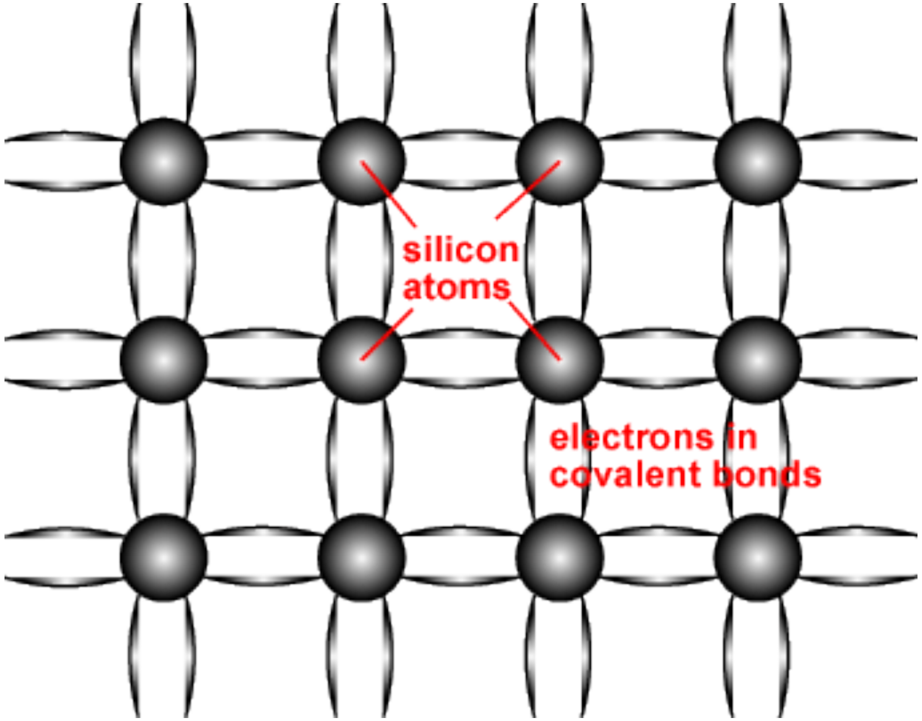
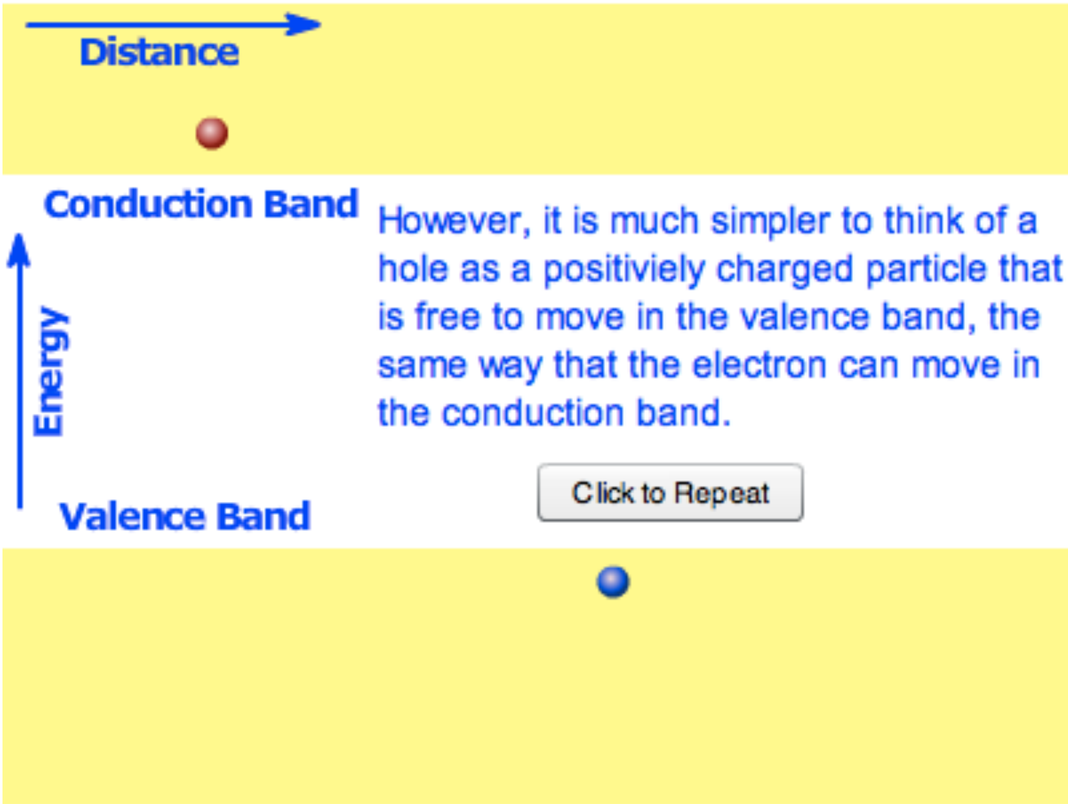
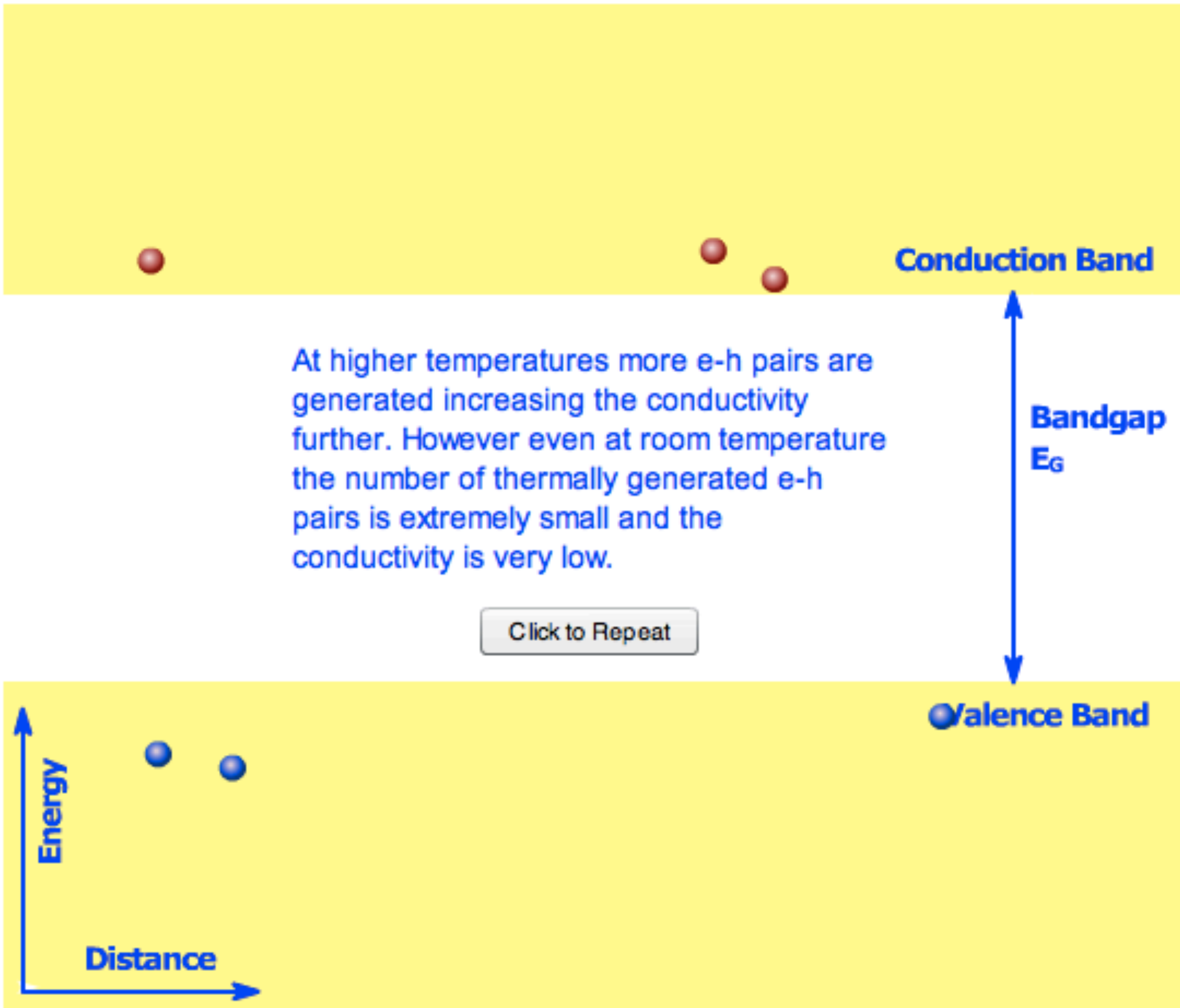
Workings of a solar cell

Semiconductor crystal



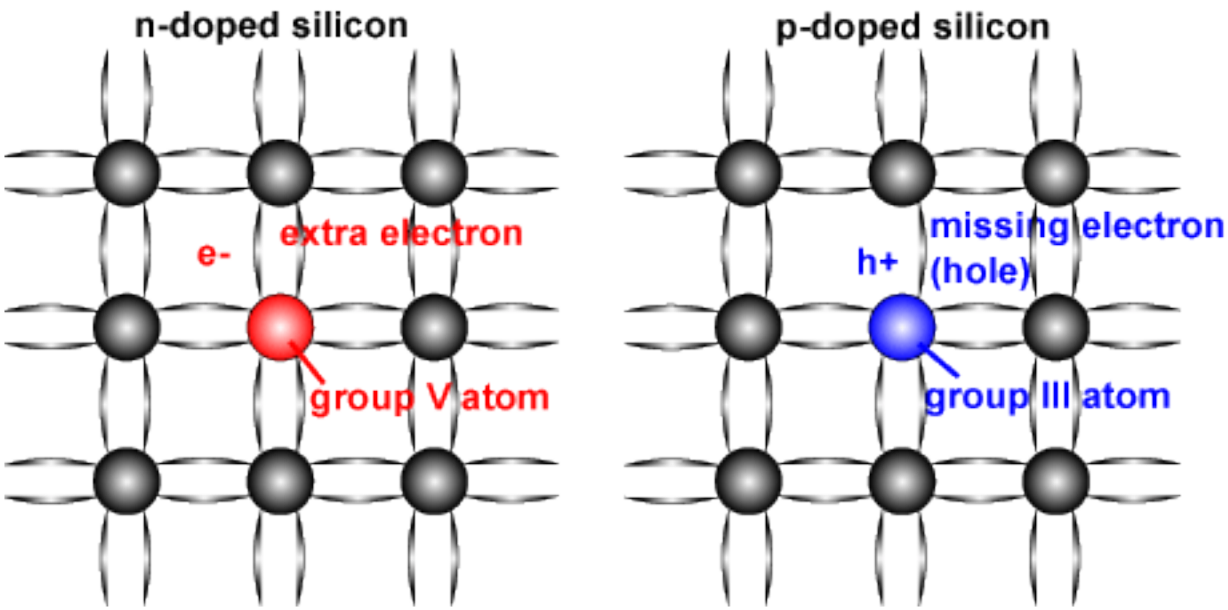
Energy bands





$n_{Si} = 8.6 \times 10^{9}\ cm^{-3}$

Doping



	P-type (positive)	N-type (negative)
Dopant	Group III (E.g. Boron)	Group V (e.g. Phosphorous)
Bonds	Missing Electrons (Holes)	Excess Electrons
Majority Carriers	Holes	Electrons
Minority Carriers	Electrons	Holes

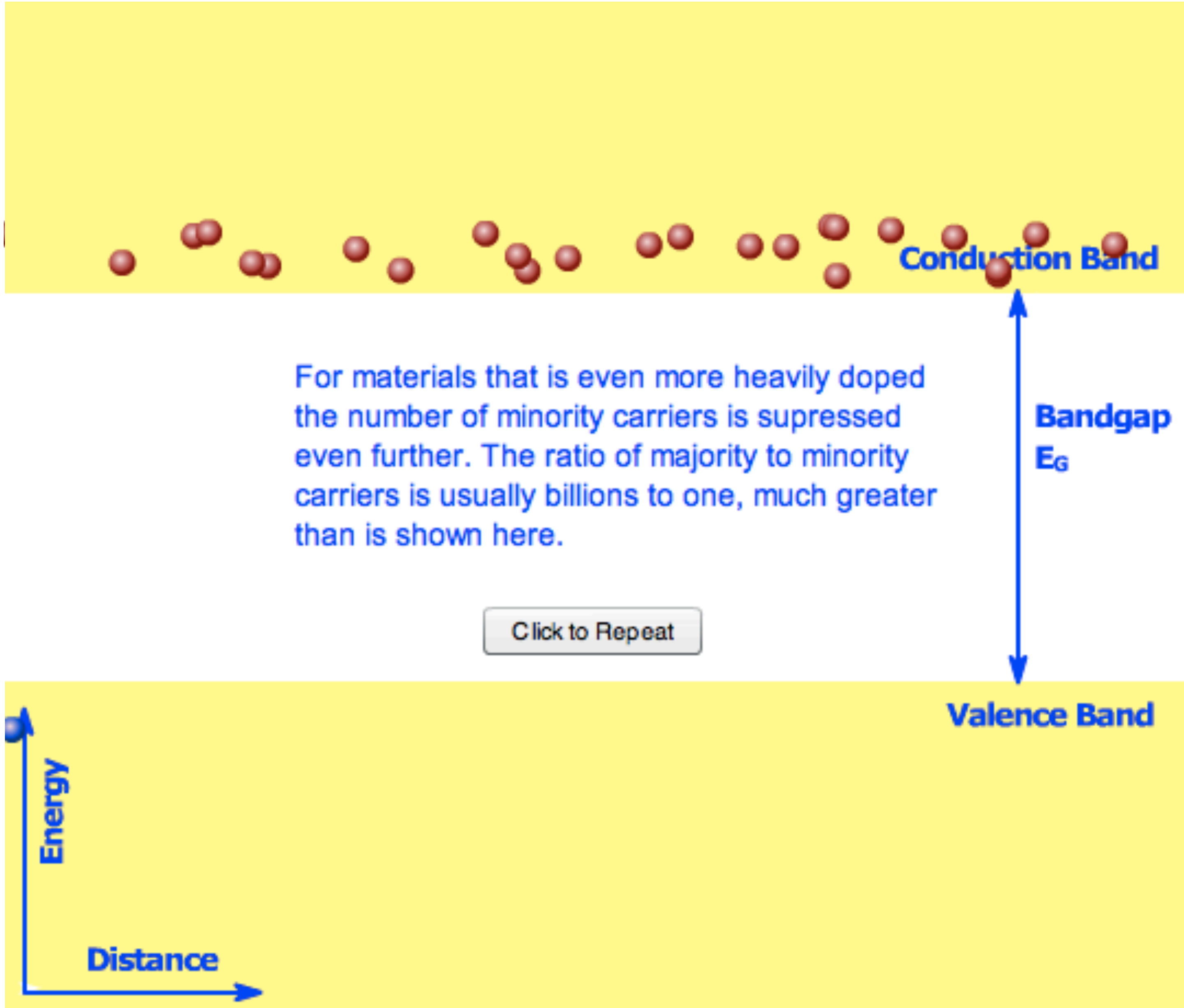
Equilibrium carrier concentration

intrinsic $$n_0 p_0 = n_i^2$$

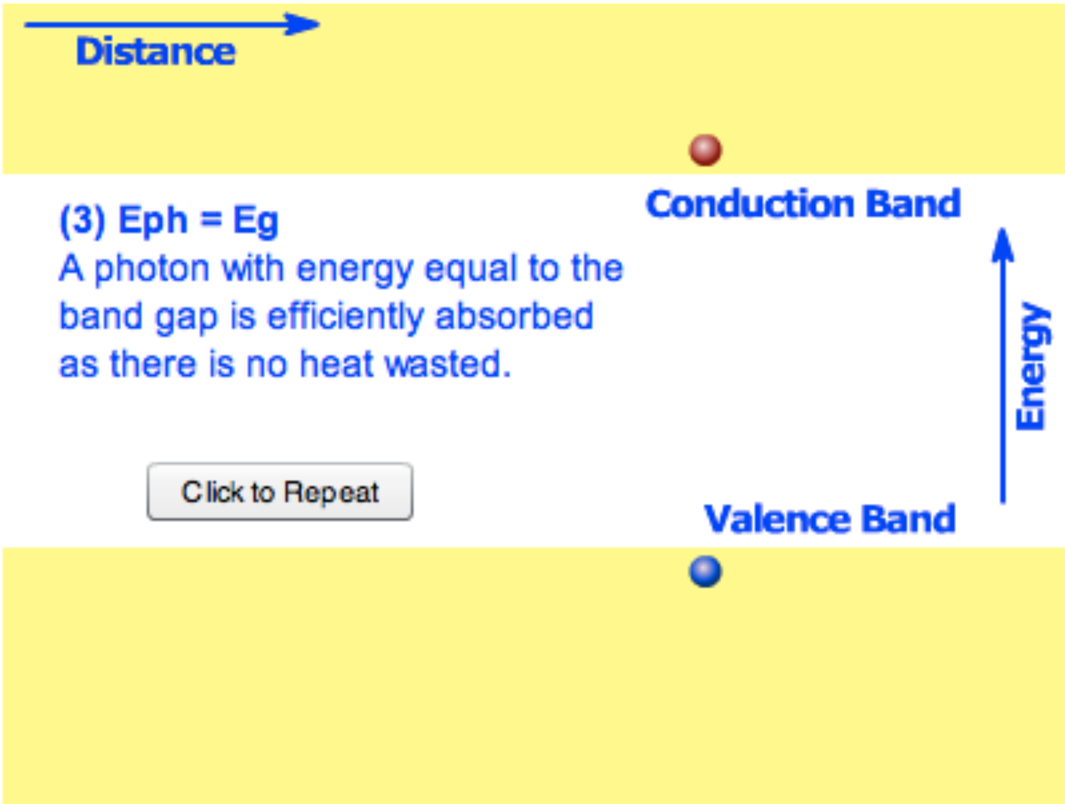
n type $$n_0 = N_D \quad p_0 = \frac{n_i^2}{N_D}$$

p type $$n_0 = \frac{n_i^2}{N_A} \quad p_0 = N_A$$

Equilibrium carrier concentration

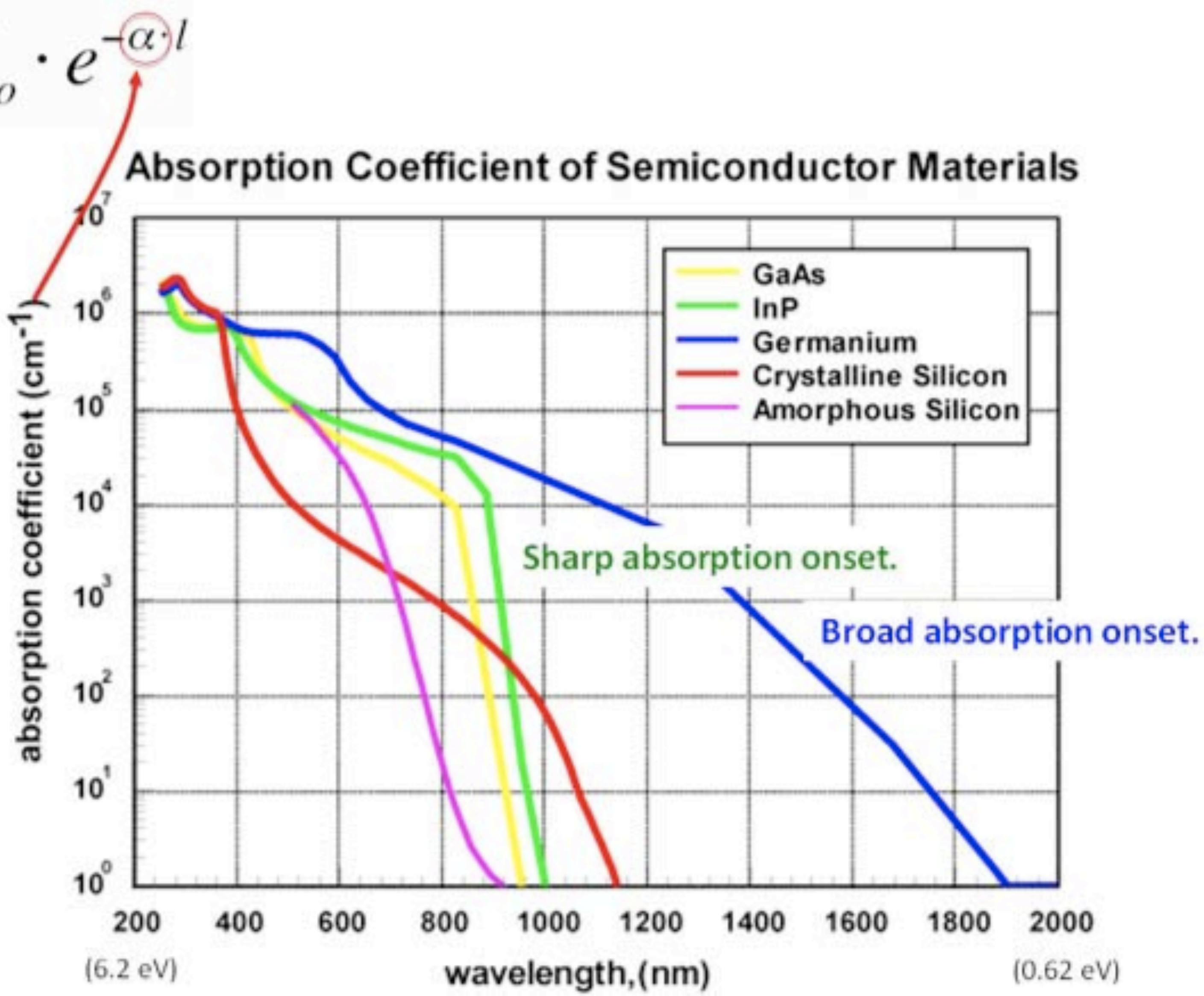


Photon absorption

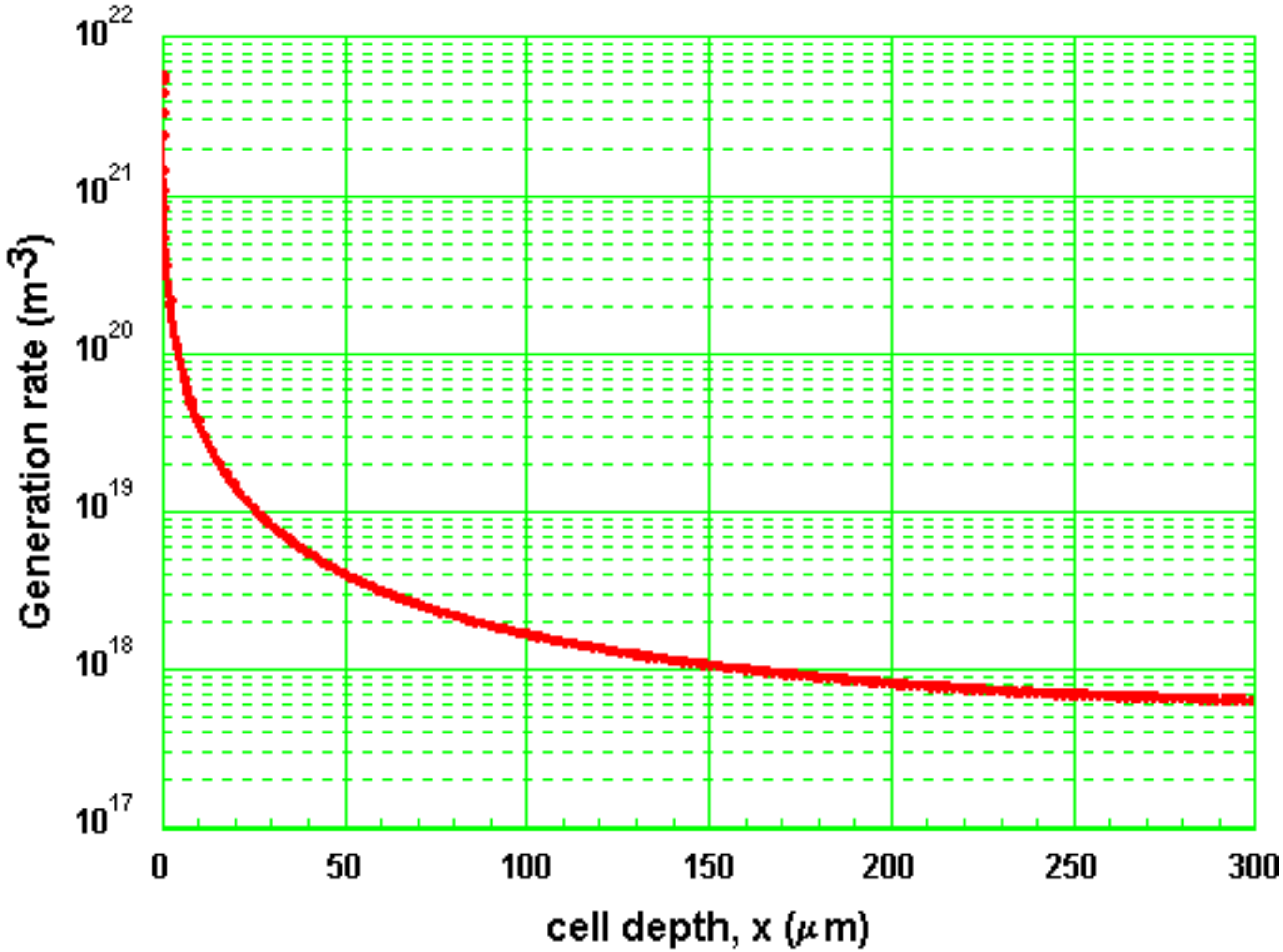


Absorption Coefficient (α) for different materials

$$I = I_o \cdot e^{-\alpha \cdot l}$$



Semiconductor crystal



$$I = I_0 e^{-\alpha x}$$

$$G = \alpha N_0 e^{-\alpha x}$$

Carrier recombination

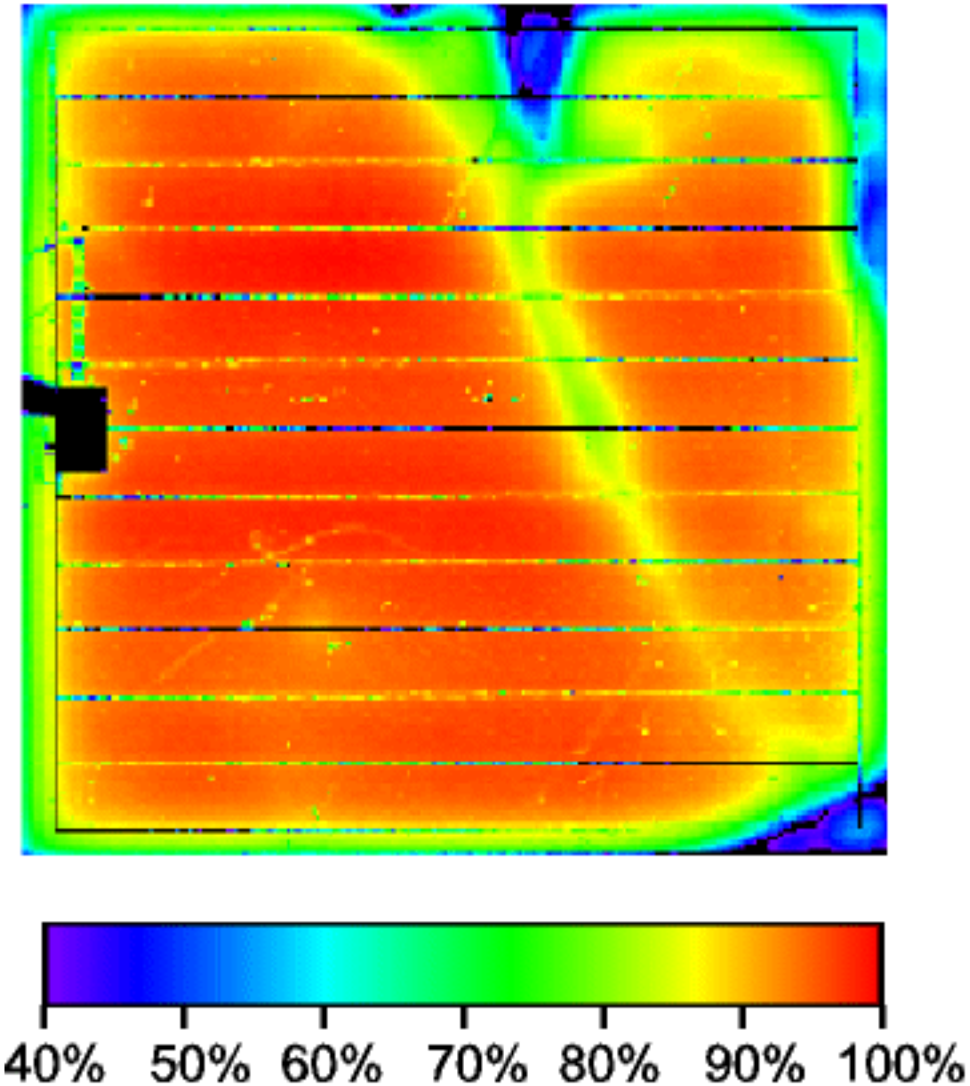
Carrier recombination

$$\tau = \frac{\Delta n}{R}$$

$$\frac{1}{\tau_{bulk}} = \frac{1}{\tau_{Band}} + \frac{1}{\tau_{Auger}} + \frac{1}{\tau_{SRH}}$$

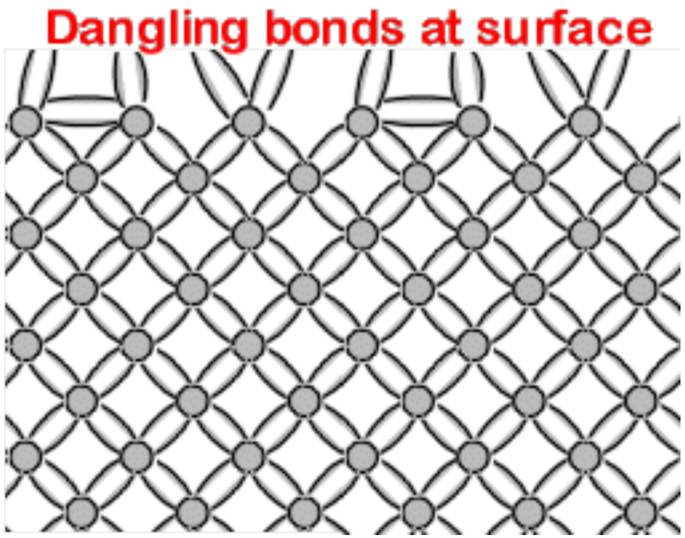
$$\tau_{Auger} = \frac{1}{CN_A^2}$$

Diffusion length

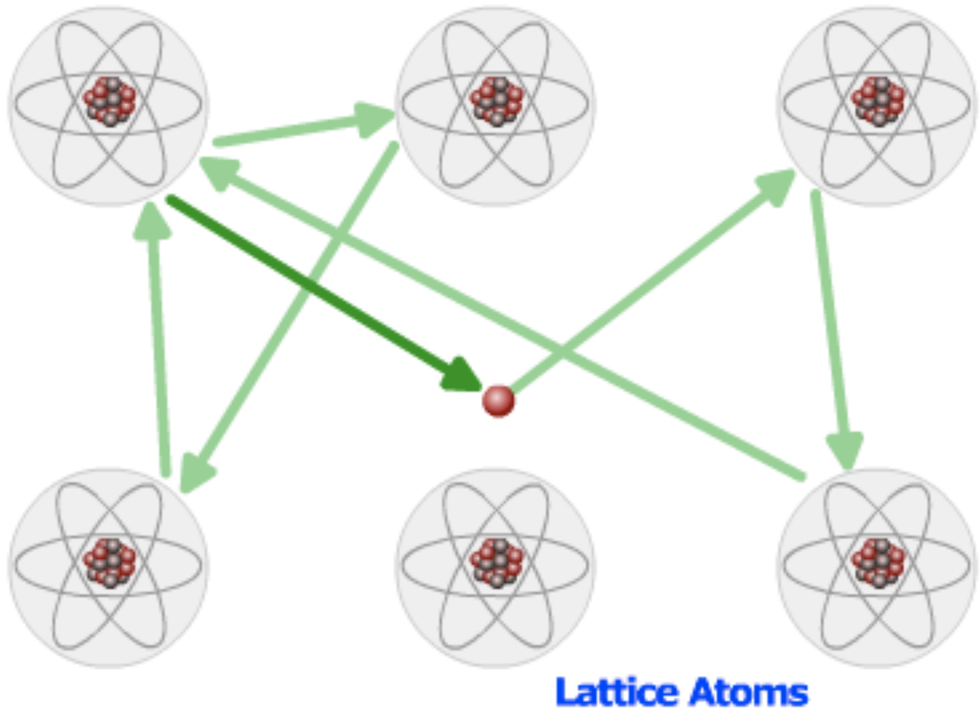


$$L = \sqrt{D\tau}$$

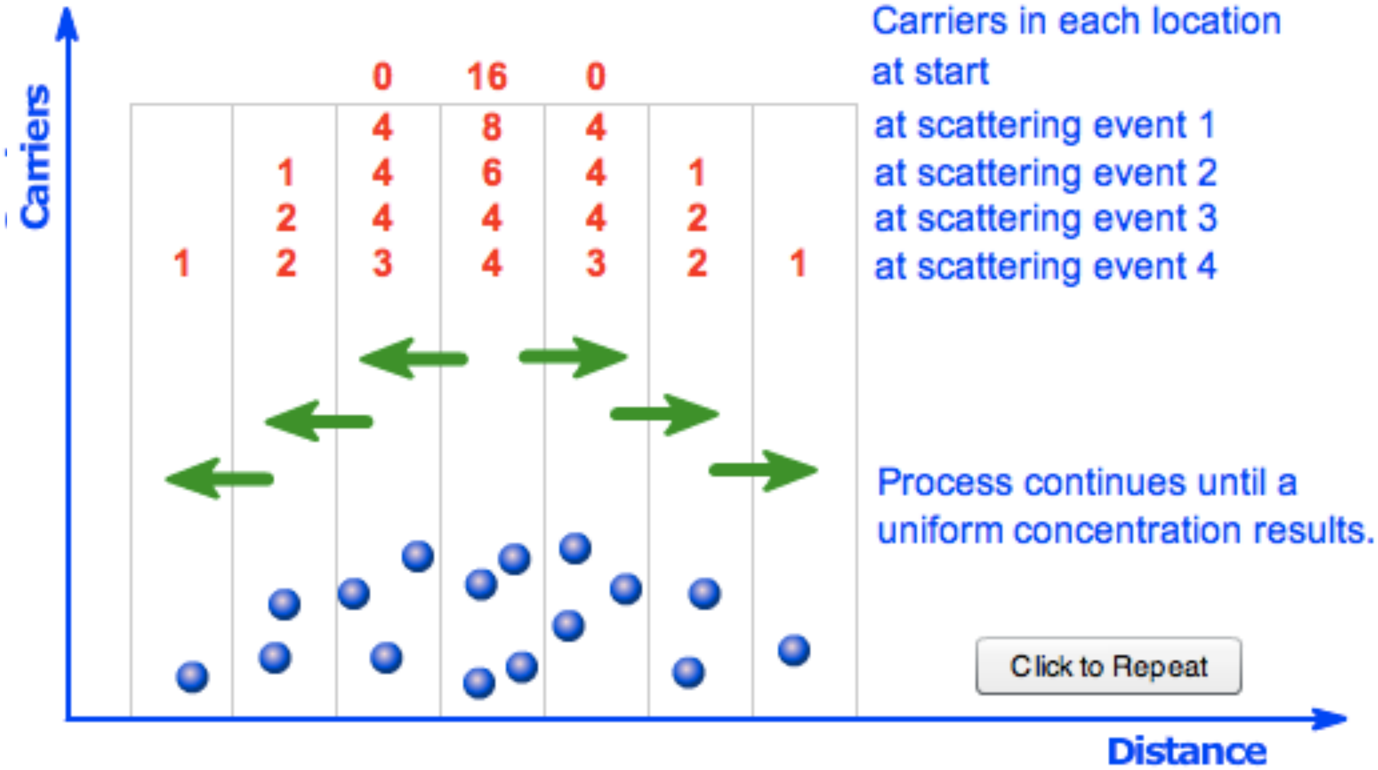
Surface defects



Carrier movement in semiconductors

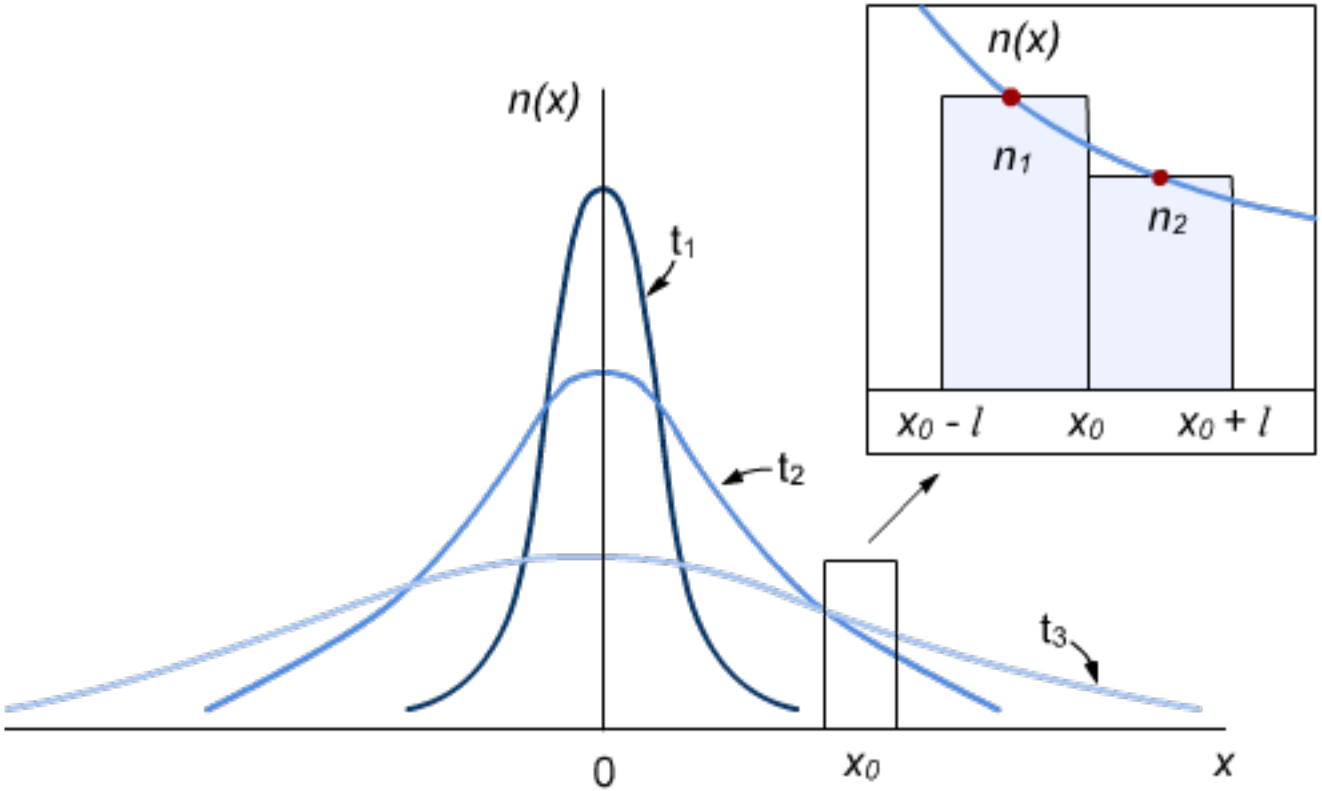


Carrier diffusion



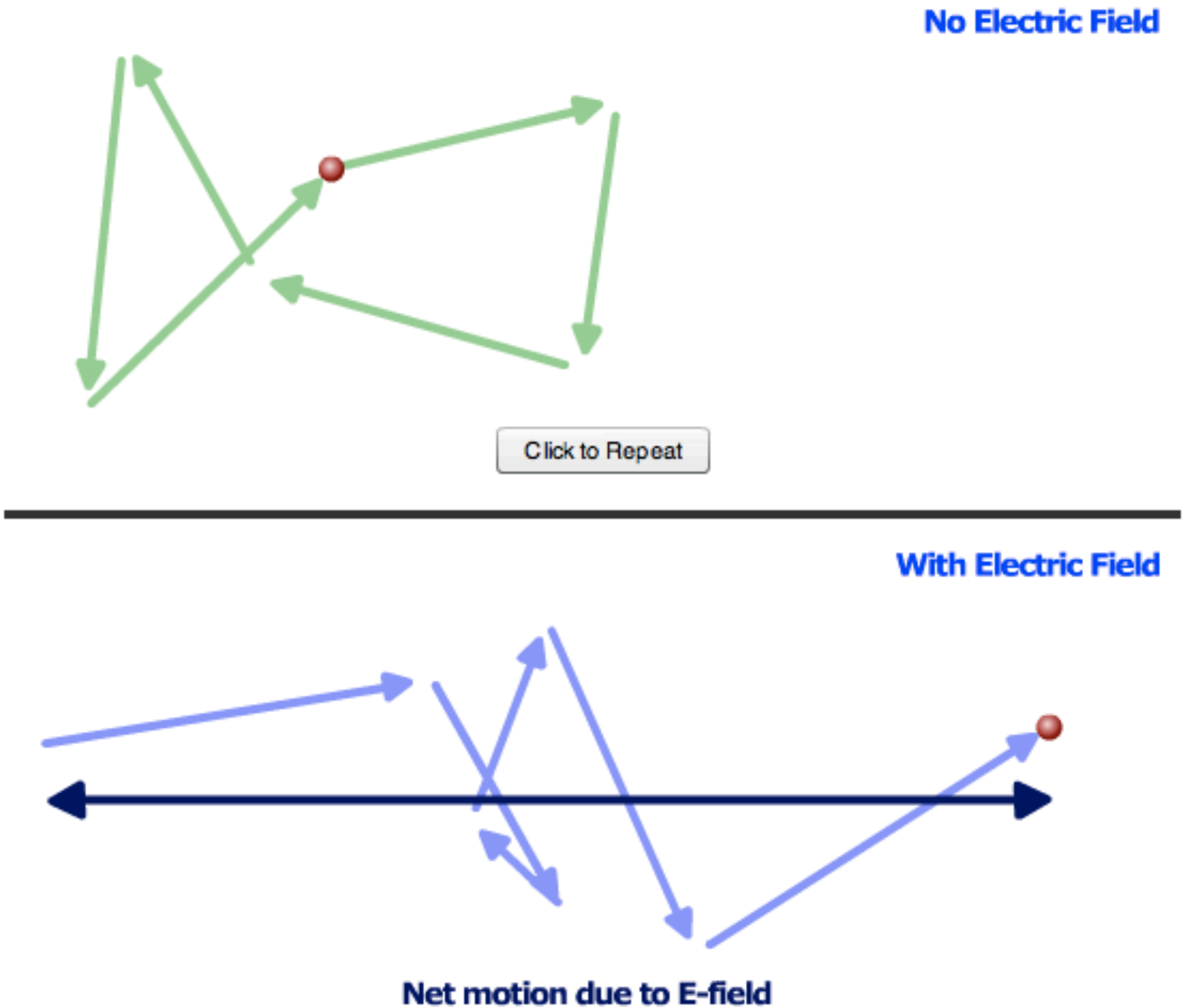
Carrier diffusion

$$J_{p\,diff} = -qD_p \frac{dp(x)}{dx}$$



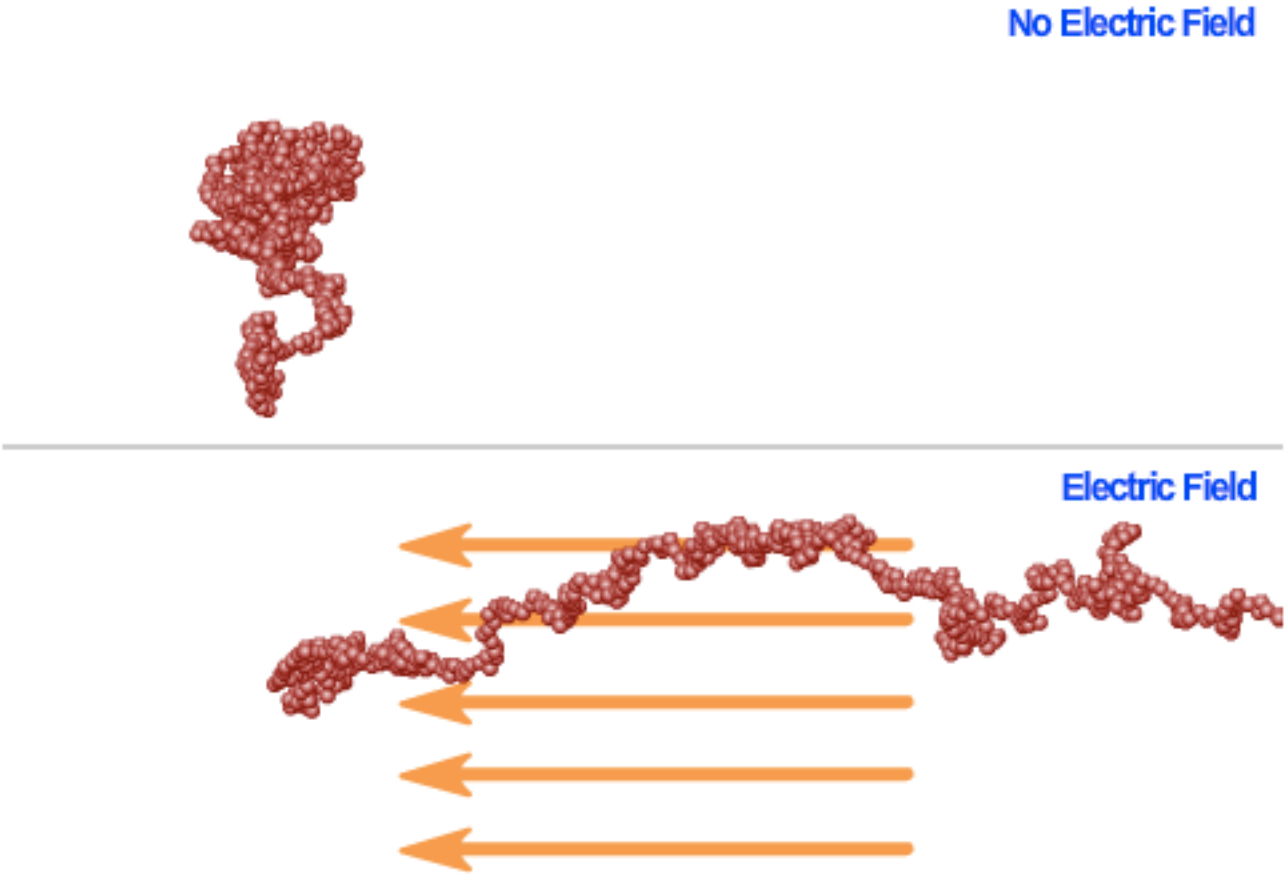
$$\frac{\partial n}{\partial t} = D_n \frac{\partial^2 n}{\partial x^2} - (U - G)$$

Carrier drift



Carrier drift

$$J_x = -qn\bar{v}_x$$



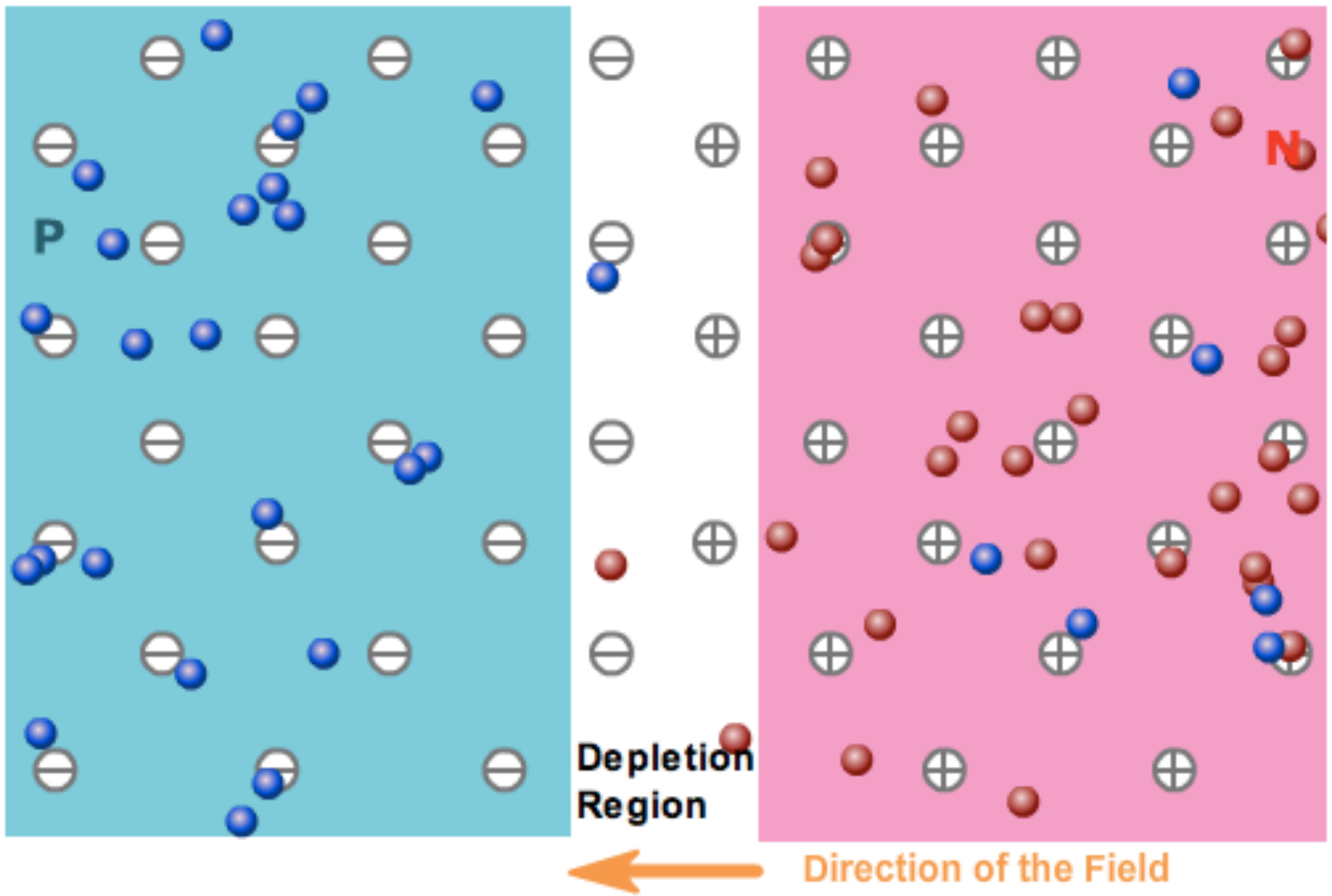
$$J_x = \frac{nq^2\bar{t}}{m_n^*}E_x \;\Rightarrow\; J_x = \sigma E_x$$

$$\sigma = \frac{nq^2\bar{t}}{m_n^*}, \quad \sigma = qn\mu_n$$

$$\mu_n = \frac{q\tau}{m_n^*}, \quad \mu_n = -\frac{\bar{v}_x}{E_x}$$

$$J_x = q(n\mu_n + p\mu_p)E_x$$

p-n junction

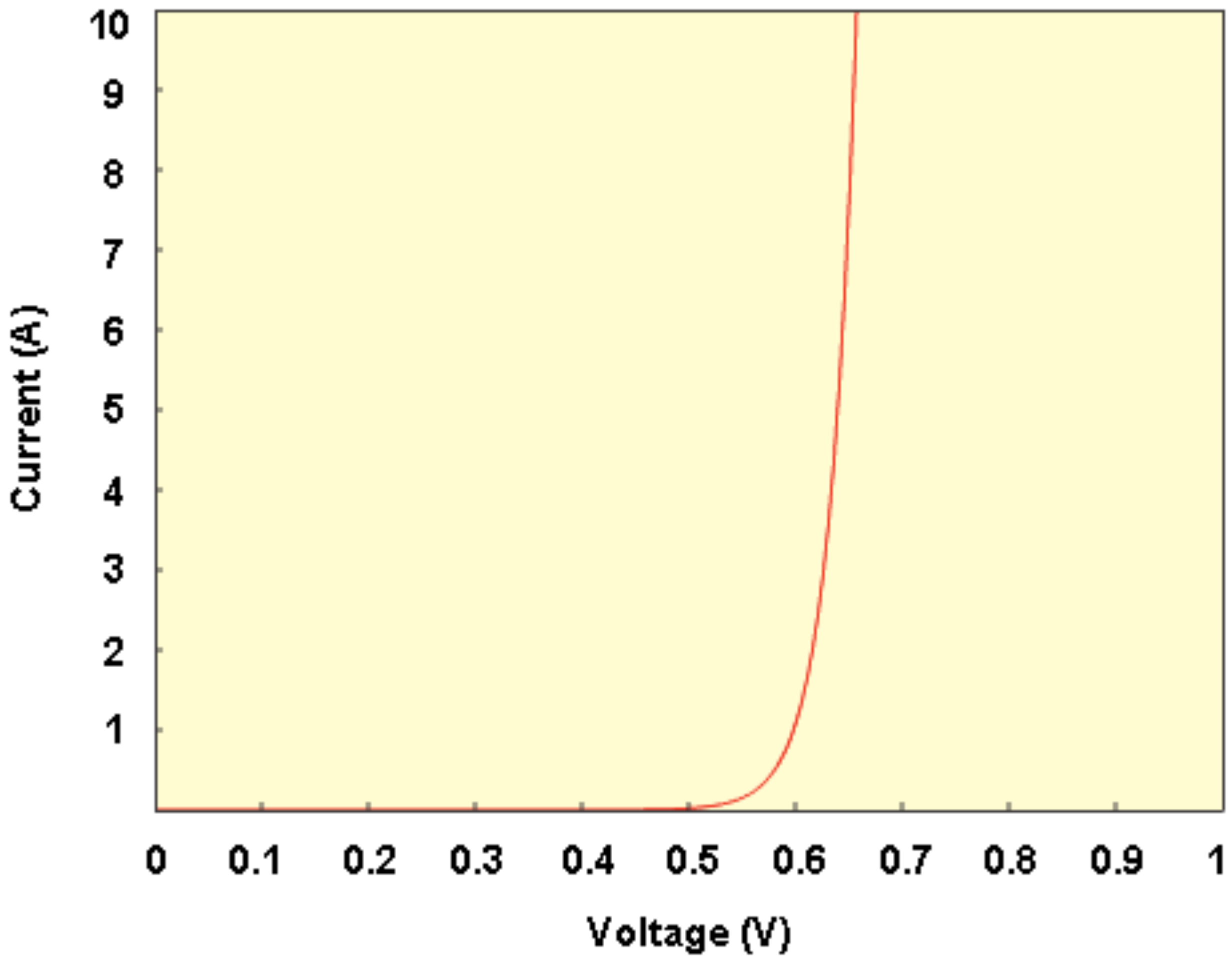


The electric field tends to keep the holes in the p-type material and the electrons in the n-type material. However, even at thermal equilibrium some carriers hae sufficient energy to cross the depletion region.

Click to Repeat

Diode characteristics

$$J_{dark}(V) = J_0\left(e^{\frac{qV}{kT}} - 1\right)$$



Diode characteristics

Poisson's Equation

$$\frac{d\hat{E}}{dx} = \frac{\rho}{\varepsilon} = \frac{q}{\varepsilon}(p - n + N_D^+ - N_A^-)$$

Transport Equations

$$J_n = q\mu_n n\hat{E} + qD_n \frac{dn}{dx} \qquad J_p = q\mu_p p\hat{E} - qD_p \frac{dp}{dx}$$

Continuity Equations

General Conditions

$$\frac{dn}{dt} = \frac{1}{q}\frac{dJ_n}{dx} - (U - G)$$

The equation below needs to be corrected. The right side should be multiplied by -1.

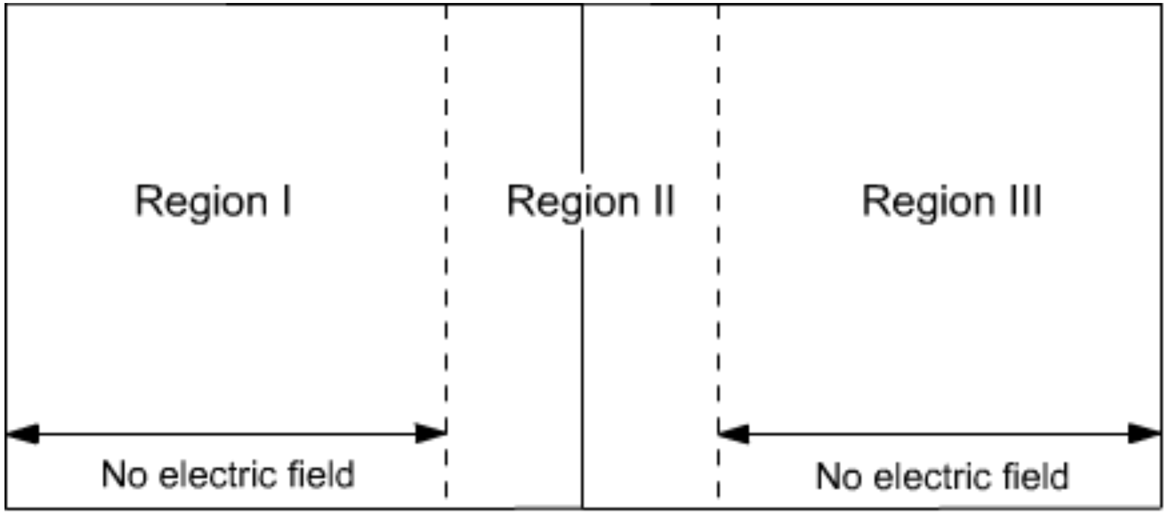
$$\frac{dp}{dt} = -\frac{1}{q}\frac{dJ_p}{dx} - (U - G)$$

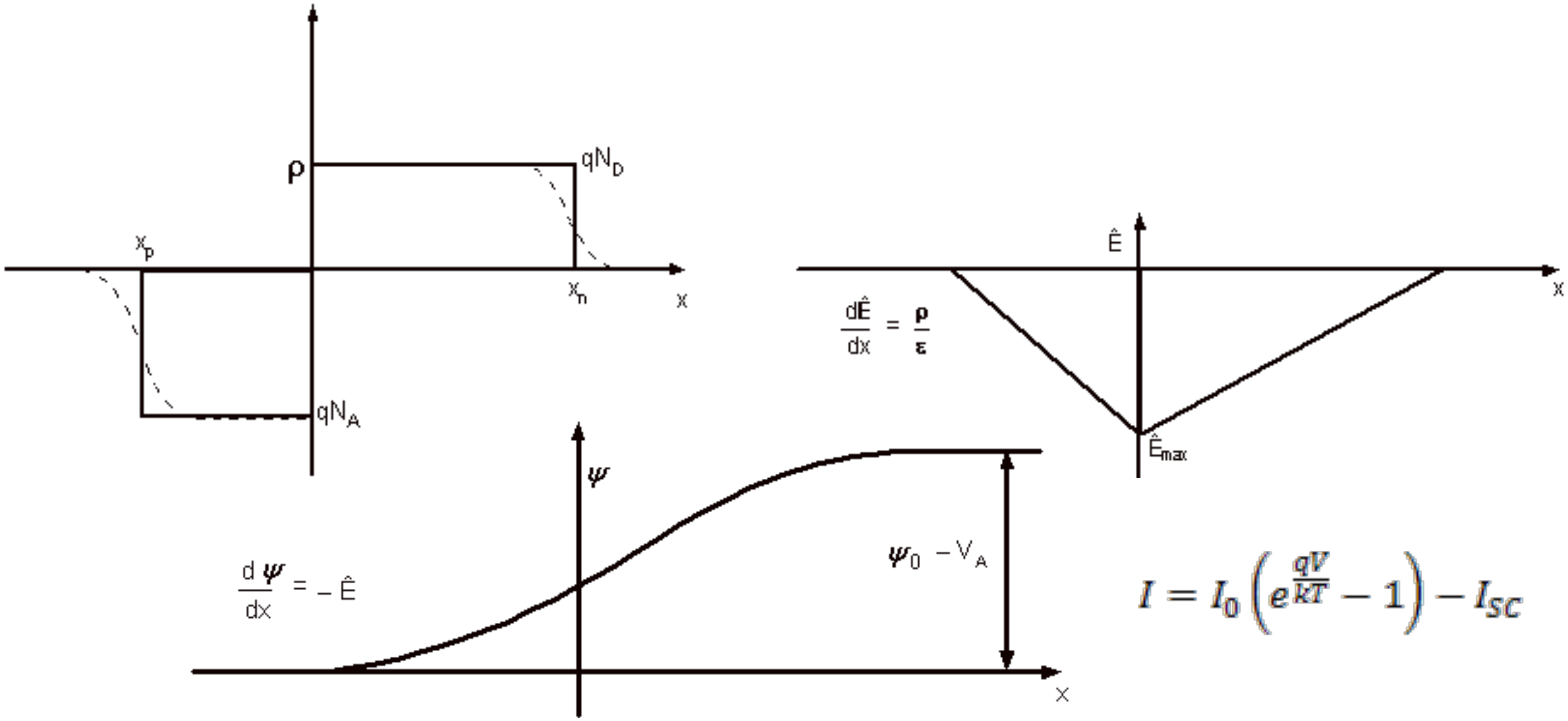
Under thermal equilibrium and steady state conditions

$$\frac{1}{q}\frac{dJ_n}{dx} = U - G$$

$$\frac{1}{q}\frac{dJ_p}{dx} = -(U - G)$$

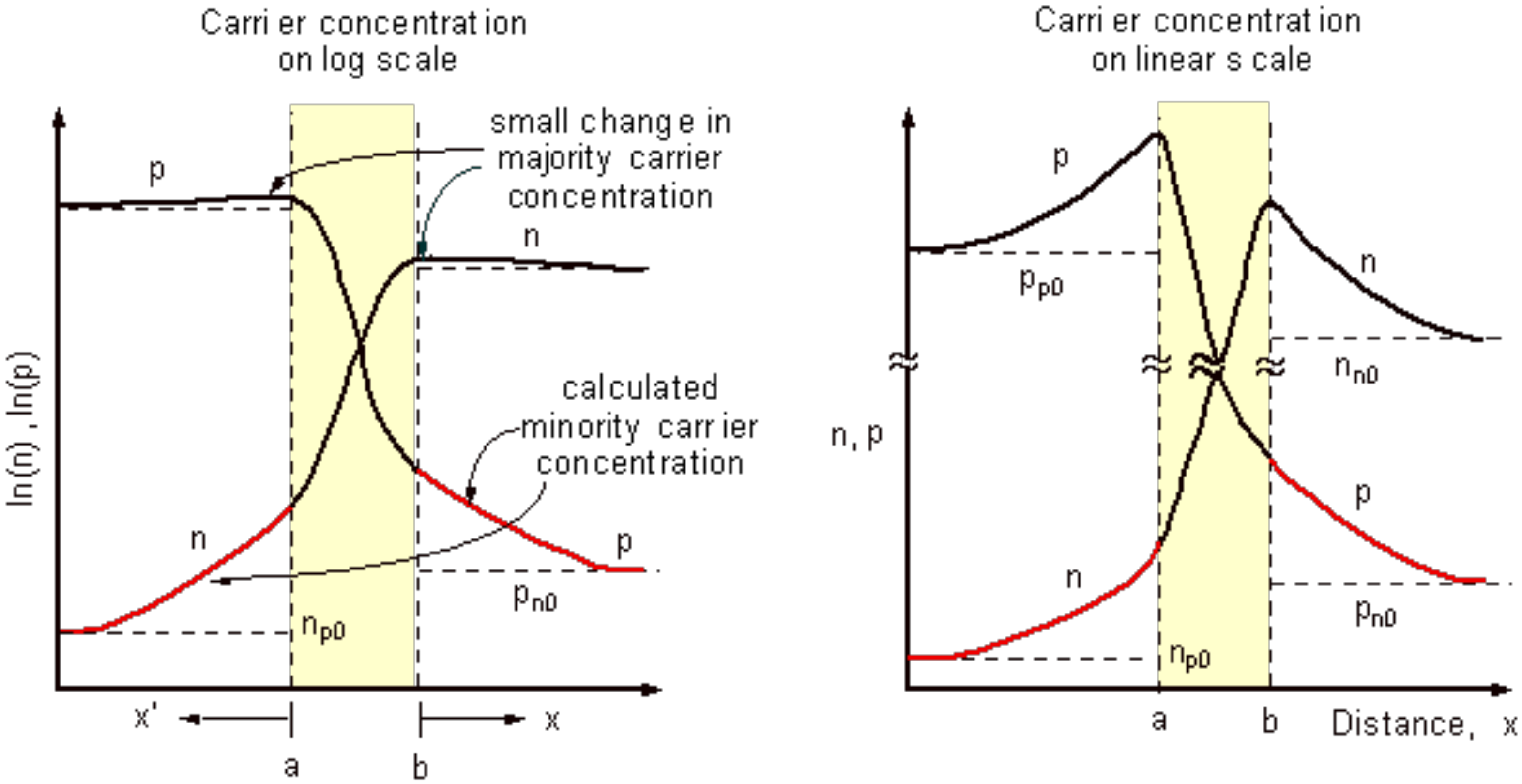
Depletion approximation



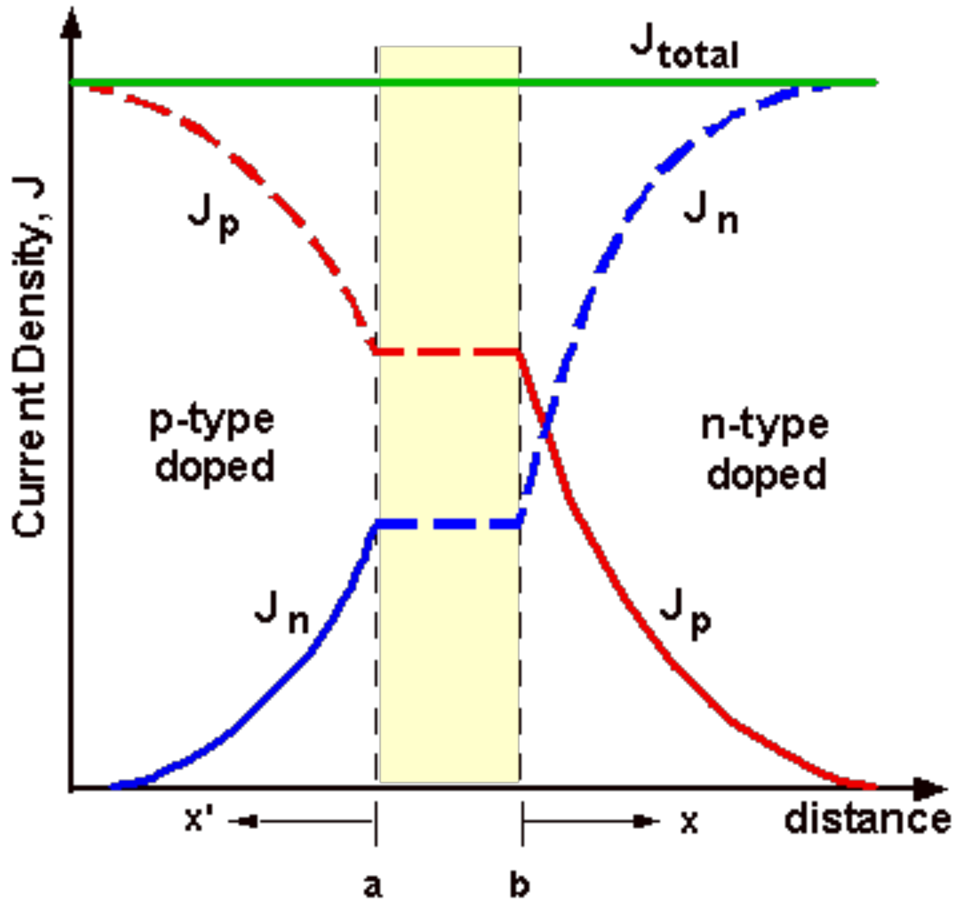


$$I = I_0\left(e^{\frac{qV}{kT}} - 1\right) - I_{SC}$$

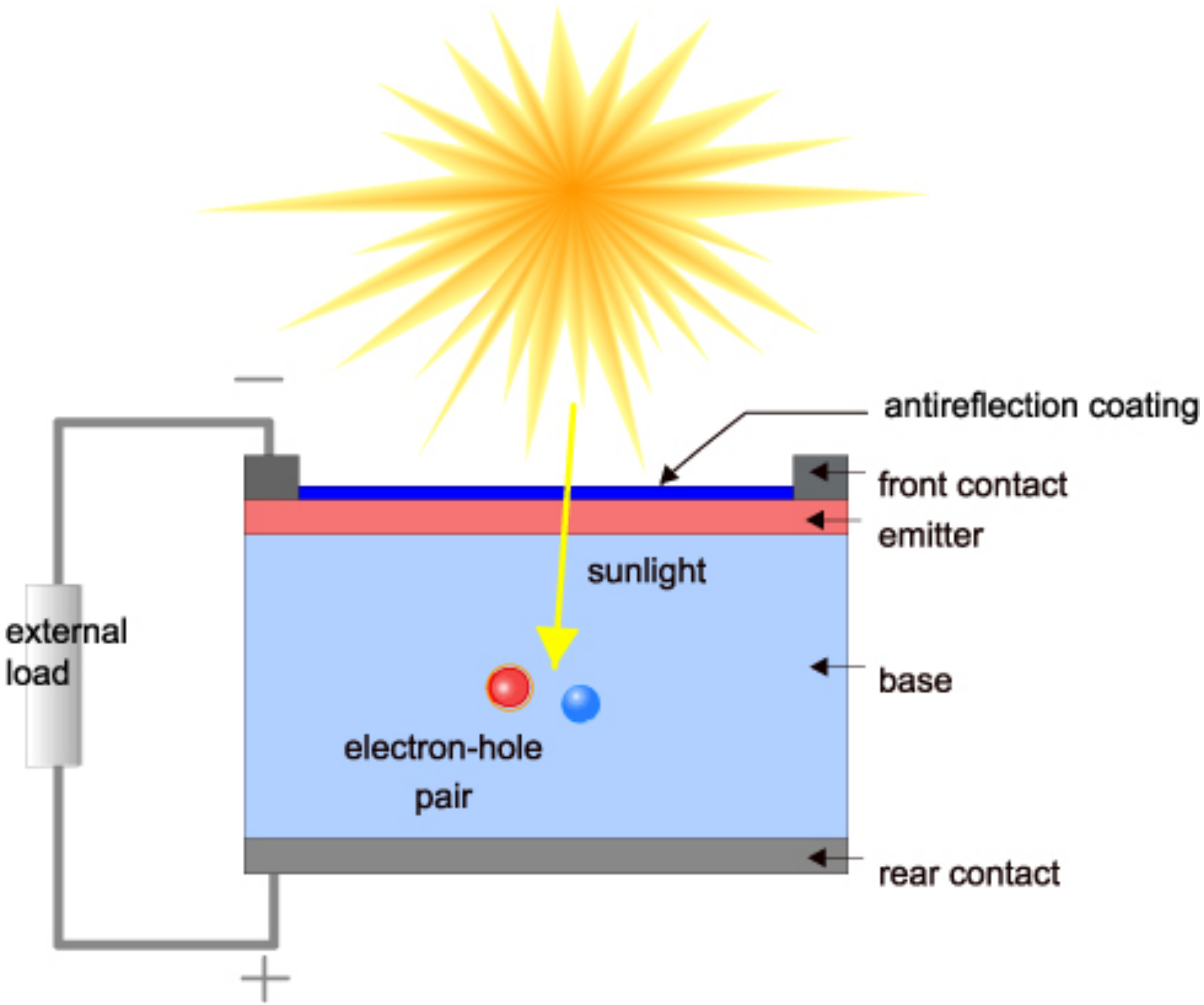
Carrier concentration



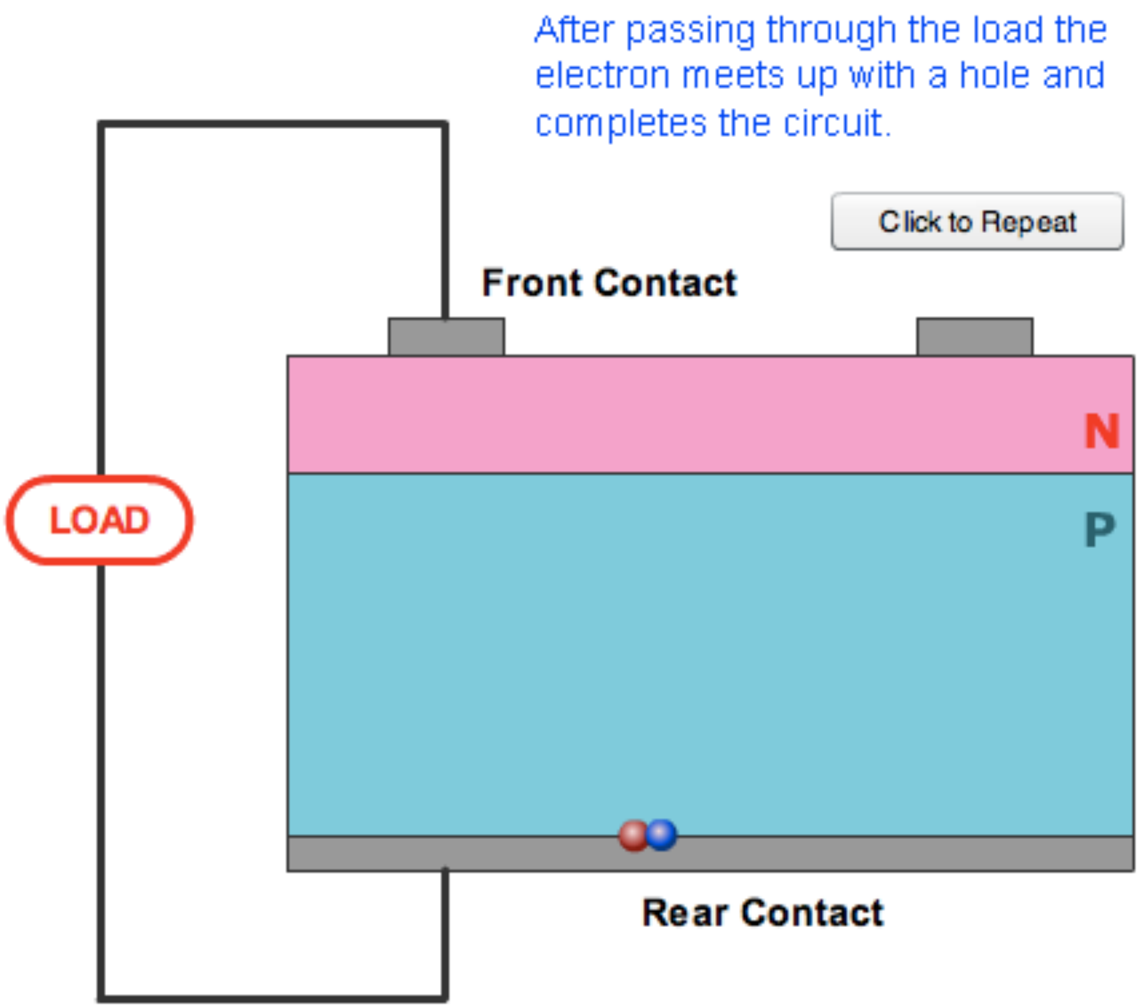
Carrier concentration



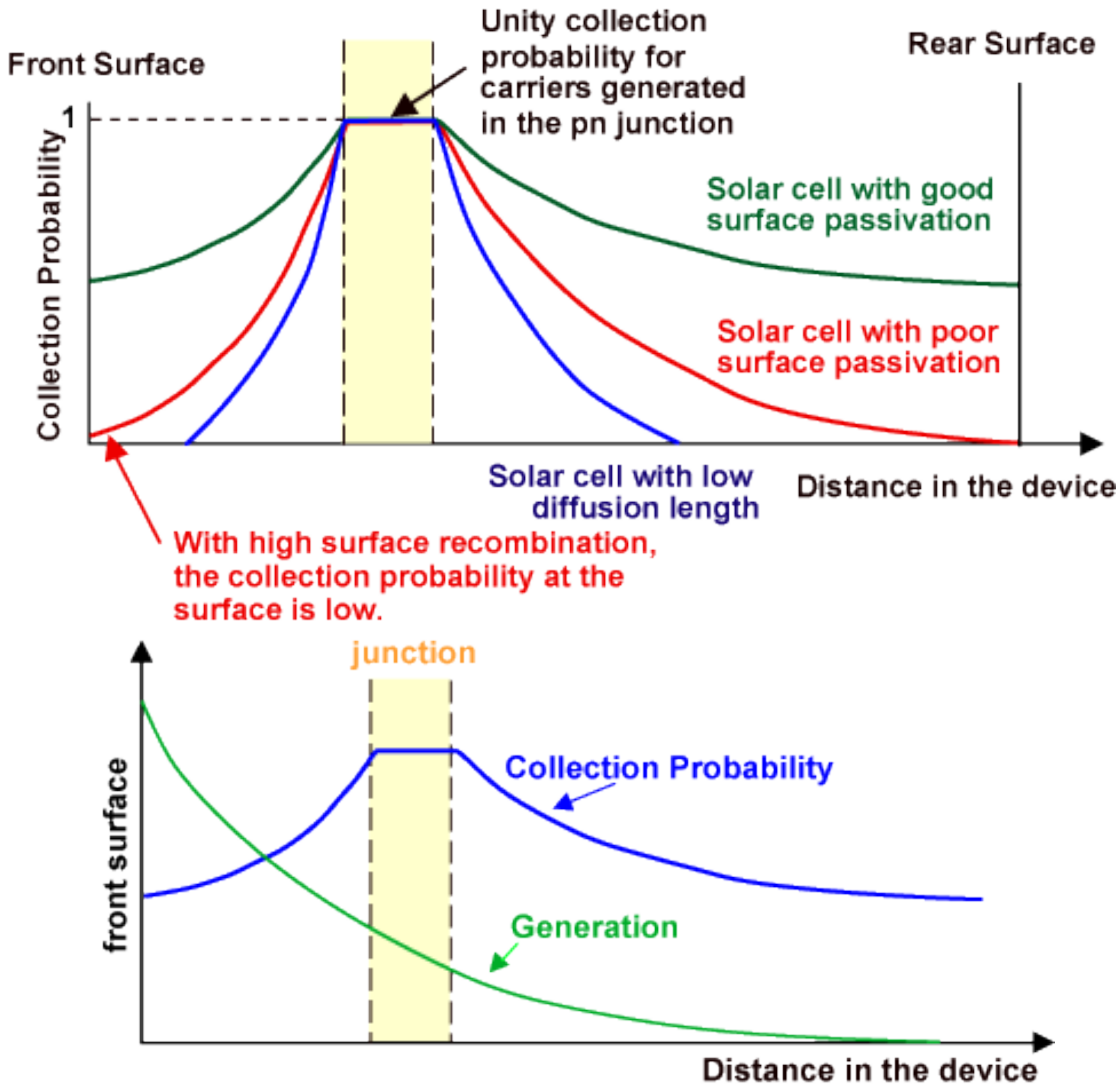
Workings of a solar cells



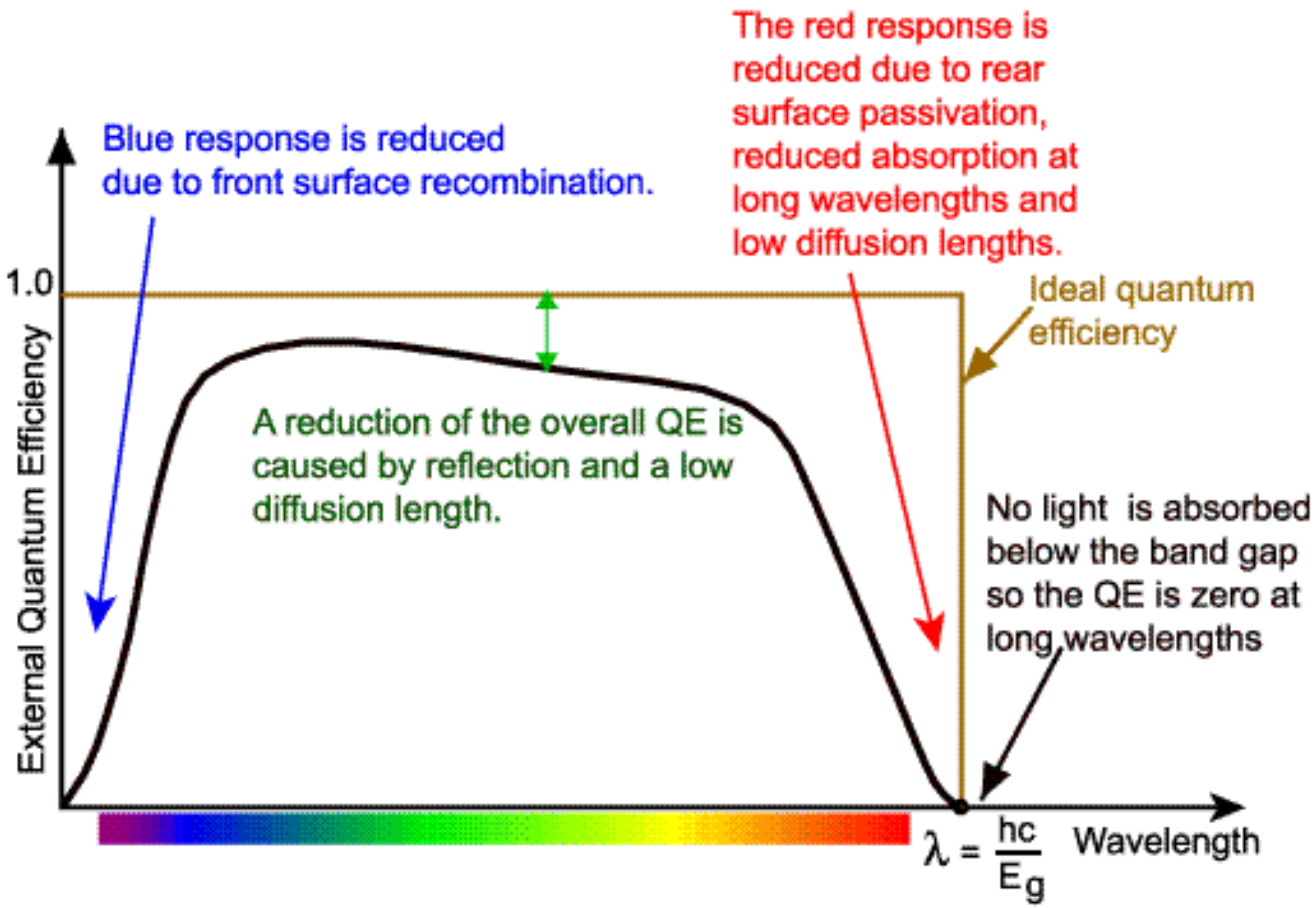
Workings of a solar cells



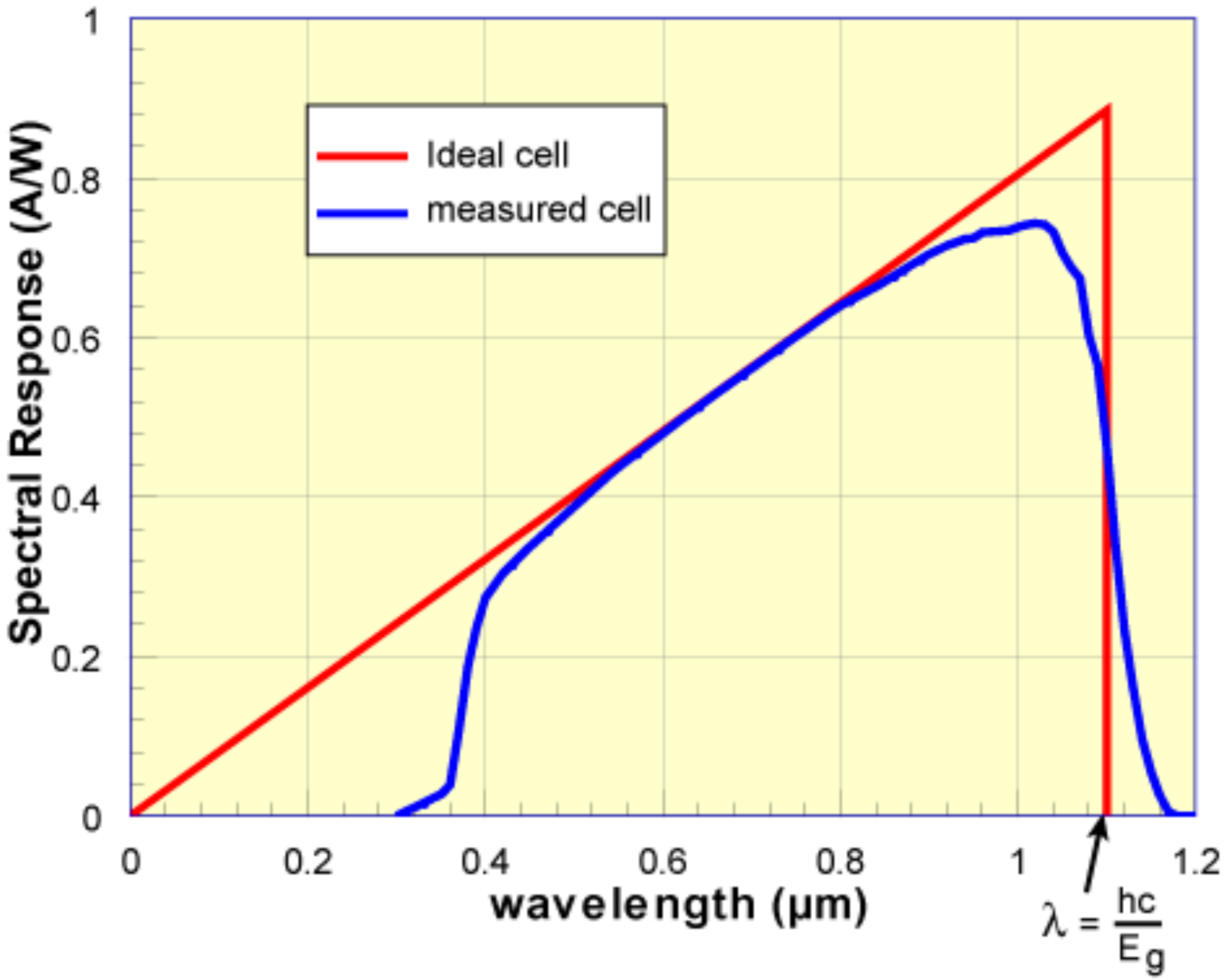
Collection probability



Quantum efficiency

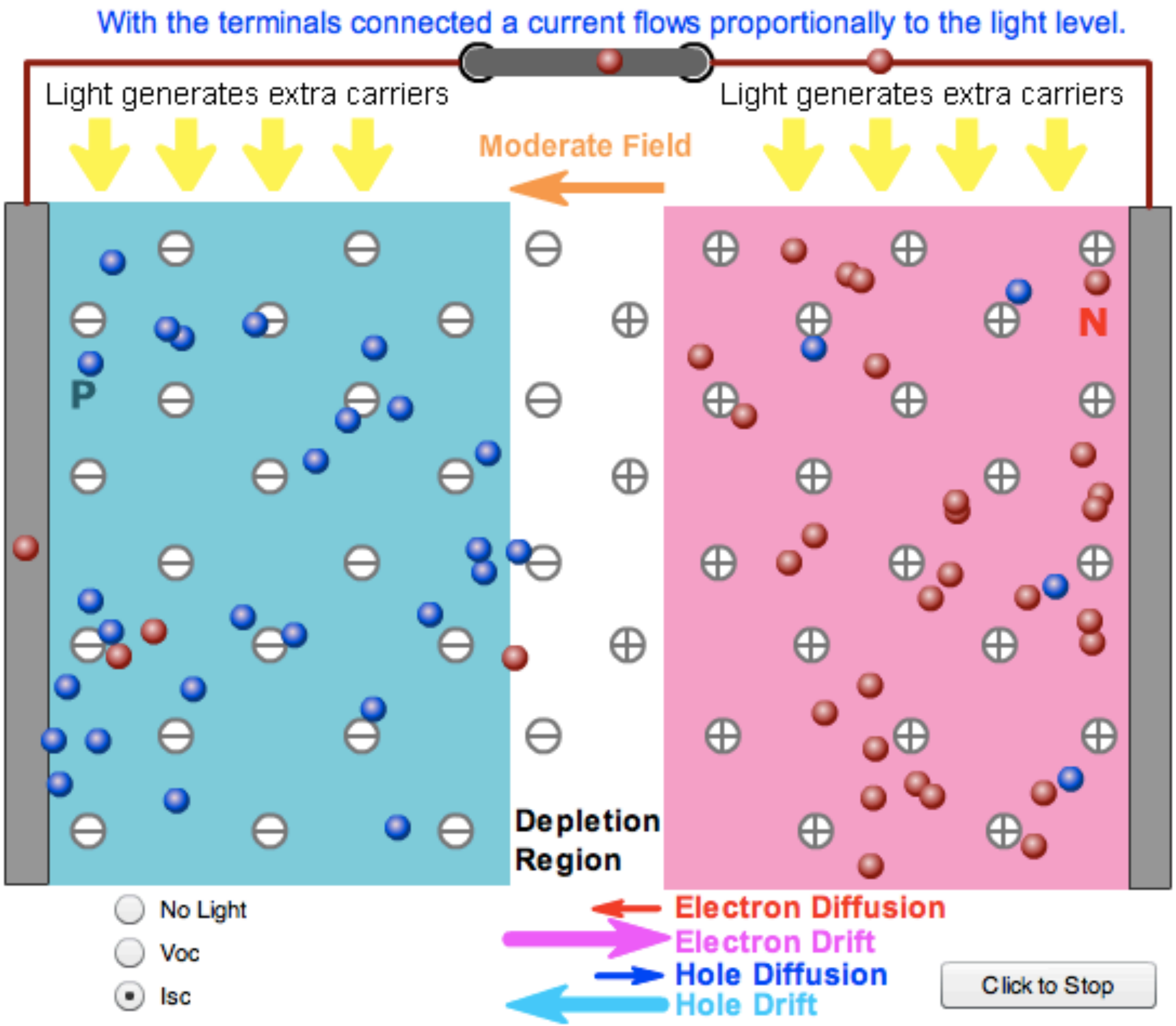


Spectral response

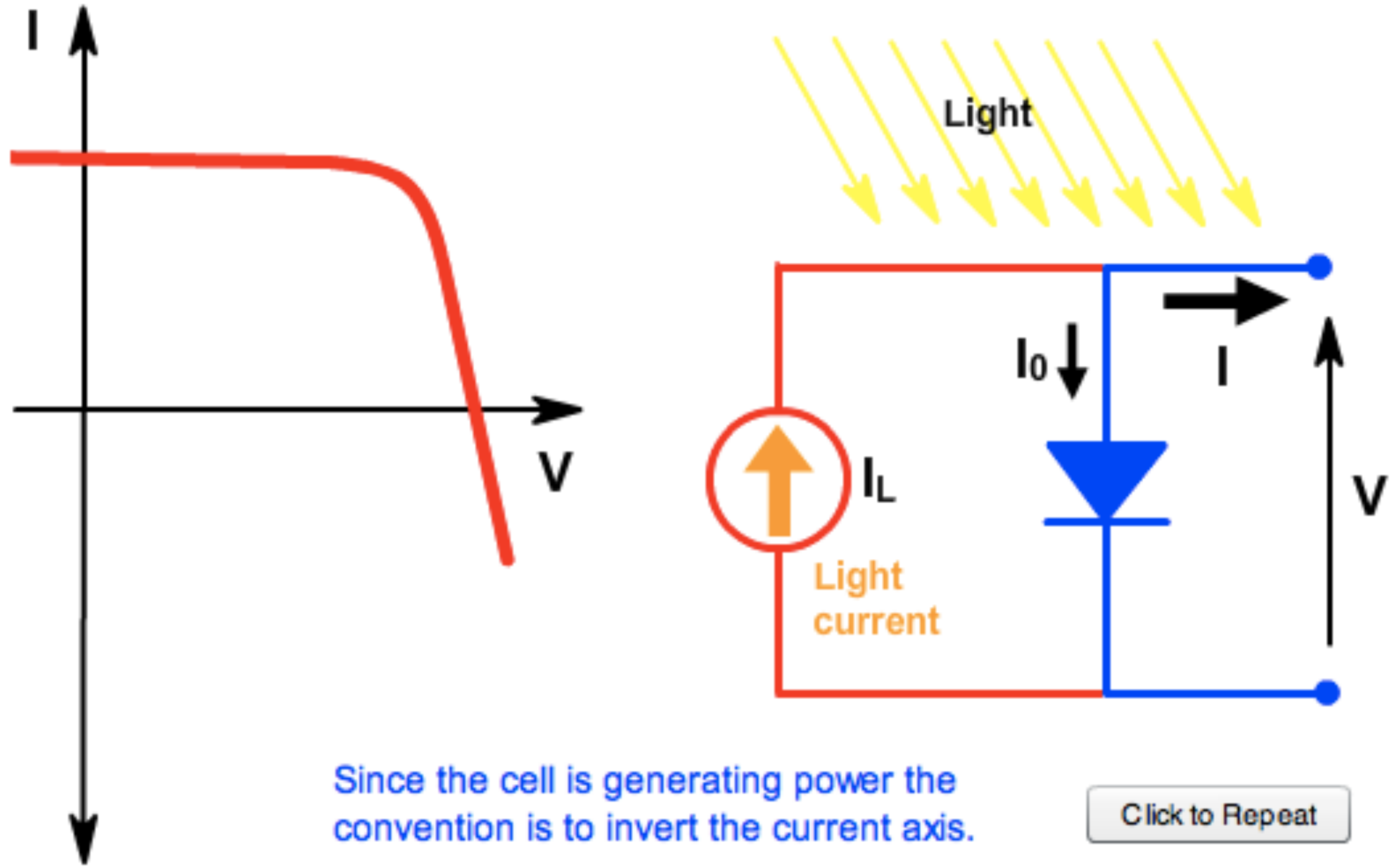


$$SR = \frac{q\lambda}{hc} QE$$

Workings of solar cells



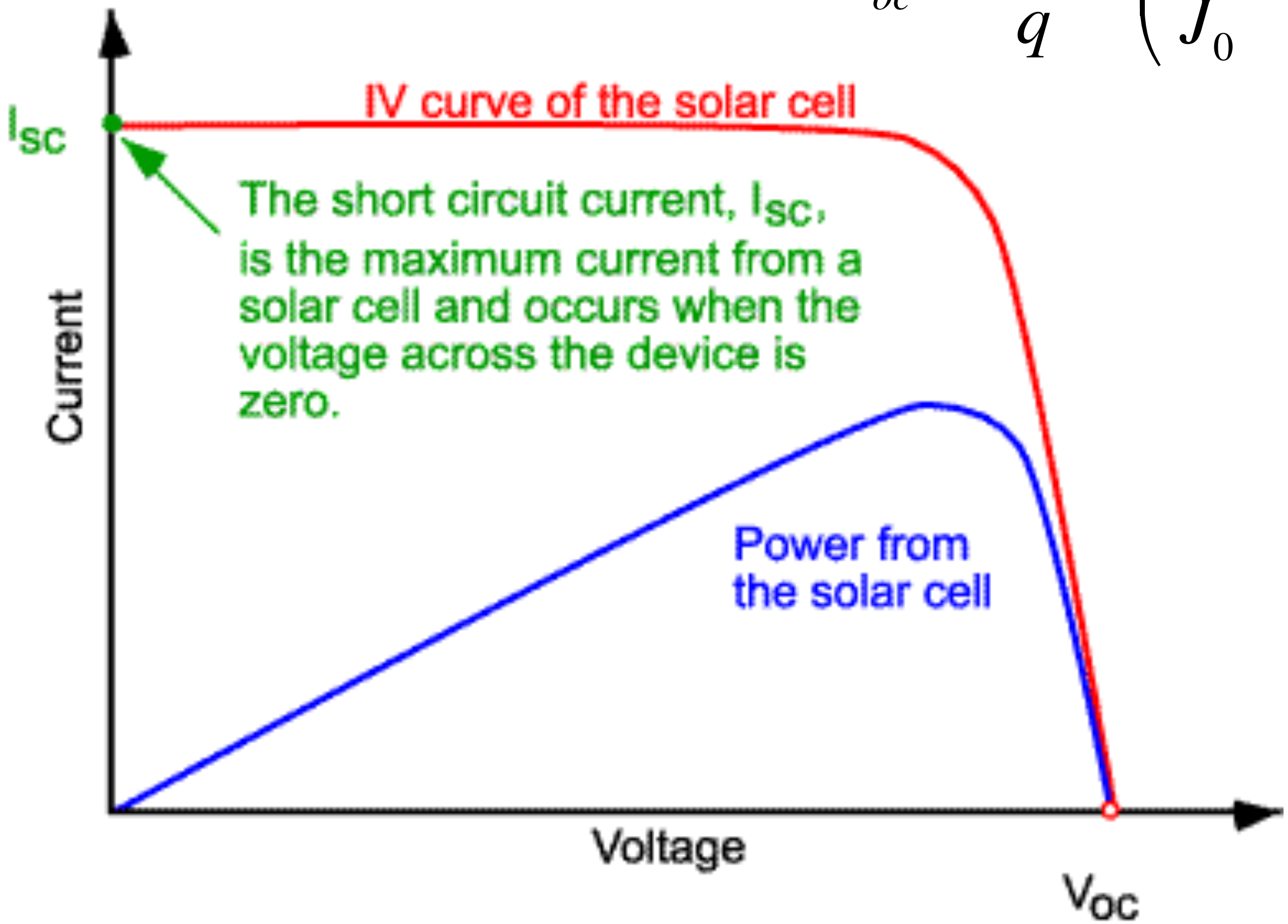
Workings of a solar cells



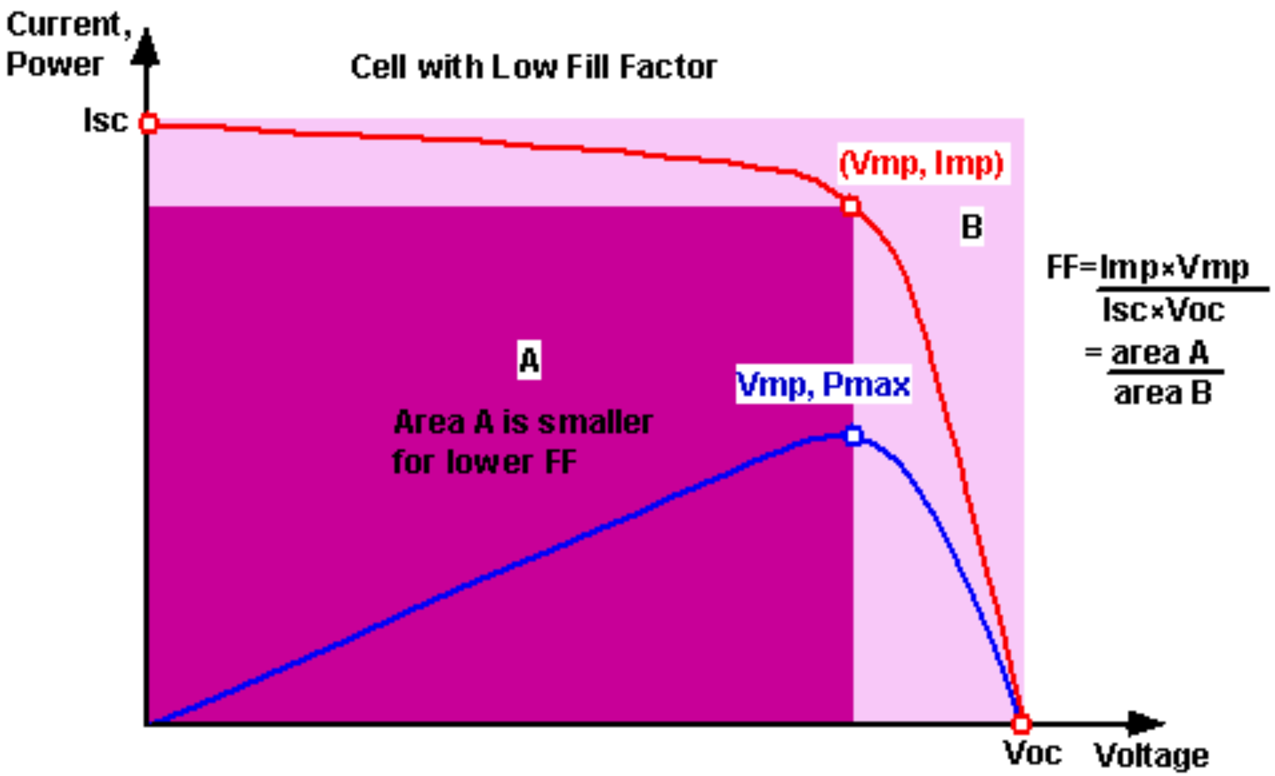
Solar cell characteristics

$$J(V) = J_{sc} - J_{dark}(V) = J_{sc} - J_0\left(e^{\frac{qV}{kT}} - 1\right)$$

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{J_{sc}}{J_0} + 1\right)$$



Fill factor



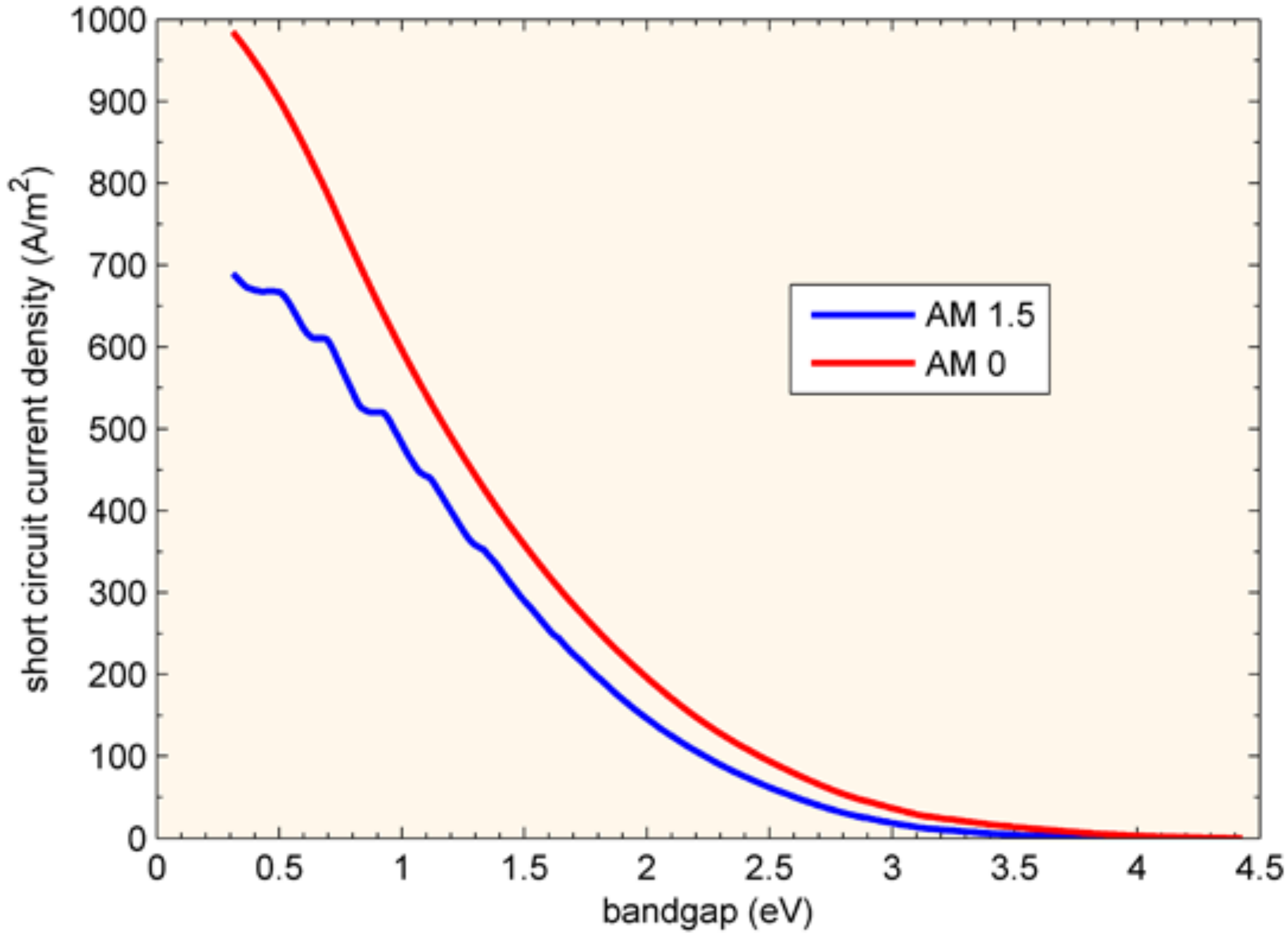
$$FF = \frac{V_{MP} I_{MP}}{V_{OC} I_{SC}}$$

Efficiency

$$P_{max} = V_{OC} I_{SC} FF$$

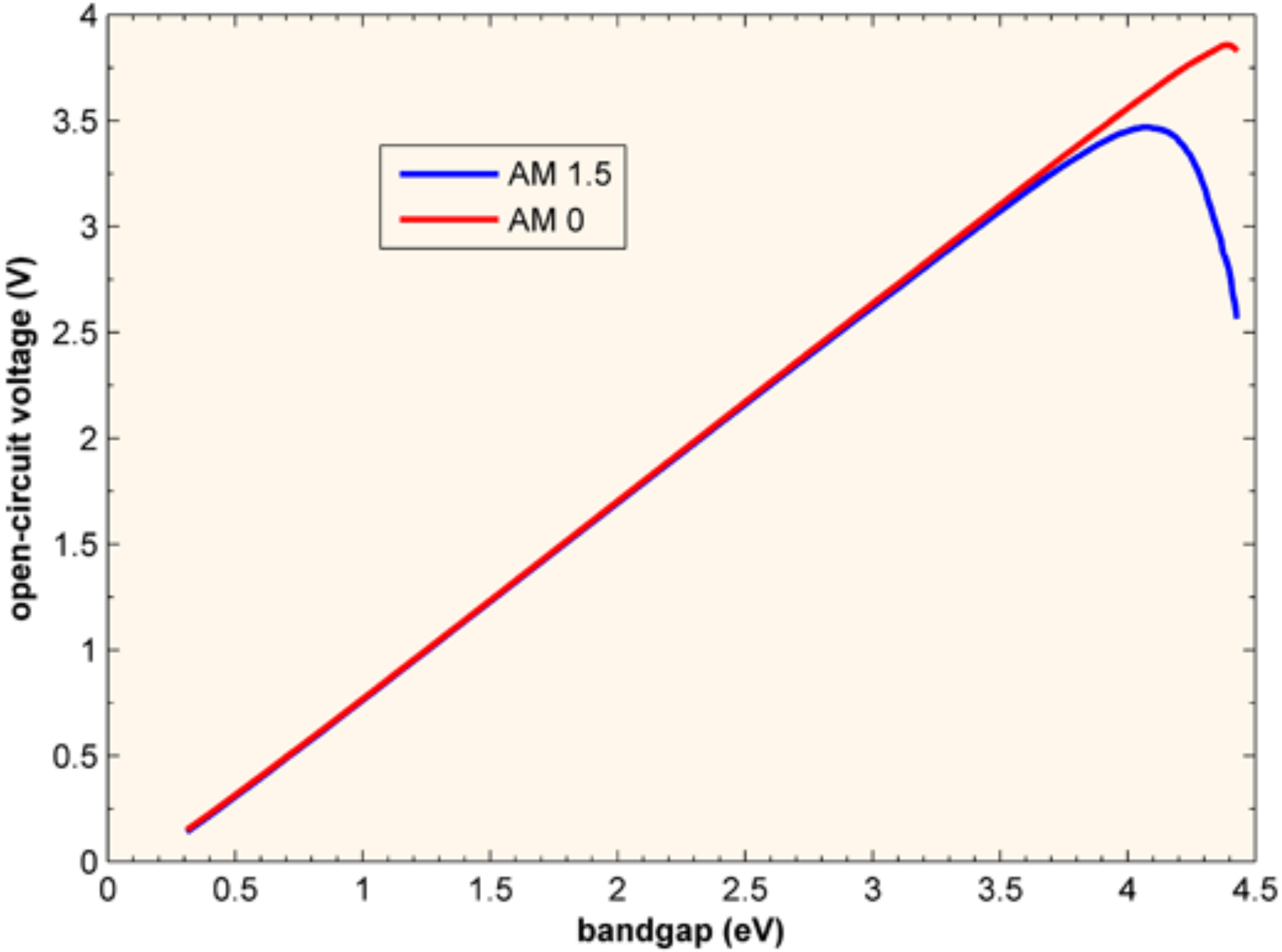
$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

Short circuit current

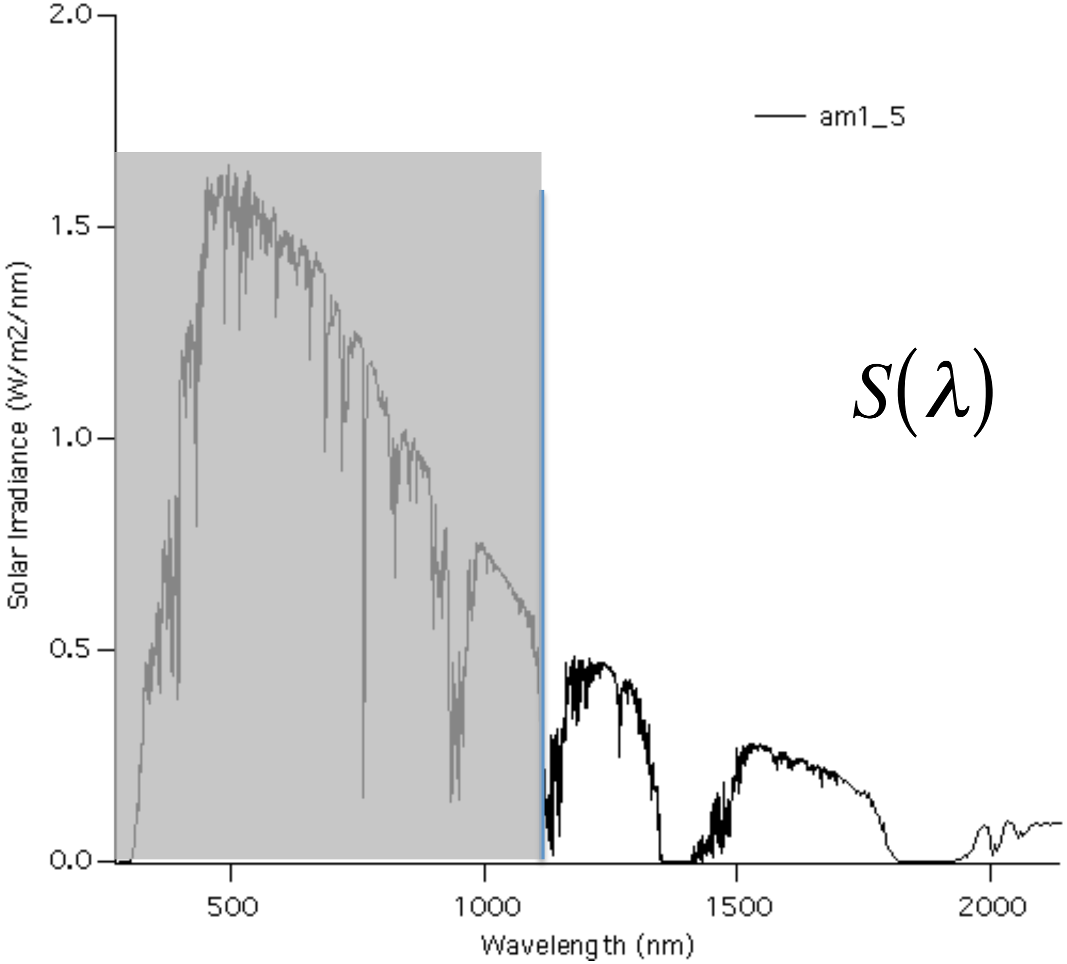


$$V_{OC} = \frac{kT}{q} \ln\left[\frac{(N_A + \Delta n)\Delta n}{n_i^2}\right]$$

Open circuit voltage

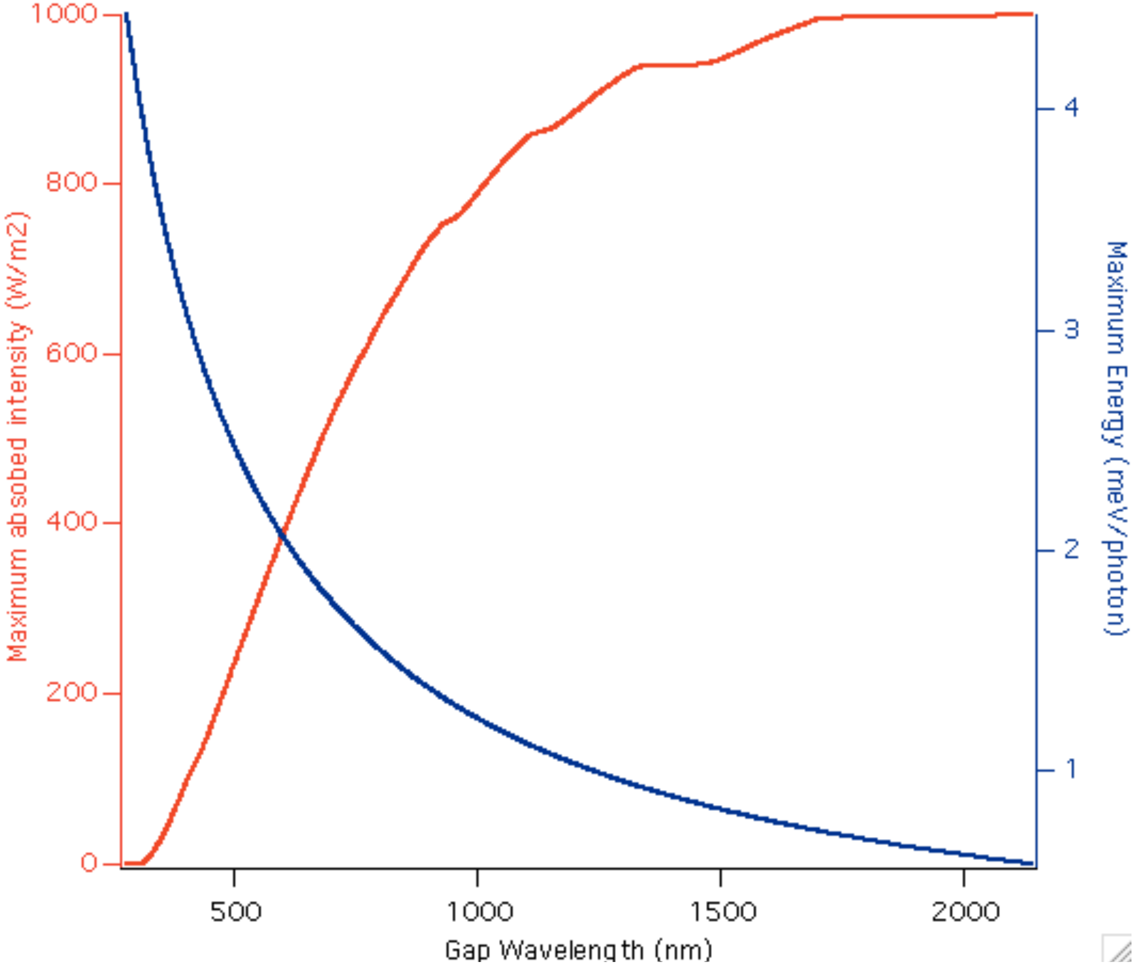


Efficiency vs bandgap



$S(\lambda)$

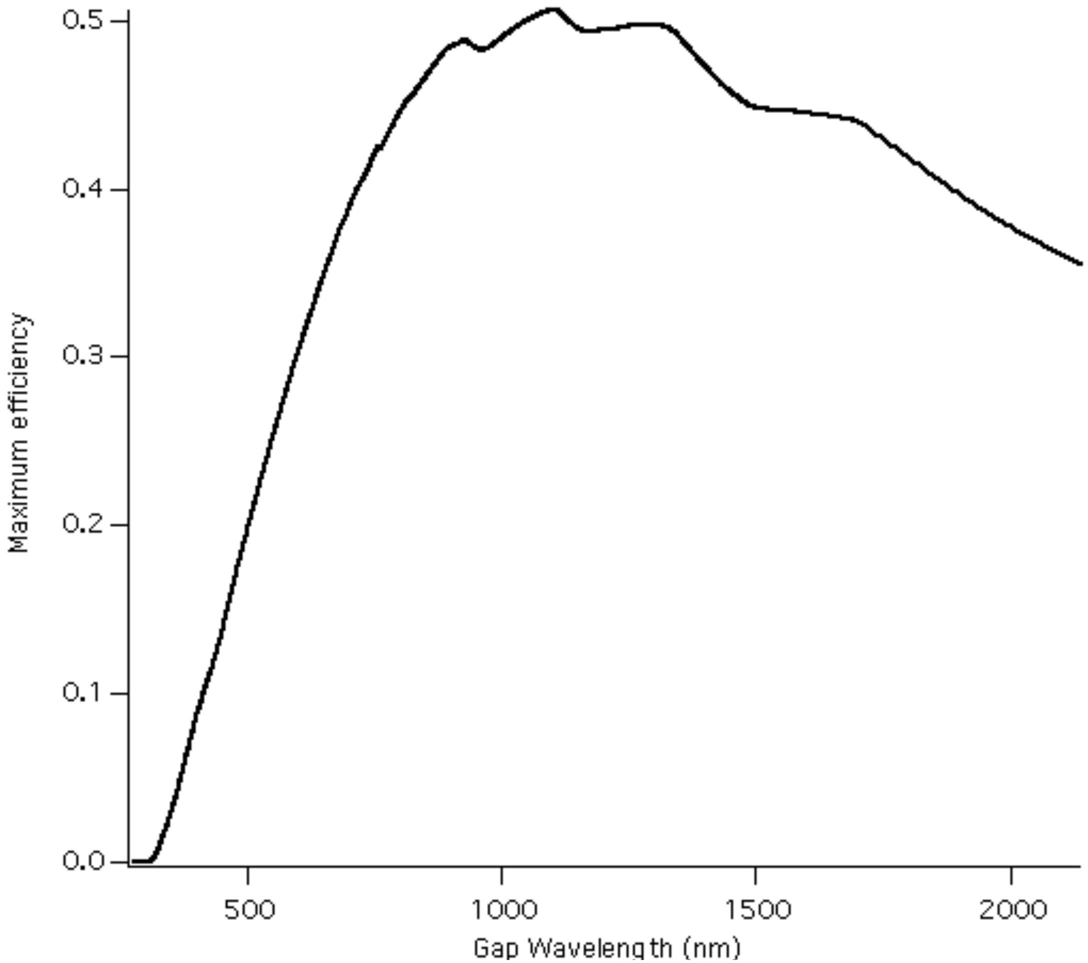
Efficiency vs bandgap



$$Abs(\lambda) = \frac{\int_0^{\lambda} S(\lambda')d\lambda'}{\int_0^{\infty} S(\lambda')d\lambda'}$$

$$E(\lambda) = \frac{hc}{\lambda}$$

Efficiency



$$\eta(\lambda) = \frac{\int_0^{\lambda} S(\lambda') \frac{E(\lambda)}{E(\lambda')} d\lambda'}{\int_0^{\infty} S(\lambda') d\lambda'}$$

$$= \frac{\int_0^{\lambda} S(\lambda') \lambda' d\lambda'}{\lambda \int_0^{\infty} S(\lambda') d\lambda'}$$