PHYS 5243

Solid State Physics

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Contents

2015-01-09: Chapter 1 - About Condensed Matter Physics

Syllabus

Read Chapters 1 and 2 before next lecture
Graduate Student $\rightarrow$ 15% of the grade is HW.
2 Midterms: Wednesday nights ($\sim$ 4 hours are given to do them).
The Final counts for $\sim$ 25% of grade for Graduate and Undergraduate Students.
Get the other books required for class $\rightarrow$ they are important!
Graduate Studnet difference $\rightarrow$ potentially a physics simulation will be required.

Class Notes

Solid State Physics
(Condensed Matter Physics)

Physics of complexity $\rightarrow$ statistical physics (thermodynamics)

Collections of atoms

Somewhat under atomic physics field

Solids, liquids, and polymers

Hamiltonian:

$$\hat{H} = \underbrace{\frac{\mathbf{p_n}^2}{2M_n}}_{\substack{momentum\\of\\ions}} + \underbrace{\frac{\mathbf{p_e}^2}{2M_e}}_{\substack{momentum\\of\\electrons}} + \underbrace{\frac{e^2}{r_{i1} - r_{j1}}}_{\substack{repulsion\\between\\ions}} + \underbrace{\frac{e^2}{r_{i2} - r_{j2}}}_{\substack{repulsion\\between\\electrons}} - \underbrace{\frac{e^2}{r_{i1} - r_{j2}}}_{\substack{attraction\\between\\electrons\ and\ ions}}$$

At the moment only $\sim$100 atoms can be solved (using supercomputer) $\rightarrow$ very difficult!

Emergent phenomenon is common

Superconductivity is emergent from collection of atoms

2015-02-20: Chapter 1 (Kittel) - Crystal Structure

Test on Everything but Crystal Structure. Closed book but will provide equations.

Primitive Cells

Crystal Structure handout.

(100) plane of atoms.

{100} family of planes.

[100] direction.

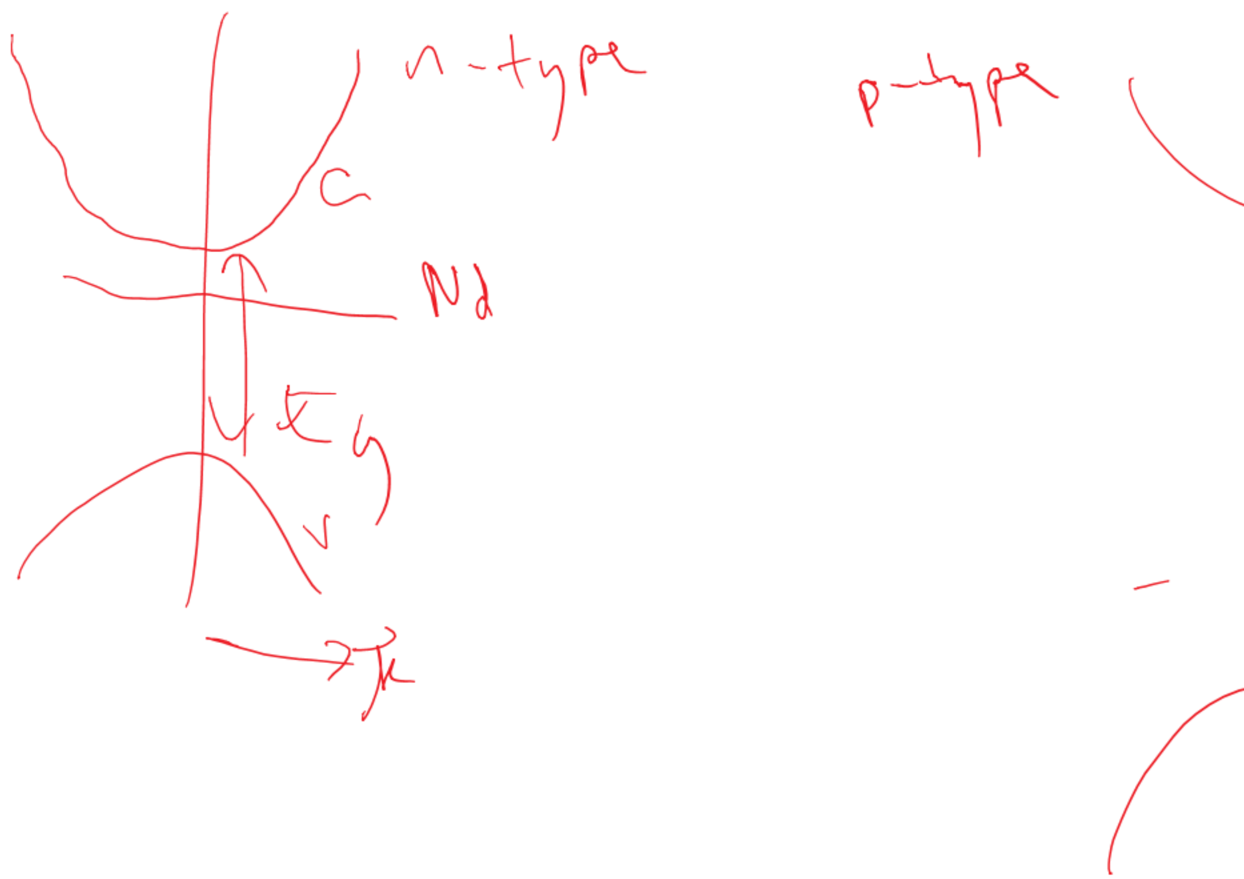
2015-04-06: Chapter 8 Kittel? - Semiconductor

Exam postponed until Wednesday next week

All material will be covered up to semiconductors, no p-n junctions, but will have n and p semiconductors.

n-type SC donor level lives close to conduction band.

p-type SC donor level below valence band



2015-04-08: Optical Properties of Materials - Chapter 14 and 16 in Kittel

Will be doing:
Superconductivity - single lecture
Graphene - single lecture

Drude Model - fermi surface shifts in the reciprocol space due to electric field
Then we talked of SdH
What we haven't talked about how light interacts with material.
Guass's Law:

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0} \tag{1}$$

$$\rho_{total} = \rho_{ext} + \rho_{int} \tag{2}$$

ρ_{int} is materials dependent

$$\mathbf{D} = \epsilon_0 \mathbf{E} + \mathbf{p} = \epsilon\epsilon_0 \mathbf{E} \tag{3}$$

$\mathbf{D}$ is function of ω and $\mathbf{k}$.

A $\epsilon(\omega, 0)$: $k \to 0$,$x \to \infty$
collective excitations of Fermi sea
$\epsilon(0, k)$: electro static response electron electron screening

A Long Wavelength Response

$$m\frac{d^2x}{dt^2} = -e\mathbf{E} \tag{4}$$

$$\mathbf{E} \sim E_0 e^{-i\omega t} \tag{5}$$

$$x \sim x_0 e^{-i\omega t} \tag{6}$$

$$-m\omega^2 x(t) = -eE9t) \tag{7}$$

$$x(t) = +\frac{eE(t)}{m\omega^2} \tag{8}$$

$$x_0 \frac{eE_0}{m\omega^2} \tag{9}$$

dipole moment of one electron

$$\mathbf{p} = -eX_0 \tag{10}$$

$$\mathbf{p}_0 = \frac{\#\text{ of dipoles}}{\text{volume}} = -ex_0 n = \frac{-e^2 n E_0}{m\omega} \tag{11}$$

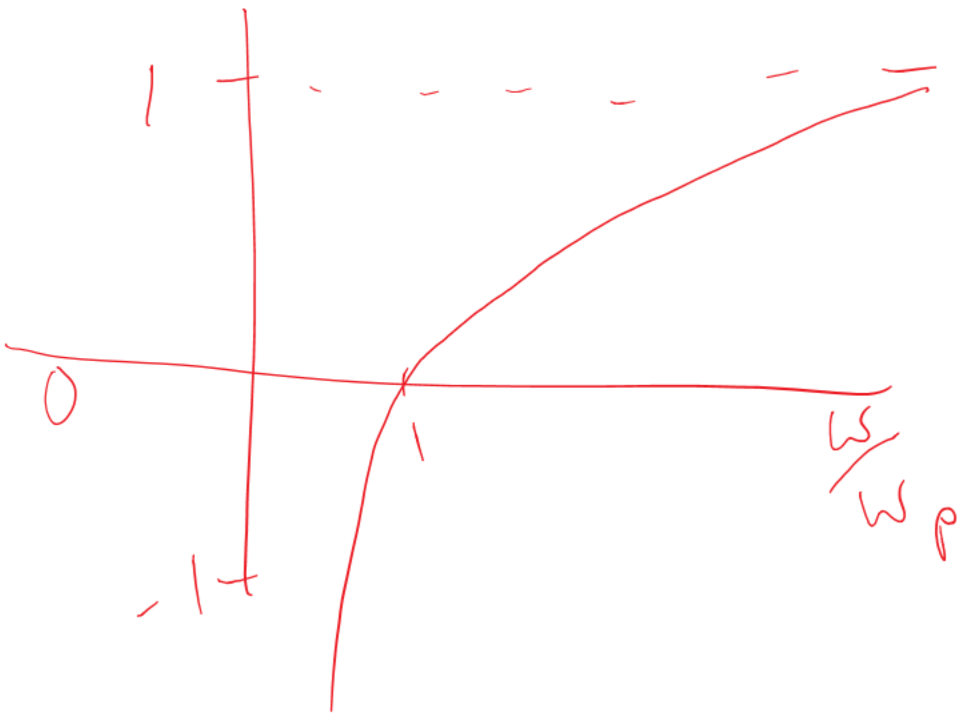
$\mathbf{p}_0$ is the polarization

$$\epsilon(\omega) = \frac{D(\omega)}{\epsilon_0 E(\omega)} = 1 + \frac{P(\omega)}{\epsilon E(\omega)} = 1 - \frac{2^2 n}{\epsilon_0 m\omega^2} \tag{12}$$

Plasmon frequency:

$$\omega_p^2 = \frac{n_e^2}{m\epsilon_0} \tag{13}$$

$$\epsilon(\omega) = 1 - \frac{\omega_p^2}{\omega^2} \tag{14}$$



Non magnetic:

$$\mu_0 \frac{d^2\mathbf{D}}{dt^2} = \nabla^2 \mathbf{E} \tag{15}$$

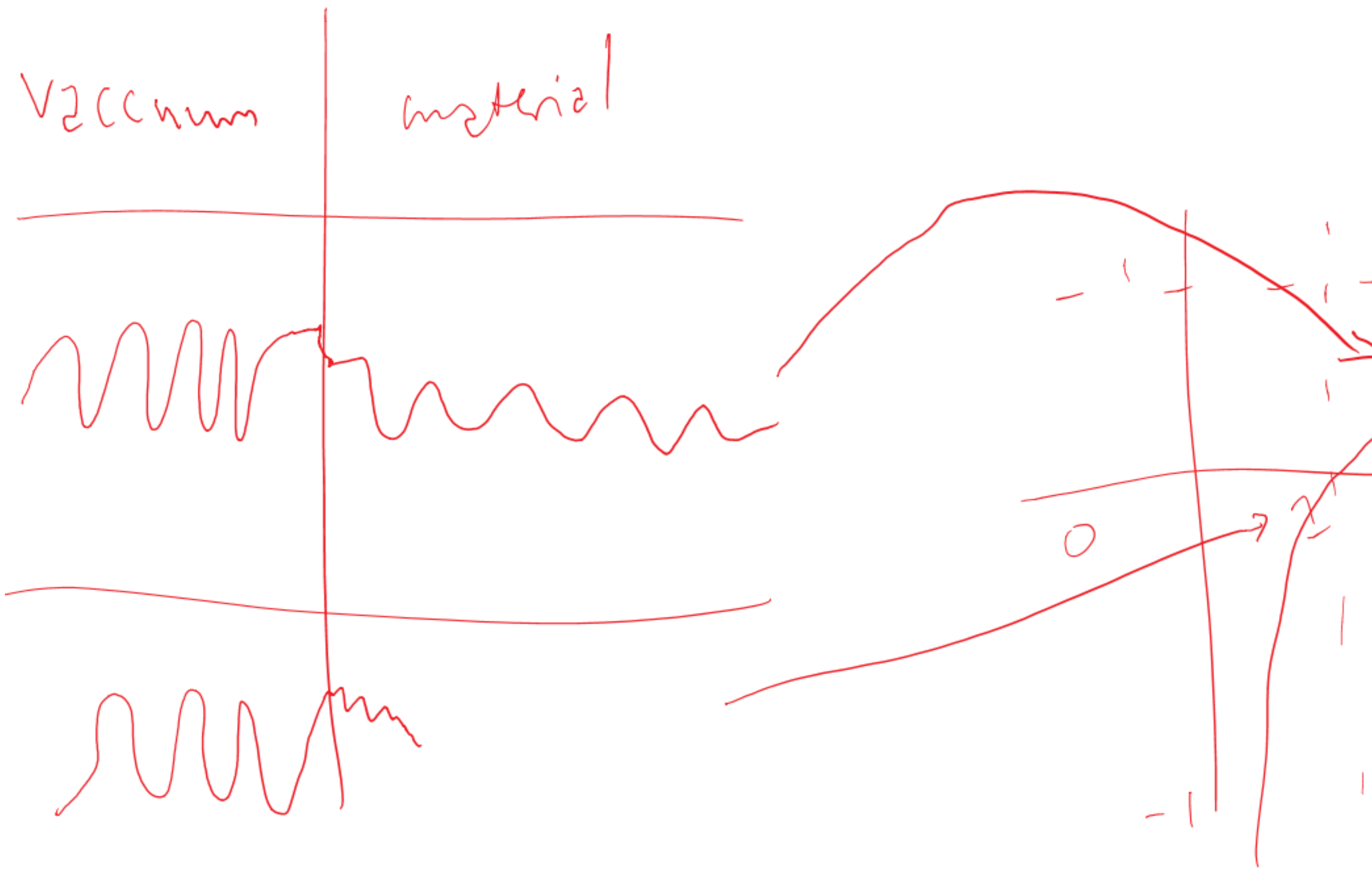
$$\mathbf{E} \propto e^{i\omega t} e^{i\mathbf{k}\cdot\mathbf{r}} \tag{16}$$

$$D = \epsilon(\omega, k)\mathbf{E} \tag{17}$$

$$\epsilon(\omega, \mathbf{k}\epsilon_0\mu_0\omega^2 = k^2 \tag{18}$$

$\epsilon(\omega, \vec{k})$	yields
real $\epsilon > 0$	$\vec{k}$ is real propagati
real $\epsilon < 0$	$\vec{k}$ is imagina damped
complex	$\vec{k}$ is complex

In general:


vaccum
material
0

2015-04-22: Tight Binding - by someone not Murphy

Tight binding In a s system with translational symetrry with $i = 1...N$ lattice sites.
If H is the Hamiltonian, we assume that:

$$\langle i|H|j\rangle = \begin{cases} -t & \text{for nearest neighbor} \\ 0 & \text{otherwise} \end{cases} \tag{19}$$

The eigenenergies are:

$$E_k = \langle k|H|k\rangle = \frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{N}\langle i|H|j\rangle \tag{20}$$

$$= \frac{1}{N}\sum_{\delta}\langle i|H|j\rangle e^{ik\cdot\delta} \tag{21}$$

$$= -t\sum_{\delta} e^{ik\cdot\delta} \tag{22}$$

where δ are the NN vectors
In a square lattice, $\delta = (\pm a, 0), (0, \pm a)$

$$e_k = -t\sum_{\delta} e^{ik\cdot\delta} = -2t[cos(k_x a) + cos(k_y a)] \tag{23}$$

Graphene Unlike a square in a triangle lattices, honeycomb lattice is not a Bravais Lattice since it cannot be generated by a single set of latice generators The two sublattices require a component bases:

$$|i, S\rangle \tag{24}$$

where $S = a, b$ for sublattice a or b.

$$\langle ks|H|ks'\rangle = \frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{N}\langle is|H|js\rangle e^{-ik\cdot r}e^{ik\cdot r} \tag{25}$$

$$\langle ks|H|ks'\rangle = \frac{1}{N}\sum_{i=1}^{N} -t(1-\delta_{s,s'})e^{ik\cdot\delta_{s,s'}} \tag{26}$$

$$\langle ka|H|kb\rangle = -t\sum_{\delta} e^{ik\cdot\delta_{ab}} \tag{27}$$

$$\langle ka|H|kb\rangle = -t\sum_{\delta} e^{ik\cdot\delta_{ba}} \tag{28}$$

Since

$$\delta_{ab}^1 = (a,0) \tag{29}$$

$$\delta_{ab}^2 = (-a/2, \sqrt{3}/2a) \tag{30}$$

$$\delta_{ab}^3 = (-a/2, -\sqrt{3}/2a) \tag{31}$$

$$H_k^{ab} = \langle ka|H|kb\rangle = -t\phi_k \tag{32}$$

$$H_k^{ba} = \langle kb|H|ka\rangle = -t\phi_k^* \tag{33}$$

where $\phi_k = \sum_\delta e^{ik\cdot\delta}$.
The eigen values are

$$E_k = \pm t|\phi_k| \tag{34}$$

Expanding ϕ_k around H:

$$\phi_{k+p} = (p_x - ip_y)\frac{3}{2}a \tag{35}$$

where p is the deviation from H

$$H_p = \nu p\cdot\sigma \tag{36}$$

(DIrac equaiton) which is why it's called a Dirac point
where $\sigma = (\sigma_x, \sigma_y)$ are Pauli matrices and $\nu = \frac{3}{2}ta$ is the Fermi velocity

Eigen vectors

$$\nu\sigma \cdot p\psi_{\pm} = \pm\nu a\psi_{\pm} \tag{37}$$

$$\psi_{\pm} = \frac{1}{\sqrt{2}} \begin{matrix} 1 \\ \pm e^{i\theta a} \end{matrix} e^{i\delta\cdot r} \tag{38}$$

(Bloch wavefunction)

Berry Phase

$$\gamma = \oint_c da \psi^{+}_{\pm,a} \nabla_a \psi_{\pm,a} \tag{39}$$