~~[illegible]~~

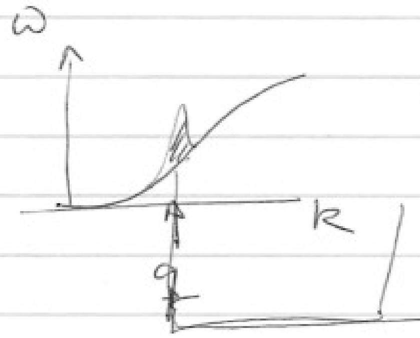
Semiclassical

Electrons in a solid as if they were particles.

$\omega(k) = E(k)/\hbar$

$\Rightarrow$ Dispersion $E(k)$

$\Rightarrow$ wavefn $e^{ikx} e^{-i\omega(k)t}$



Wavepacket $\psi(x, t=0)$

$= A(x) e^{iqx}$

carrier wave

$A(x)$ includes a mixture of nearby wave-vectors

$$A(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} dk\, B(k) e^{i\underline{k}\cdot\underline{x}}$$

$$\text{Thus } \psi(x, t) = \int dk\, B(k) e^{i(k+q)\cdot x} e^{-i\omega(k+q)t}$$

$$\omega(k+q) = \omega(q) + k\omega'(q) + \tfrac{1}{2}k^2\omega'' + \ldots$$

$$\psi(x,t) = e^{i(qx - \omega(q)t)} \times \int dk\, B(k) e^{ik(x-\omega' t)} \times e^{-\frac{1}{2}i\omega'' k^2 t} + \ldots$$

$\Rightarrow$ Group velocity $v_g = \omega' = \frac{1}{\hbar} \nabla_k E(k)$

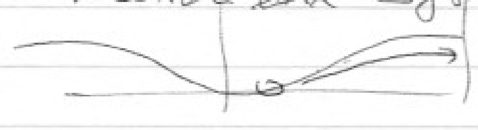
Spreading: Diff. const $D = \frac{i\omega''}{2}$.

Rate of doing work

$$\frac{d\varepsilon_k}{dt} = \frac{d\varepsilon}{dk}\cdot\frac{dk}{dt} = F v_g = F\frac{1}{\hbar}\frac{\partial\varepsilon}{\partial k}$$

$$\Rightarrow \boxed{\hbar\dot{k} = F = -e\left(E + v_g \times B\right)}$$

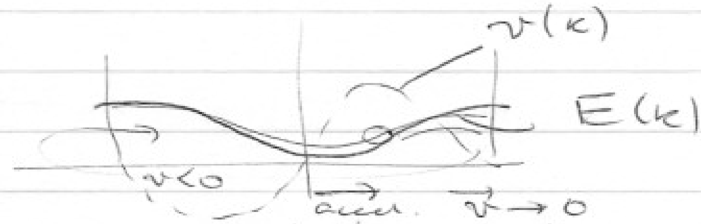
Electric field :— motion in crystal momentum



Mag field : Conservative — motion along line of constant energy $\perp^r$ to B

— ~~orbits~~ along equipotentials.

Bloch osc



Since k(t) good up to lattice vector

$\longleftrightarrow 2\pi/a$

— motion in real space oscillates due to repeated bragg ref^n. — real momentum is transferred to lattice

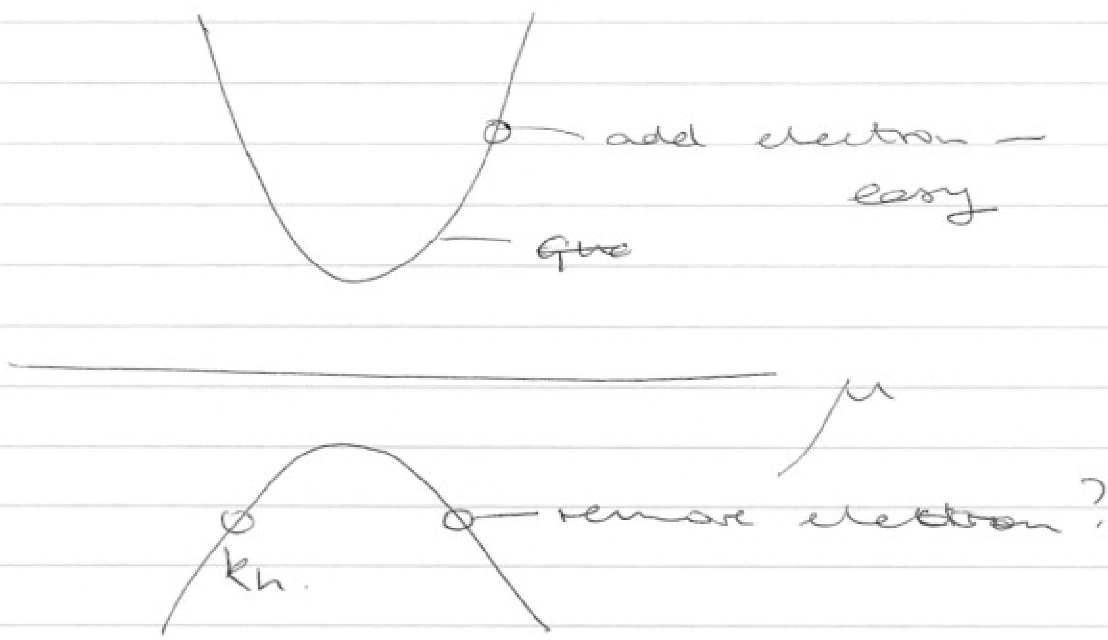
o Hard to see because of scattering. (neglected so far)

— k gets very large, easily scattered off disorder, impurities etc

— quantum wells — large spacing, small k — now possible

⇒ DC in AC out.

Semiconductors — electrons and holes.



Filled band in electric field?
— sum over all states → 0
— one removed?

Holes: ① $k_h = -k_e$ (optical abs).

② $\mathcal{E}_h(k_h) = -\mathcal{E}_e(k_e)$ (adding hole requires work

③ $v_h \propto \nabla_{k_h}\mathcal{E}(k_h) \propto \nabla_{k_e}\mathcal{E}(k_e) = v_e$ (vel)

④ Effective mass: quadratic dispersion

$$\mathcal{E} = \mathcal{E}_0 + \frac{\hbar^2 k^2}{2m^*} \qquad m_h^* = -m_e^*$$

⑤ Charge +ve

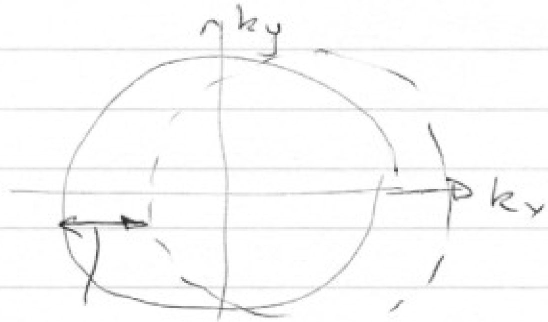
$$\hbar\dot{k}_e = -e(E + v_e \times B).$$

$$\hbar\dot{k}_h = +e(E + v_h \times B).$$

Scattering — frictional force

$$\hbar\dot{k} = F - \frac{\hbar k}{\tau}$$

— relaxation of distribution to eqm
in characteristic time τ.



Shift
by $\delta k = -\frac{eE\tau}{\hbar}$.

$\Rightarrow \delta v = \delta k / m^*$ (parabolic band)

$$j = -ne\,\delta v = \underbrace{\frac{ne^2\tau}{m^*}}\,E$$

$\sigma = ne\mu \quad \mu = e\tau/m^*$

mobility.

Coorsdl

Transport in E & B fields

$$\hbar \dot{k} + \frac{\hbar \vec{k}}{\tau} = e\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

Stationary state $\quad B$ in $\hat{z}$

E in x-y plane

Parabolic bands $\quad \hbar \vec{k} = m\vec{v}$

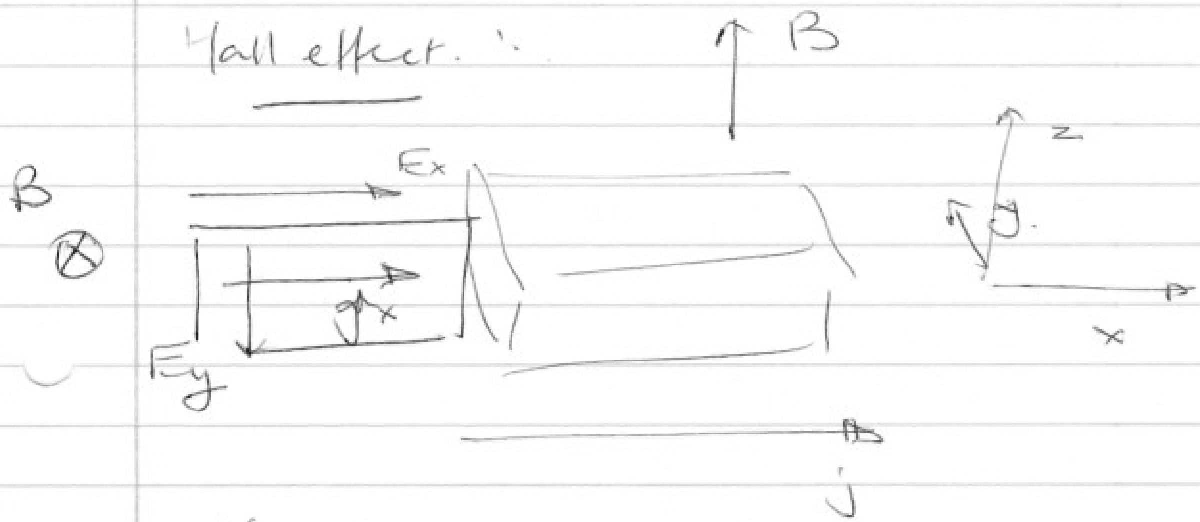
$$v_z = -\frac{e\tau}{m} E_z \qquad (1)$$

$$v_x = -\frac{e\tau}{m} E_x - \beta v_y \qquad (2)$$

$$v_y = -\frac{e\tau}{m} E_y + \beta v_x \qquad (3)$$

$$\beta = \frac{eB\tau}{m} = \omega_c \tau = \mu B$$

Hall effect.



If current flows in x dir^n only

$\Rightarrow v_y = 0 \quad \therefore \quad v_x = -\frac{e\tau}{m} E_x \qquad$ from (2)

$\beta v_x = \frac{e\tau}{m} E_y \qquad$ from (3)

or $\quad E_y = -\beta E_x$

At large fields $\beta \gg 1$ so electric fields normal to current flow

Useful measure.

Hall coeff. $R_H = \frac{E_y}{j_x B} = -\frac{1}{ne}$

— depends on density
— on sign of carriers (+ve for holes)