: ratio of the power at MPP to the product of V_{oc} and I_{sc}.

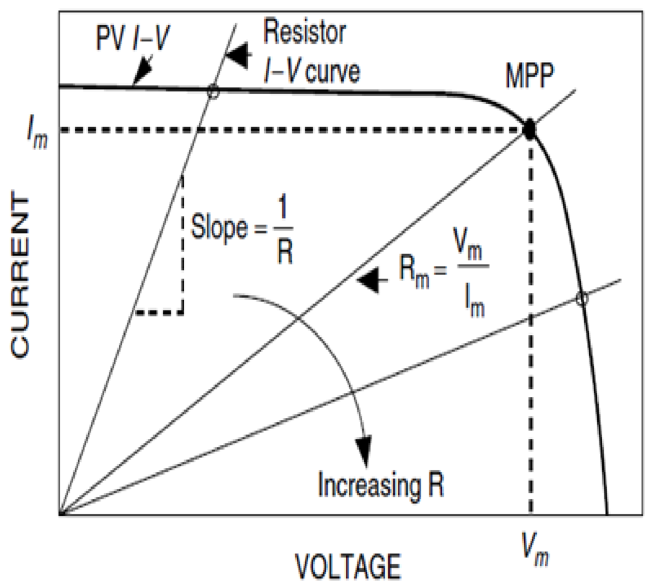


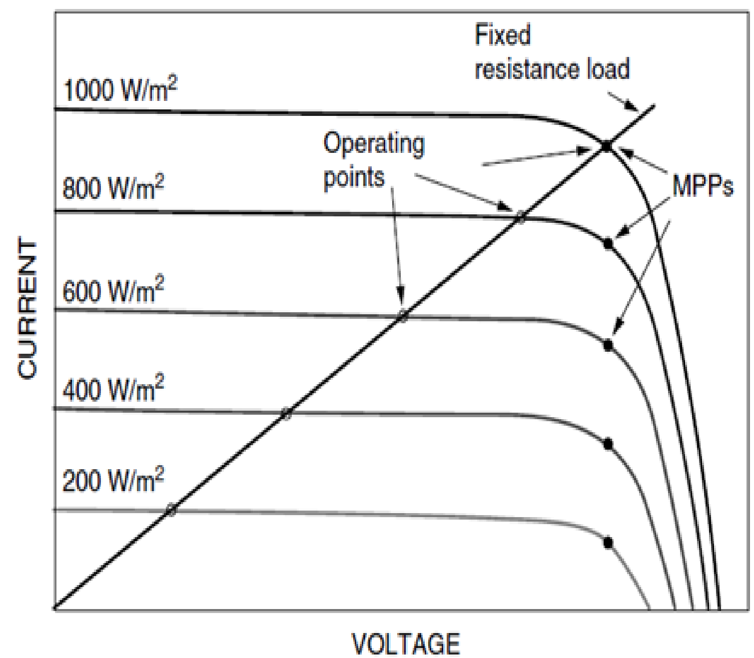
Operating Point



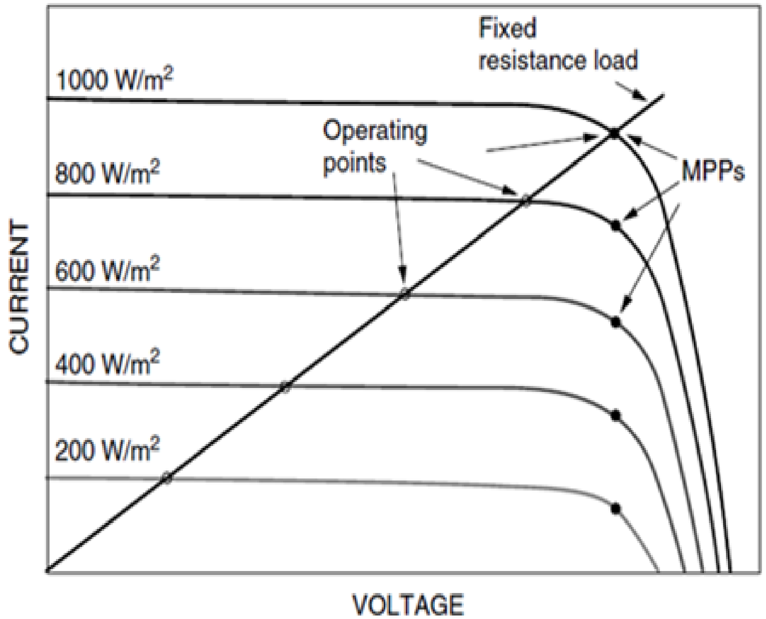


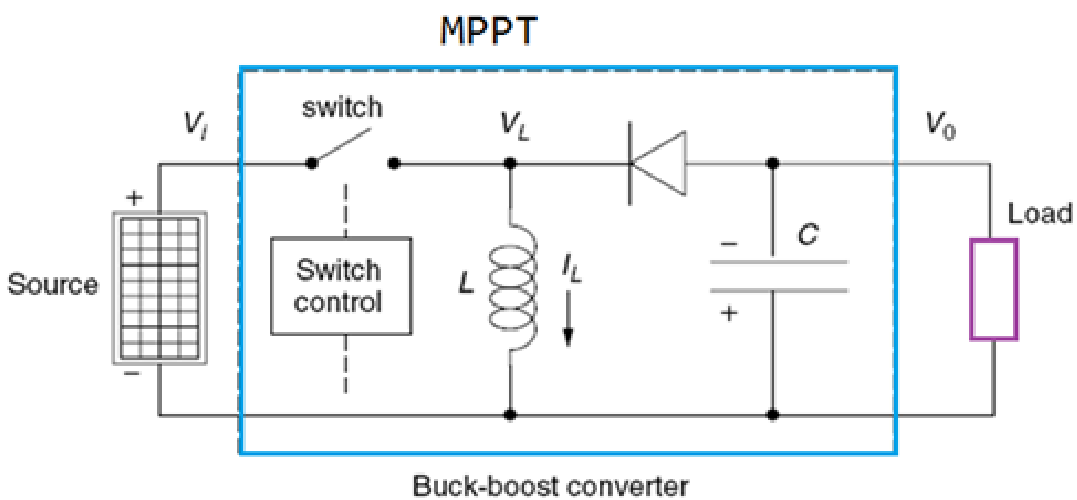
I-V Curve of Resistive Load

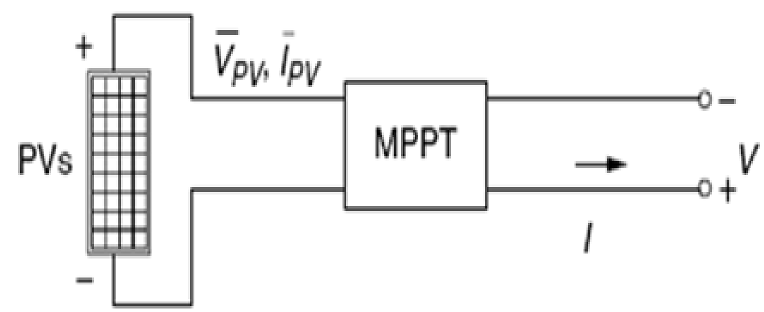




Maximum Power Point Tracker



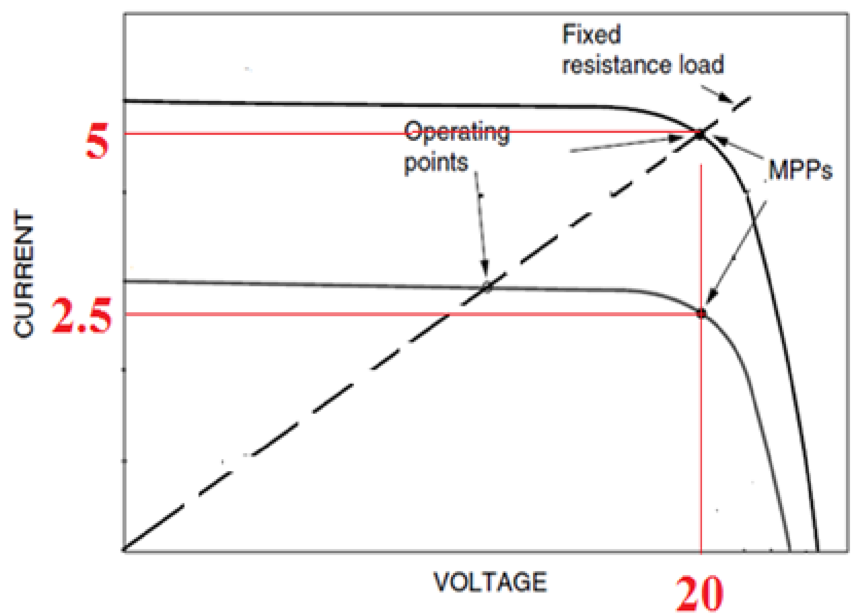


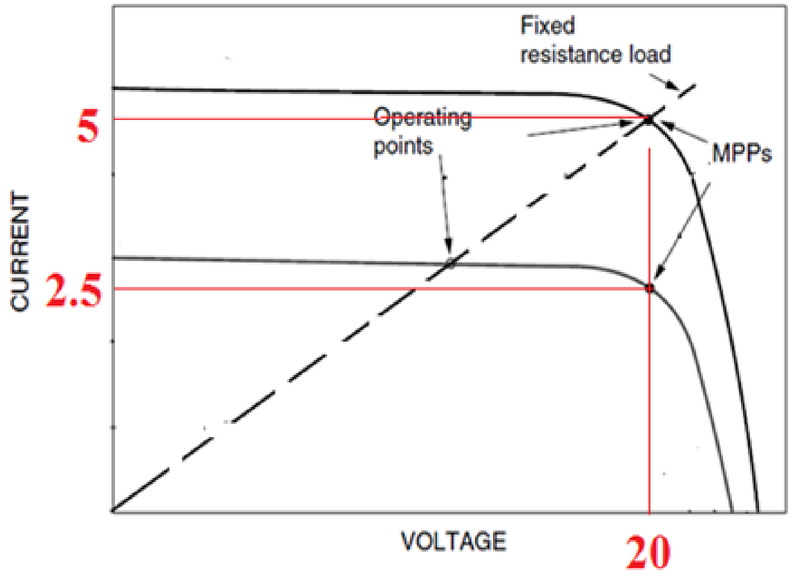


Maximum Power Point Tracker

MPPT - Example

- A PV module is delivering power to a resistive load of 4 ohms. Under an 1-sun condition, a PV module has its maximum power point at V_m=20 volts and I_m = 5 A. In the late afternoon (under ½ sun) , the maximum power point moves to I_m = 2.5 A and V_m=20 volts. (a) What is the power delivered to the load under 1-sun, (b) What is the power deliver to the load under ½ sun, (c) In ½ sun, what should be the output voltage to deliver maximum power to the load ?





1/2- sun condition

MPPT condition for maximum power to the load.