Metal Mania
Simple Models of the Material World

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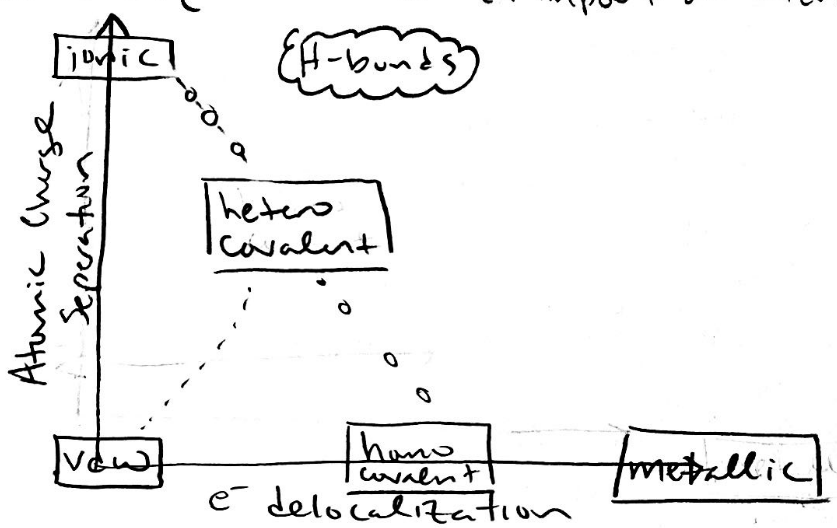
Questions

Why are some materials insulators and some conductors?
Why do thermal and electrical conductivity go hand-in-hand?

Bonding

Gas → Liq → Solid (↑ import of interact.)



- generalizes to intermolecular bonding

- directional bonding
⟺
e⁻ pairing
⟺
band filling
⟺
insulator/semiconduct

However, all bonding types play a role

Quantum

B.C. (Box, Lattice) → Discrete E Lvls "Quantization"

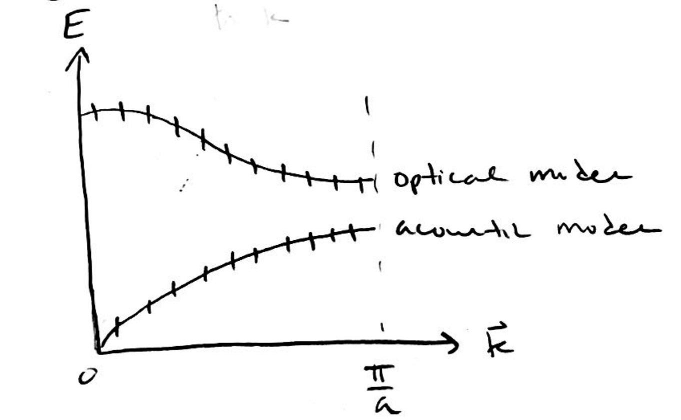
- Quantize dynamical variable (property of system)
  Ex: $\vec{L}$, $\vec{p}$, $\vec{k}$ (periodic), $\vec{S}$ (intrinsic) $[s=\frac{1}{2}]$

N Inputs → N States $N \to \infty$ → Continuum

* Counterintuitive continuous states from quantum theory

Scope: Macroscopic Object | Restrict to Crystals
Molecular | ↓
Atomic |
e^- | Periodicity
Nucleonic

Atoms

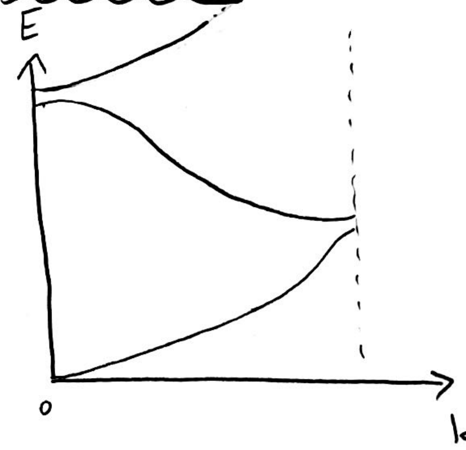


Coupled SHO

Hooke's Law

$V = \frac{1}{2} G x^2$

Electrons



2N
b/c
Spin
$S = \frac{1}{2}$

"Free e^- Model"
"Drude Model"

$KE = \frac{p^2}{2m} \rightarrow \frac{\hbar^2 k^2}{2m}$

Symmetry Allows Rerepresent

Electrical Conduction

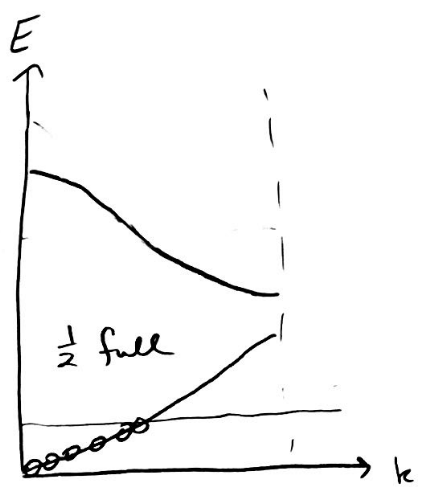
Charges accelerate in an E field

$$j = \frac{dq}{dt} = -ne\langle v \rangle$$

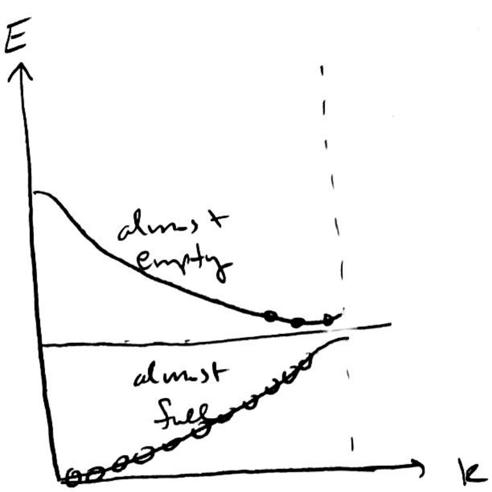
$$\langle v \rangle = -\frac{e\tau}{m} E$$

Key is n

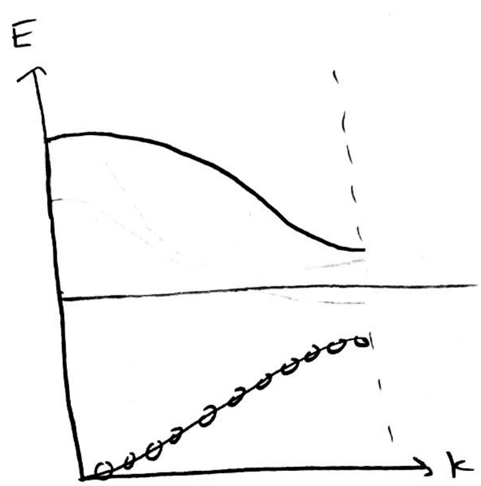
$$j = \sigma \left(\frac{dV}{dx} \right) = \sigma E \qquad \sigma = \frac{ne^2\tau}{m} \qquad \sigma = \frac{1}{\rho} \qquad \rho = \frac{RA}{l}$$



Conductor



Semiconductor
- Intrinsic T
- Extrinsic (Dope)



Insulator

Key Point: Symmetry of $\vec{k}$

- not full $\rightarrow$ destabilize
- full $\rightarrow$ net zero motion

$\Rightarrow n = \#\, e^-$ in not filled band

Thermal Conduction

$$j = \frac{dQ}{dt} = -k\,\frac{dT}{dx}$$

- e^- + phonon can carry E $\langle v \rangle$
- e^- more free $\Rightarrow$ carry more E

 b/c e^- dominate !!!

$\Big\} \Rightarrow e^-$ + thermal conduct similar

Thermal $\cap$ Electrical "Thermocouple"

Difference in $\langle v \rangle \rightarrow e^-$ build up

$V = \frac{e \cdot e}{r}$ repulsive Coulomb Potential

$\Rightarrow$ opposing E field $\Rightarrow$ ΔV measure

Summary:

- Bonding intuition $\rightarrow$ detailed quantum bands
  - nonmetallic bonds play role in Semiconductors
- Quantum Atomic v Electronic Roles
- Springs or Free e^- qualitatively describe material