Primer on Semiconductors

Unit 1: Material Properties

Lecture 1.5: Free carriers in semiconductors

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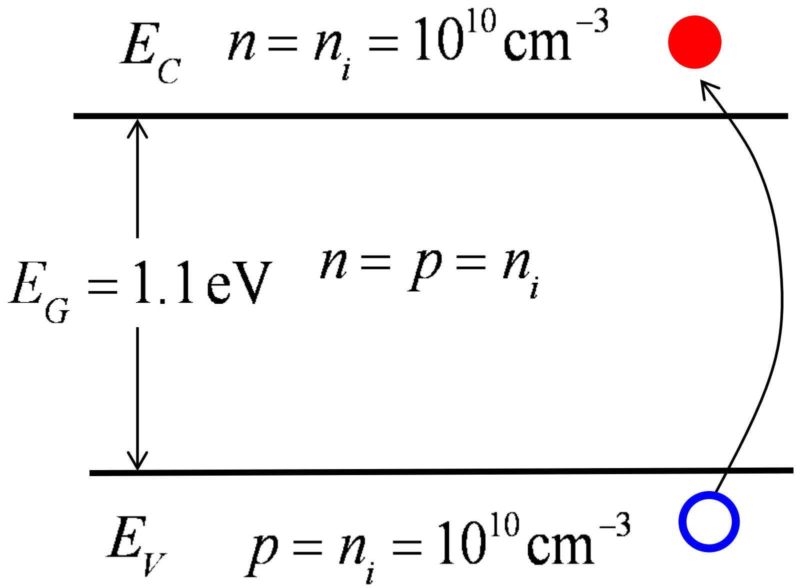
Electrons and holes in semiconductors

Intrinsic Si

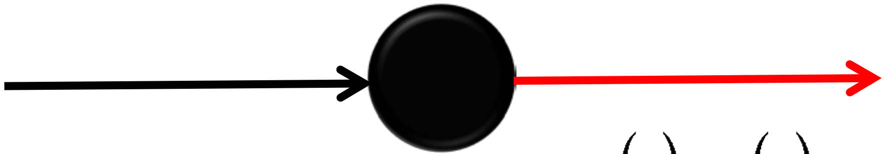


What are the properties of **electrons** in the conduction band?

What are the properties of **holes** in the valence band?

Free electron mass

$F = -q\mathcal{E}$



$F = m_0 a$

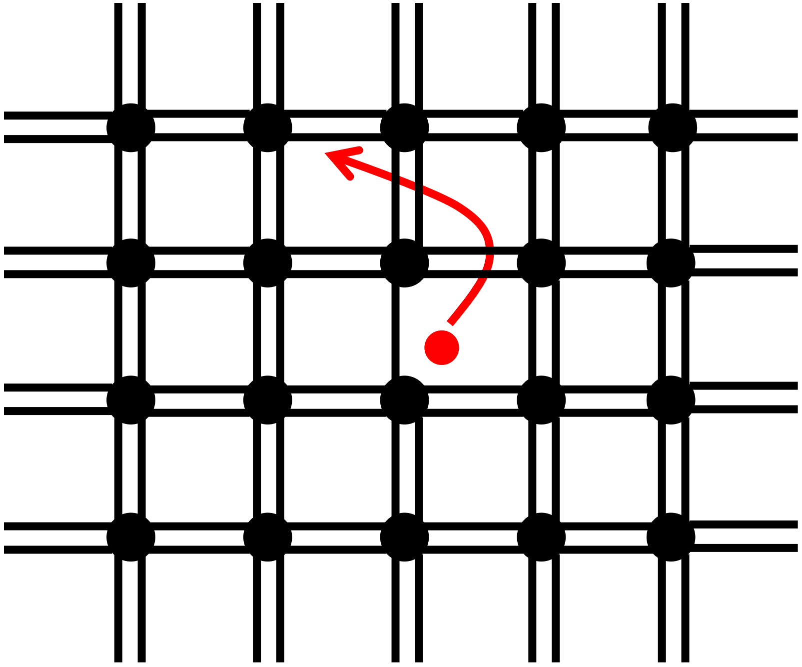
$\upsilon(t) \quad x(t)$

$$m_0 = 9.11 \times 10^{-31}\ \mathrm{kg}$$

$$q = 1.6 \times 10^{-19}\ \mathrm{C}$$

$$\mathrm{charge} = -q$$

“Effective mass” of electrons



“crystal potential”

classical semi-classical

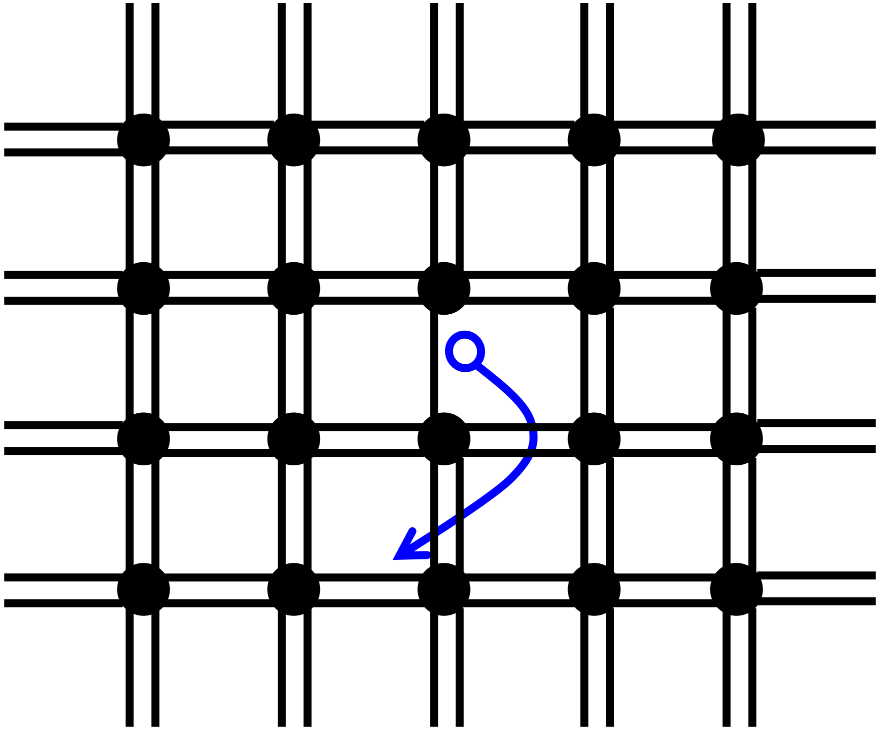
$$F = m_0 a \rightarrow m_n^* a$$

“effective mass” for electrons

Si: $m_n^* = 1.18 m_0$

GaAs: $m_n^* = 0.066\, m_0$

Effective mass of holes



"crystal potential"

$$F = m_0 a \rightarrow m_p^* a$$

effective mass for holes

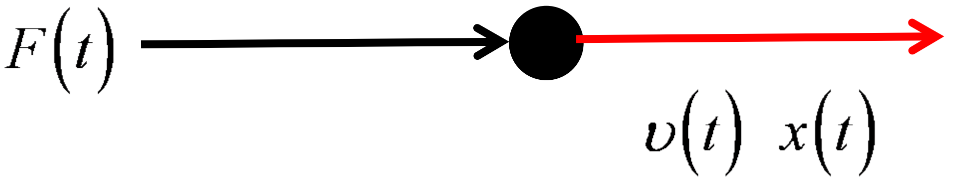
Si: $m_p^* = 0.81 m_0$

$\left(m_n^* = 1.18 m_0\right)$

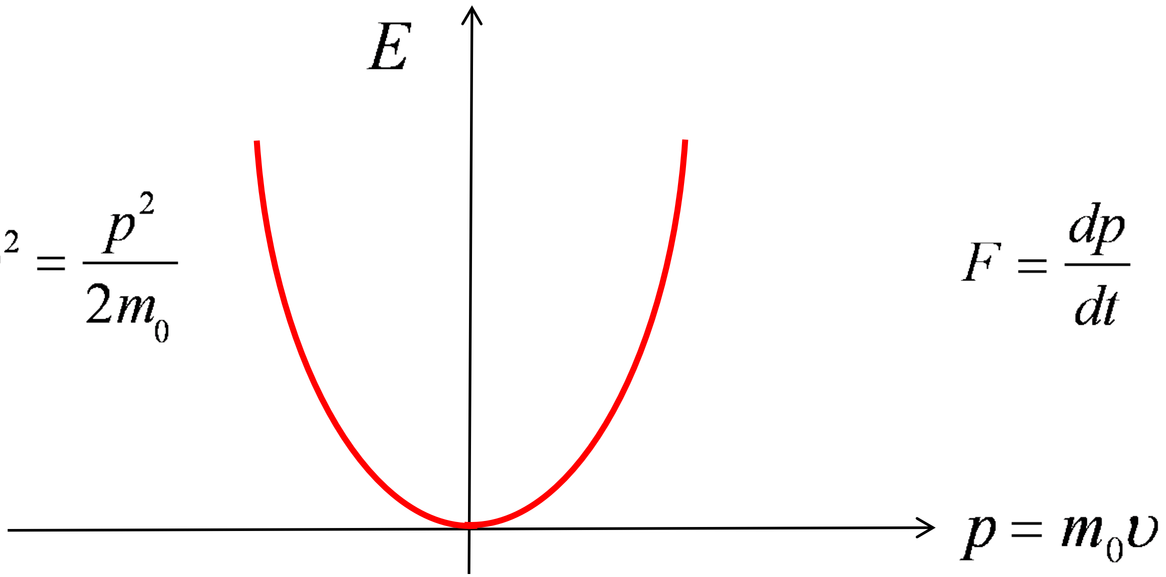
GaAs: $m_p^* = 0.52 m_0$

$\left(m_n^* = 0.066 m_0\right)$

Energy and momentum (free electron)



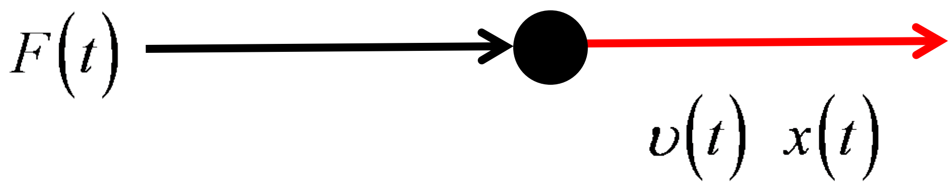
$$F = m_0 a$$



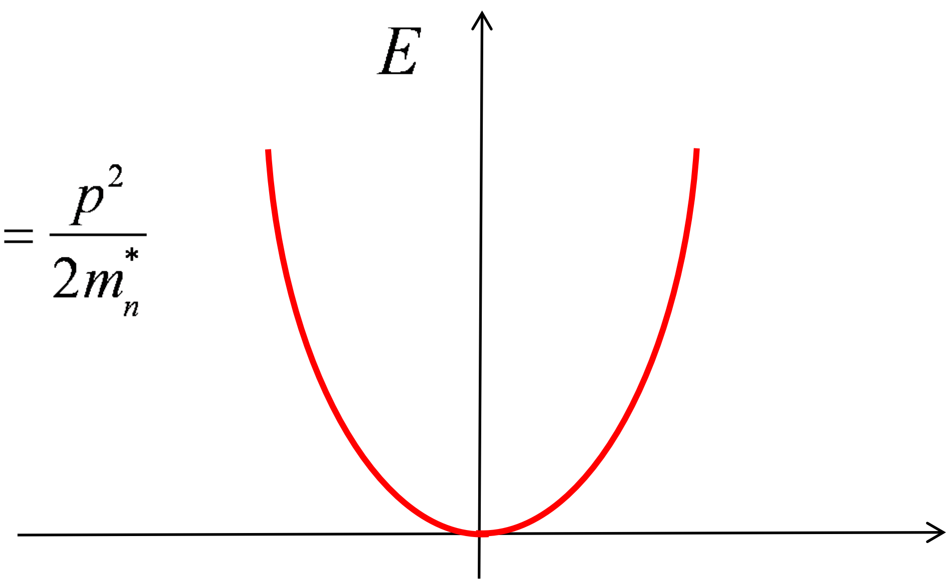
$$E = \frac{1}{2} m_0 \upsilon^2 = \frac{p^2}{2m_0}$$

$$F = \frac{dp}{dt}$$

Energy and “crystal momentum” (electron in cb)



$$F = m_n^* a$$



$$E = \frac{1}{2} m_n^* \upsilon^2 = \frac{p^2}{2m_n^*}$$

$$F = \frac{dp}{dt} \rightarrow \frac{d(\hbar k)}{dt}$$

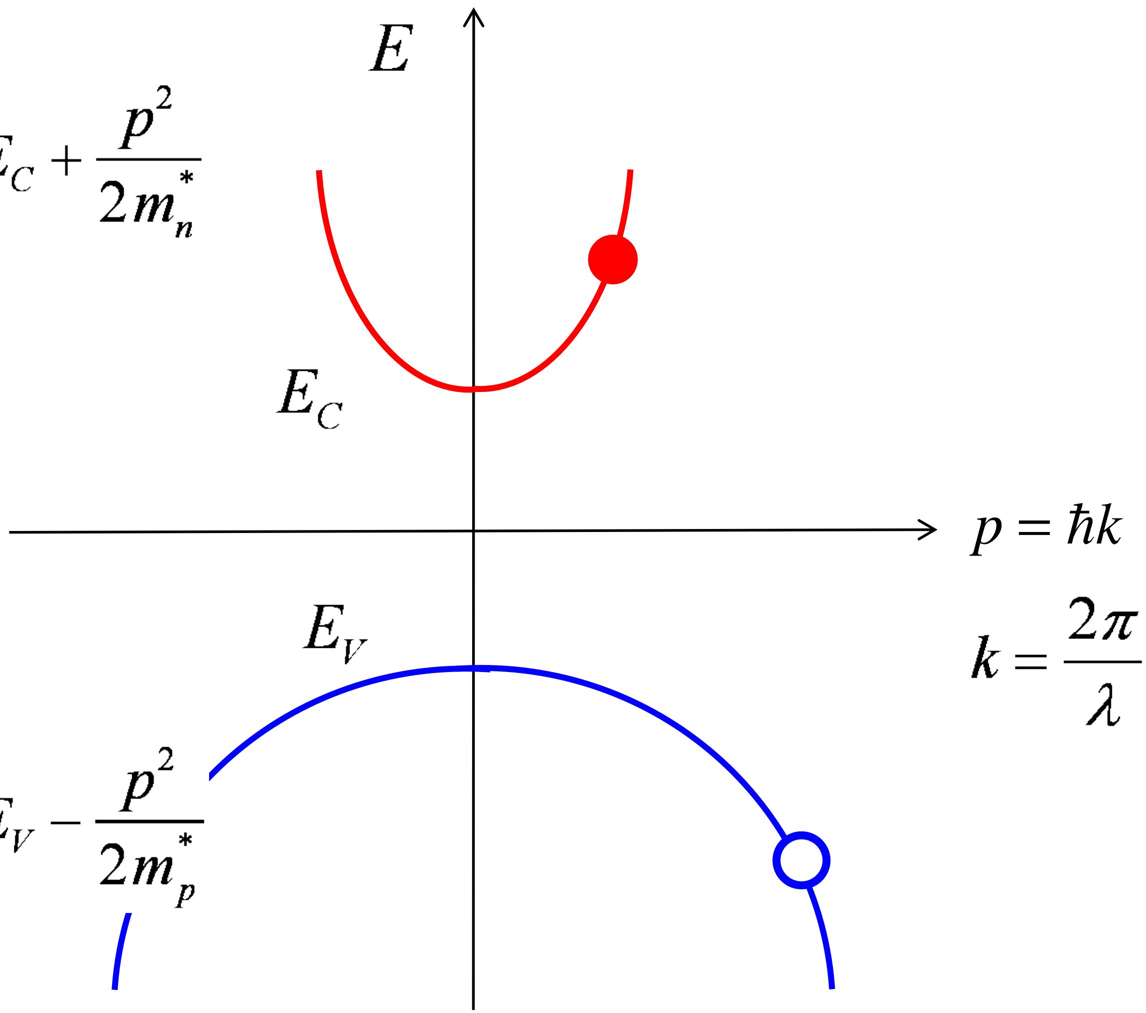
$$p = \hbar k \qquad \hbar = \frac{h}{2\pi}$$

Electrons are particles **and** waves!

$$k = \frac{2\pi}{\lambda}$$

Conduction and valence band

$$E = \frac{p^2}{2m_0} \rightarrow E = E_C + \frac{p^2}{2m_n^*}$$

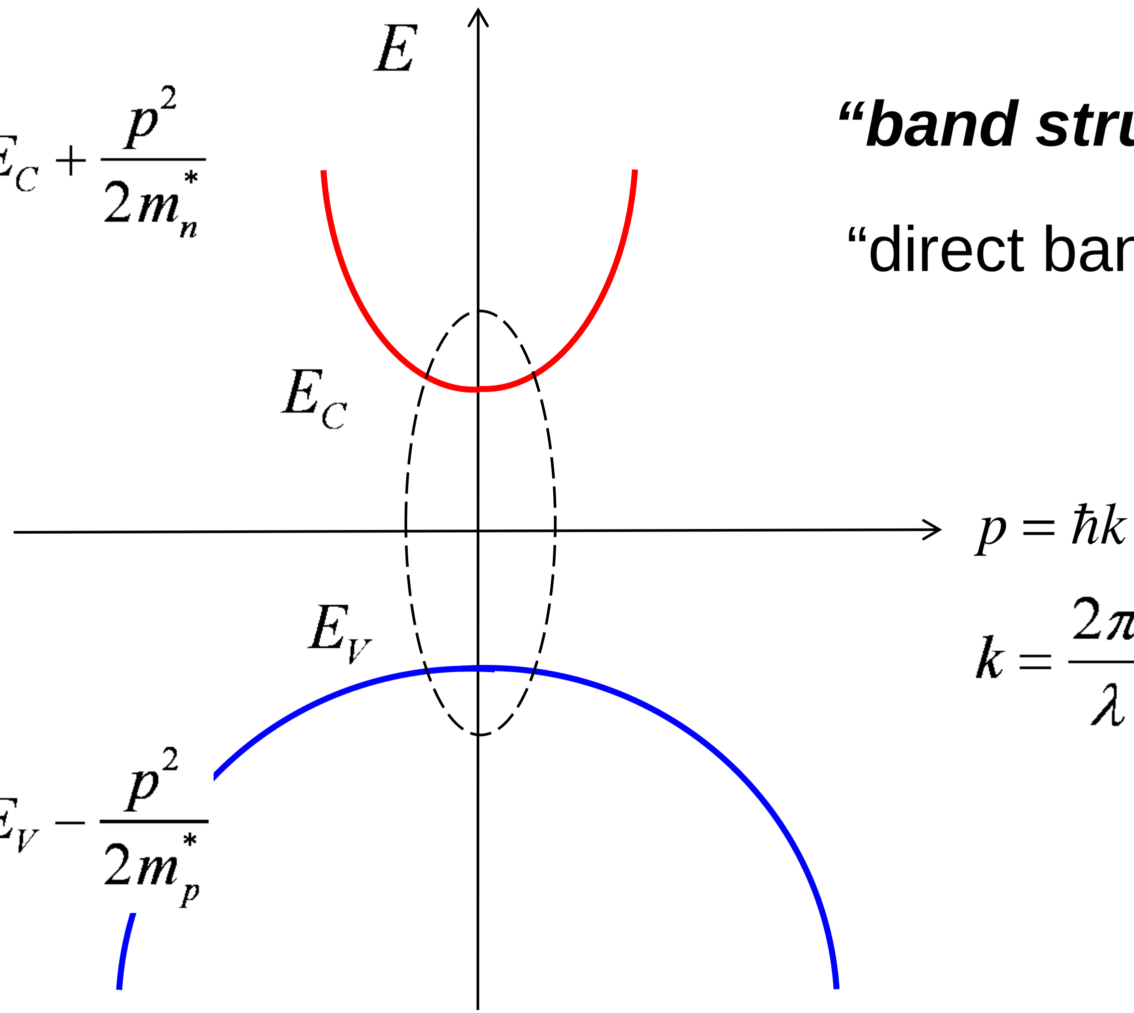


$$E = \frac{p^2}{2m_0} \rightarrow E = E_V - \frac{p^2}{2m_p^*}$$

“Direct gap semiconductors”

$$E = \frac{p^2}{2m_0} \rightarrow E = E_C + \frac{p^2}{2m_n^*}$$

$$E = \frac{p^2}{2m_0} \rightarrow E = E_V - \frac{p^2}{2m_p^*}$$

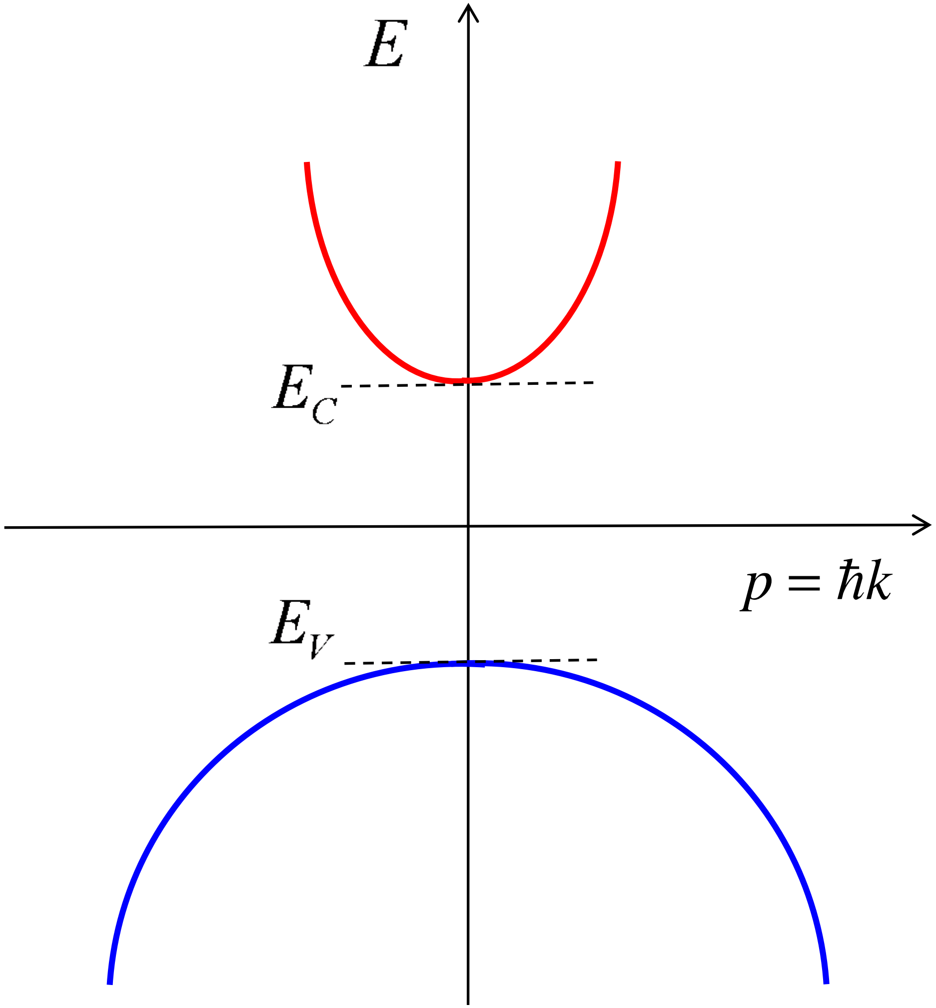


“band structure”

“direct bandgap”

$$k = \frac{2\pi}{\lambda}$$

Band structure vs. energy band diagram

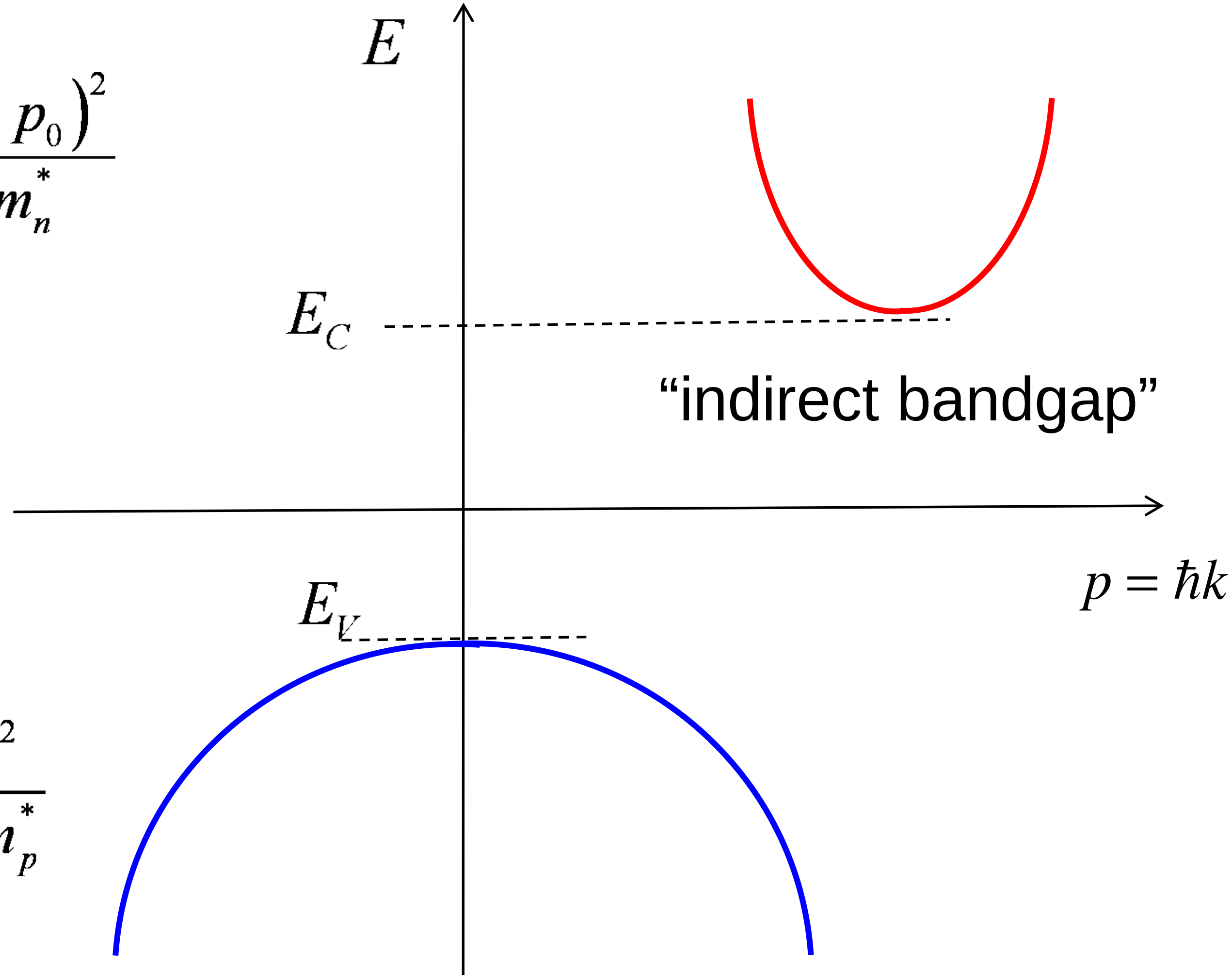


Band structure is a plot of energy **vs. crystal momentum** (or *k*).

An energy band diagram is a plot of the bottom of the cb and top of the vb **vs. position.**

“Indirect gap semiconductors”

$$E = E_C + \frac{(p - p_0)^2}{2m_n^*}$$



$$E = E_V - \frac{p^2}{2m_p^*}$$

Summary

1) Electrons in the conduction band (“electrons”):

Free to move about within the crystal.
Can often be treated as Newtonian particles with an effective mass.

2) Holes in the conduction band (“holes”):

Free to move about within the crystal.
Can often be treated as Newtonian particles with a different effective mass.