**Effective Mass**

- **Problem:** Where would you apply the crystal potential?
  - Near some edges, at quadrants?

- **Solution:** Position electron at bottom of slope, how does it behave?

  - Free electron: \( E = \frac{\hbar^2 k^2}{2m} \)  
    \[ \frac{dE}{dk} = \frac{\hbar^2 k}{m} \]
    \[ \frac{d^2E}{dk^2} = \frac{\hbar^2}{m} \]

  - Electron in crystal potential

  - **Notation:** \( m^* = \frac{m}{m_e} \)

  - **Heavy mass**

  - **Light mass**

  - Some examples: \( m^* \approx 0.1 \text{ - 1 m e}_\text{e} \)

  - *Note:* Pauli's \( \uparrow \downarrow \) law not violated for crystal as a whole

  - But it means when electron has force on it by \( \vec{E} \) applied \( E_\text{e} \) and field, it gets accelerated more than you would expect because forces also applied to \( \vec{F} \) by the ions (nuclei) that are causing the overall \( \vec{F} \) periodic potential.

  - If curvature is different in different directions, there need tension
    \[ \frac{1}{m_\text{eff}} \frac{\partial^2 E}{\partial k^2} = \frac{\hbar^2 k}{m} \]
    \[ \frac{\partial^2 E}{\partial k_1^2} = \frac{\hbar^2}{m} \]

  - Then \( \vec{F} \) in \( \vec{F} \) \( \vec{F} \) \( \vec{F} \) \( \vec{F} \)

  - \( \frac{d\vec{v}}{dt} = \frac{\vec{F}}{m} \rightarrow \frac{d\vec{v}}{dt} = \frac{\vec{F}}{m} \rightarrow \frac{d\vec{v}}{dt} = \frac{(\hbar^2 k_1)}{m_\text{eff}} \)

  - \( \frac{d\vec{y}}{dt} \) etc.
metal can can be negative.

What it means: going from k to k'.

the lattice causes a larger \( \frac{d^2}{dx^2} \)

than the applied forces.

Correct old eqns:

\[
\sigma = \frac{\varepsilon_0 \rho}{m} \rightarrow \varepsilon = \frac{\rho \varepsilon_0}{m} \\
W_c = \varepsilon B \rightarrow W_c = \frac{\varepsilon B}{\varepsilon_0} \\
\Omega(E) = \frac{N}{2\pi^2} \left( \frac{2\pi k}{h} \right)^{3/2} \sqrt{E} \\
E_p = \left( \frac{3m^2N}{V} \right)^{2/3} \left( \frac{h^2}{2m^2} \right) \\
\]

Holes:

like an auditorium with empty seats.

also like bubbles.

electron picture:

\( m^* \) negative.

\( m_{he} - m_e \)

\( m_h = m_e \)

\( k_h = -k_e \)

\( E_h = -E_e \) - band flipped upside down.

Charge = +ke

Spin = also reversed.

people usually talk about but don't usually draw bands like U instead.
Volume + Conductive bands

\[ e_{VB} \quad \text{band gap} \quad E_g < 1.2 - 3 \text{ eV} \]

\[ e_{CB} \]

General Rule (Pekar, 90, p3): \[ m^* \sim E_g \] approximately

Ar direct gap materials

\[ \text{for m-type, uses } \psi_L \]

\[ \text{under perturbation theory,}
\]

\[ \text{uses first order, would need to translate} \]

Table of \( E_g \): pg 190 Table 1

Table of \( m^* \): pg 201 Table 2

\[ \text{handout of}
\]

\[ \text{Don't get this...} \]

\[ \text{fig?} \]

\[ \text{for Ge} \]

\[ \text{or what for Si + Ge?} \]

\[ \text{see Fig. 14}\]

\[ \text{from p. 150 for Ge} \]

\[ \text{or what for Si + Ge?} \]

\[ \text{split off by } \text{sp radial coupling}. \]
\[ n = \frac{2\pi m}{\hbar k} \]

[Handwritten calculations and notes]
No some theory for bands in valence band

\[ f_\mathbf{1} (E) = 1 - f(E) = 1 - \frac{1}{e^{(E - E_F)/kT} + 1} \]

\[ \frac{E}{e^{E/kT}} = \frac{E - E_F}{e^{(E - E_F)/kT}} \]

\[ = \frac{1}{e^{E/kT}} \]

\[ \mu = \frac{E - E_F}{kT} \]

\[ (\text{energy of electron) } \]

\[ \text{multiplied by energy of hole with opposite sign) } \]

Someubject \[ f_{val}(E) = f_{val}(E) \]

\[ p = \sqrt{\frac{2}{\pi}} \left( \frac{2}{\pi} \right) \left( \frac{k_BT}{m^*} \right)^{3/2} \left( \frac{1}{e^{E/kT} + 1} \right) \]

\[ p = 2 \left( \frac{2}{\pi} \right) \left( \frac{k_BT}{m^*} \right)^{3/2} \left( \frac{1}{e^{E/kT} + 1} \right) \]

\[ \text{Equation 8.42} \]

\[ \text{Typo pg 206} \]

\[ \text{Typo in Kittel!} \]

\[ \text{pg 206} \]

\[ \text{Typo in Kittel!} \]

\[ \text{Double checked p, but still in Kittel, I'll use your symbol later through} \]

\[ n_p = \frac{4}{\pi} \left( \frac{k_B T}{m^*} \right)^{3/2} \left( \frac{1}{e^{E/kT} + 1} \right) \]

\[ n_p = \frac{4}{\pi} \left( \frac{k_B T}{m^*} \right)^{3/2} \left( \frac{1}{e^{E/kT} + 1} \right) \]

\[ \text{Multiply together} \]

\[ \text{only one place, } \mu = \text{for hole both } C_3 \text{ vs } V_3 \]

\[ \text{case is positive, } \text{case in bipolar} \]

\[ \text{cell vs transistor, } \text{cell vs transistor, } \text{cell vs transistor, } \text{cell vs transistor, } \text{cell vs transistor, } \text{cell vs transistor, } \]