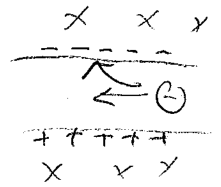
Last item from chapter: magnetic fields



transverse voltage

but how strong?

$$\vec{F} = q\vec{E} + q\,\vec{v}\times\vec{B} \quad \text{(Phys 220)}$$

$$\vec{F} = -e\left(\vec{E} + \vec{v}\times\vec{B}\right)$$

also assume a damping term $\sim \vec{v}$ (like air resistance)

$$\Sigma F = ma \longrightarrow m\frac{d\vec{v}}{dt} = -e\left(\vec{E} + \vec{v}\times\vec{B}\right) - \frac{m\vec{v}}{\tau}$$

τ ← characteristic damping time

Steady state: $\frac{d}{dt} \rightarrow 0$

$$\frac{m\vec{v}}{\tau} = -e\left(\vec{E} + \vec{v}\times\vec{B}\right)$$

Typically $\vec{E} \perp \vec{B}$ in "Hall Effect" experiments

$\vec{E}$ in x-y plane; $\vec{B}$ in $\hat{z}$

v also in x-y plane

$$\frac{m v_x}{\tau} = -e\left(E_x + v_y \underbrace{B_z}_{\text{just "B"}}\right) \longrightarrow v_x = -\frac{e\tau}{m}E_x - \left(\frac{eB}{m}\right)\tau v_y$$

$\frac{eB}{m}$: units of frequency: ω_c "cyclotron"

and $$\frac{m v_y}{\tau} = -e\left(E_y - v_x B_z\right) \longrightarrow v_y = -\frac{e\tau}{m}E_y + \left(\frac{eB}{m}\right)\tau v_x$$

---

day 24 pg 1

Now, force $v_y = 0$ for current like ←

$$v_x = -\frac{e\tau}{m}E_x \quad ; \quad 0 = -\frac{e\tau}{m}E_y + \left(\frac{eB}{m}\right)\tau v_x$$

$$0 = -\cancel{\frac{e\tau}{m}}E_y + \left(\frac{\cancel{e}B}{\cancel{m}}\right)\cancel{\tau}\left(-\frac{e\tau}{m}E_x\right)$$

$$\boxed{E_y = -\frac{e\tau}{m}B\,E_x}$$

Transverse field! Leads to "Hall voltage", what you actually measure

negative number because $e = +1.6\cdot 10^{-19}$ C

"Hall coefficient"

$$R_H = \frac{E_y}{j_x B} = \frac{-\frac{e\tau}{m} B E_x}{\left(\frac{ne^2\tau E_x}{m}\right) B}$$

I think we covered a few days ago

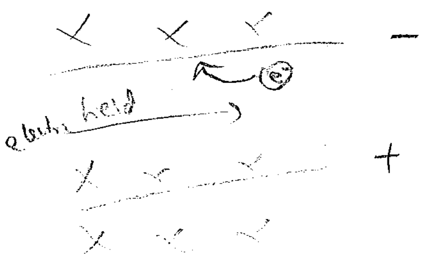
$$\boxed{R_H = -\frac{1}{ne}}$$

⟶ excellent way to measure n.

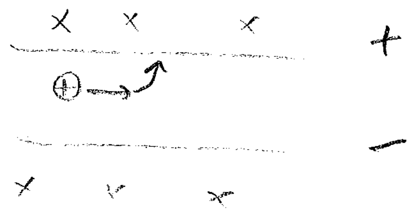
This model: n = atomic density × # valence electrons

Semiconductors n = # dopants.

Cool: if electrons



if positive charges



also excellent way to measure sign of charge carrier.

Not always negative? No! "Holes"

Final thought:

since $\vec{J}$ and $\vec{E}$ are not parallel

$\vec{J} = \sigma \vec{E}$ doesn't work

need $\vec{J} = \overleftrightarrow{\sigma} \vec{E}$ ← rank 2 tensor!

$$\begin{pmatrix} \sigma_{xx} & \sigma_{xy} \\ & \text{etc} \end{pmatrix}$$

can have transverse conductivity ≠ long. conductivity

Crystal directions important; like our stiffness tensor get some terms = 0 depending on symmetry of crystal.

(see Stokes Ch. 1)

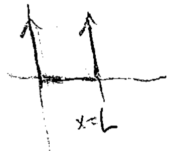
End of Ch 6

Chap. 7: Band Theory!

QM review

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + U(x)\psi = E\psi$$

Inf square well

$U(x) =$  then $\psi_n = A\sin\frac{n\pi x}{L}$ $\quad$ ~~$E_n = n^2\pi^2$~~ ?

$x=L$

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} = E\psi$$

only $0 < x < L$

→ 0 at body → $\sin\frac{n\pi x}{L}$

sin's + cosines

$$-\frac{\hbar^2}{2m}\left(-\frac{n^2\pi^2}{L^2}\right)\psi = E\psi$$

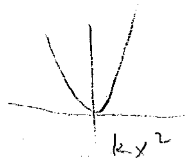
$$\boxed{E_n = \frac{n^2\pi^2\hbar^2}{2mL^2}}$$

→ In general!

$$\psi = \sum C_n\psi_n$$

$$\psi \to \begin{pmatrix} c_1 \\ c_2 \\ \vdots \\ c_\infty \end{pmatrix}$$

SHO

$U(x) =$  then $\psi_n =$ cosh?

kx^2

$E_n = (n+\frac{1}{2})\hbar\omega_0$

$\omega_0 = \sqrt{\frac{k}{m}}$

exponential decay when $E <$ barrier U?

"Matrix Elements" $\begin{pmatrix} c_1 \\ \vdots \\ c_\infty \end{pmatrix} = E\begin{pmatrix} c_1 \\ \vdots \\ c_\infty \end{pmatrix}$

eigenvalue eqn!

or $i\hbar\frac{d}{dt}$?

$\langle\psi_n|H|\psi_m\rangle$

called that even when no matrices in picture!

$\int \psi_n^* \left(-\frac{\hbar^2}{2m}\frac{d^2}{dx^2} + V(x)\right)\psi_m\,dx$

Discrete energy levels - characteristic of bound states

free particle: Doesn't always happen. For example

$U(x) =$ ——— (just 0)

then $-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} = E\psi$ $\qquad \psi = A\cos(kx+\phi)$

$$\psi = \tilde{A}e^{ikx}$$

k could be anything!

$$-\frac{\hbar^2}{2m}(-k^2)\psi = E\psi$$

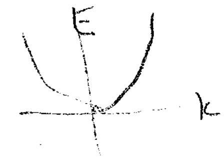
$$\boxed{E = \frac{\hbar^2k^2}{2m}}$$

compare $E = \frac{p^2}{2m}$

$\hbar k$ = momentum of wave

$|\psi|^2 =$ constant

equally likely to find particle at all points in space!

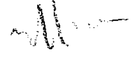


No discrete levels.

Energy "indexed" by k instead of by n

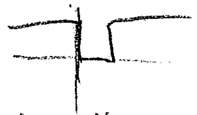
"Wave packets"

$$\psi = \sum C_k\psi_k$$

can get  for example

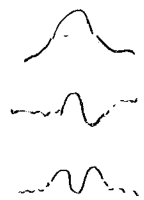
QM review, cont.

$U(x) =$



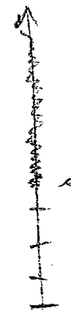
finite well

Numerical Plots ξ

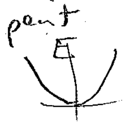


but a finite # of bound states. ⟹ but still infinite # of unbound states when energy is high enough

E



← at some point



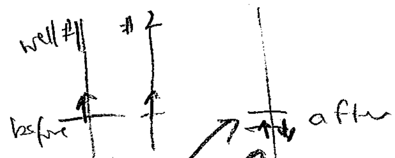
(perhaps)

$U(x) =$

Numerical plots?

↳ compared to single well

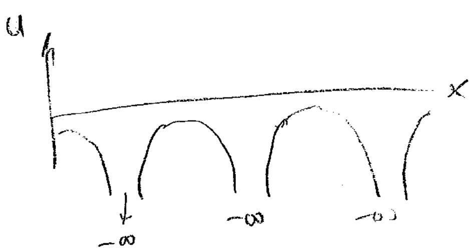
lowest E



plots of eigenfunctions?

⟶ spreading out can lower energy!

Many



wavefunction of lowest state ⟶ energy = reduced!