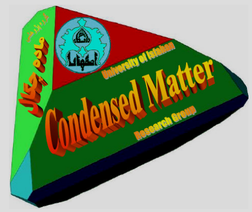
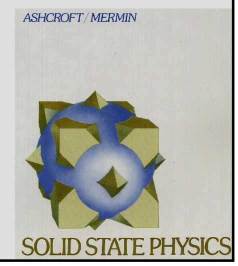
Solid State Physics

Welcome to Solid State Physics!





References:

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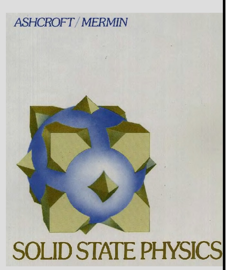
Solid State Physics, Giuseppe Grosso, Giuseppe Pastori Parravicini (2000).
Introduction to Solid State Physics written by Charles Kittel, 8th edition (2004).
FUNDAMENTALS OF SOLID STATE ENGINEERING, *2nd Edition*, Manijeh Razeghi (2006).
Principles of condensed matter physics, P. M. CHAIKIN, T. C. LUBENSKY (1995).
A Theoretical Treatise on the Electronic Structure of Designer Hard Materials, HÅKAN WILHELM HUGOSSON (2001).

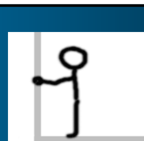


My lectures are on the web

All my lectures in PDF will be on my web site:
http://sci.ui.ac.ir/~sjalali

Please download them before class, so you don't have to take many notes in class.

I'll be creating and continually modifying them as the term progresses, so it's best not to download them all the first day, and instead to download each lecture a day or two before class.



Homework

You would give me your homework per week at my office **not in class or under my door**.

You can work with others on homework (I encourage you to do so!), but write it yourself.

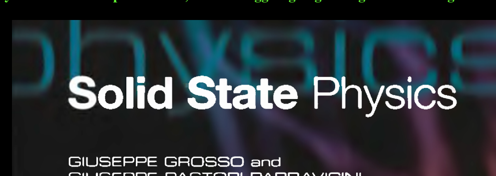
Evaluation Procedures:

1) Midterm (40% or 45%) + Final (50% or 45%) + Homework (10%)

2) Midterm (25% or 30%) + Final (40% or 35%) + Homework (10%) + Research (25%)

N.B. Choice is yours to select procedure Number 1 or Procedure Number 2

If you wish to select procedure 2, I would suggest going through the following textbooks:



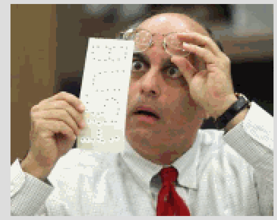
The Importance of Having Class

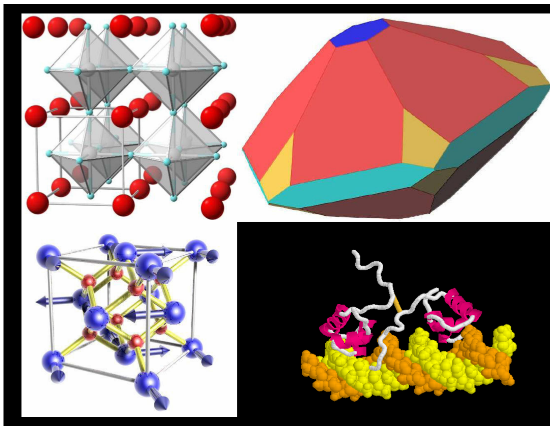
You should come to class because there's a lot that I'll say that won't be in the Power Point files. And which will be on the quizzes.

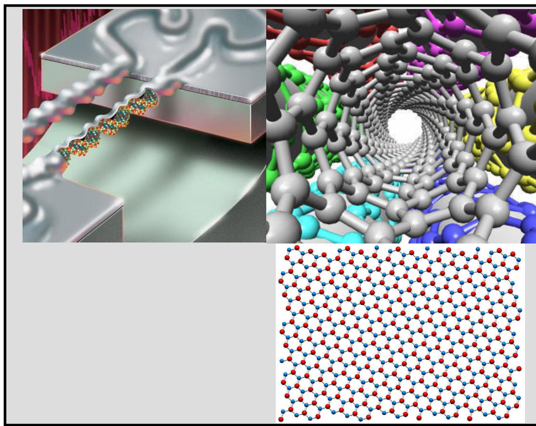
In the past, people who have skipped a lot of classes have received very bad grades. Conversely, people who've come to most or all of the classes nearly always receive A's and B's.

Understanding the ideas of each lecture requires the knowledge of the previous lectures.

If you keep up, you won't end up looking like this the night before the exams!







The Drude Theory of Metals

The Sommerfeld Theory of Metals

Failures of the Free Electron Model

Crystal Lattices
The Reciprocal Lattice
Determination of Crystal Structures by X-Ray Diffraction
Classification of Bravais Lattices and Crystal Structures

Electron Levels in a Periodic Potential

Electrons in a Weak Periodic Potential

The Tight-Binding Method

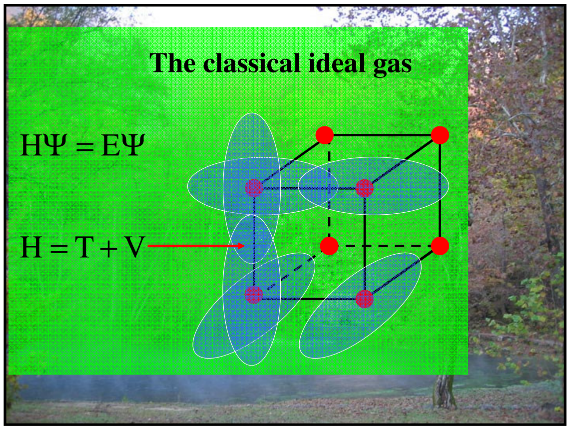
Other Methods for Calculating Band Structure

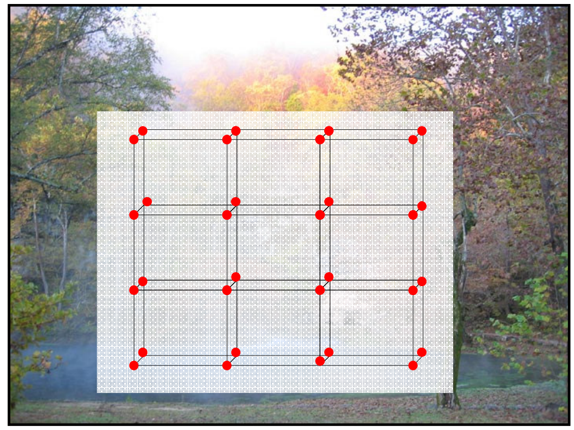
The Semiclassical Model of Electron Dynamics

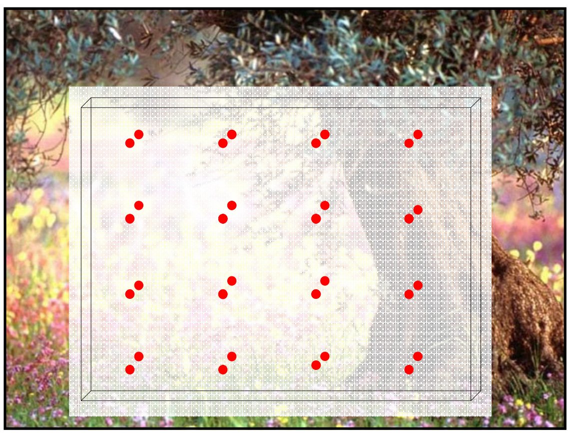
The Semiclassical Theory of Conduction in Metals

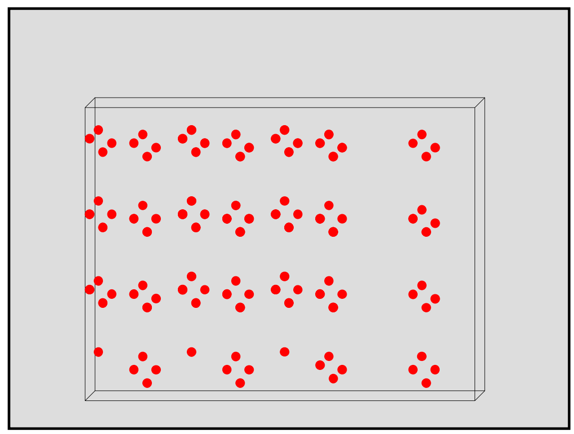
Measuring the Fermi Surface

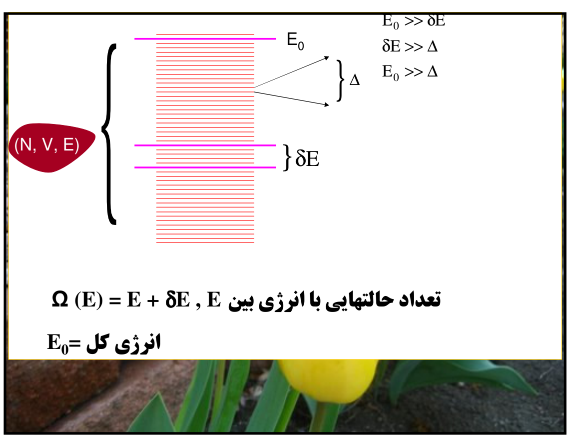
Band Structure of Selected Metals

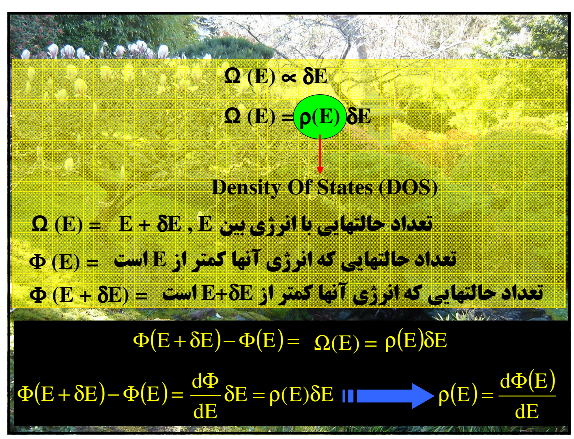

The classical ideal gas
HΨ = EΨ
H = T + V








$E_0 >> \delta E$
$\delta E >> \Delta$
$E_0 >> \Delta$
E_0
Δ
(N, V, E)
δE
Ω (E) = E + δE , E تعداد حالتهایی با انرژی بین
E_0= انرژی کل


Ω (E) ∝ δE
Ω (E) = ρ(E) δE
Density Of States (DOS)
Ω (E) = E + δE , E تعداد حالتهایی با انرژی بین
Φ (E) = تعداد حالتهایی که انرژی آنها کمتر از E است
Φ (E + δE) = تعداد حالتهایی که انرژی آنها کمتر از E+δE است
$\Phi(E+\delta E)-\Phi(E)= \Omega(E)=\rho(E)\delta E$
$\Phi(E+\delta E)-\Phi(E)=\frac{d\Phi}{dE}\delta E=\rho(E)\delta E$ $\rho(E)=\frac{d\Phi(E)}{dE}$

$$E=\frac{\hbar^2K^2}{2m}=\frac{\hbar^2n^2\pi^2}{2mL^2}$$

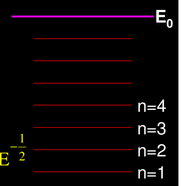
$$\Phi(E)=?$$

$$\Phi(E)=n$$

$$n=\frac{L}{\pi\hbar}(2mE)^{1/2}=\Phi(E)$$

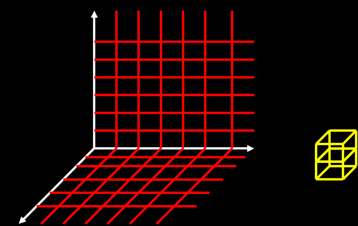
$$\rho(E)=\frac{d\Phi(E)}{dE}=\frac{L}{2\pi\hbar}(2m)^{1/2}E^{-\frac{1}{2}}$$

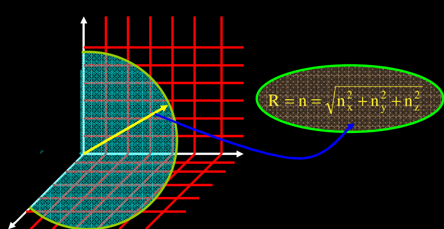
$$\Omega(E)=\rho(E)\delta E=\frac{L}{2\pi\hbar}(2m)^{1/2}E^{-\frac{1}{2}}\delta E$$



$$\Omega(E)\propto L$$

$$E=\frac{\hbar^2K^2}{2m}=\frac{\hbar^2\pi^2}{2mL^2}\left(n_x^2+n_y^2+n_z^2\right)$$





$$\phi(E)=\frac{1}{8}\times\frac{4}{3}\pi\left(\frac{2mL^2E}{\pi^2\hbar^2}\right)^{3/2}=\frac{\pi}{6}\left(\frac{2mV^{2/3}E}{\pi^2\hbar^2}\right)^{3/2}\quad;V=L^3$$

$$E=\frac{\hbar^2K^2}{2m}=\frac{\hbar^2\pi^2}{2mL^2}\left(n_x^2+n_y^2+n_z^2\right)$$

$$R=n=\sqrt{n_x^2+n_y^2+n_z^2}=\left(\frac{L}{\pi\hbar}\right)(2mE)^{1/2}$$

$$\phi(E)=\frac{1}{8}\times\frac{4}{3}\pi\left(\frac{2mL^2E}{\pi^2\hbar^2}\right)^{3/2}=\frac{\pi}{6}\left(\frac{2mV^{2/3}E}{\pi^2\hbar^2}\right)^{3/2}\quad;V=L^3$$

$$\rho(E)=\frac{d\phi(E)}{dE}=\left(\frac{2m\hbar^{-2}V^{2/3}}{\pi^2}\right)^{3/2}\frac{3}{2}E^{1/2}$$

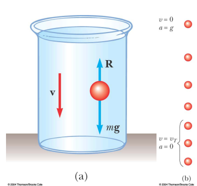
$$\Omega(E)=\rho(E)\delta E=\left(\frac{2m\hbar^{-2}V^{2/3}}{\pi^2}\right)^{3/2}\frac{3}{2}E^{1/2}$$

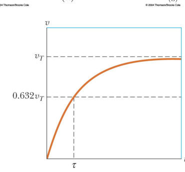
$$\Omega(E)\propto V$$

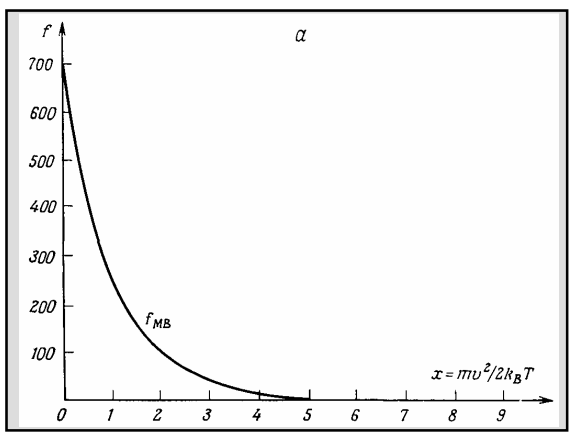
Drude Model

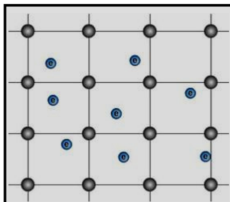
Quasi independent electrons

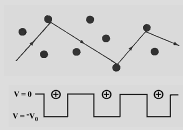
- Linear Case
  F = -*b***v**
- Terminal Velocity
  $ma=mg-bv=0$
  $$v_T=\frac{mg}{b}$$
- Solution for $\mathbf{v}_0=0$
  $$\frac{dv}{dt}=g-\frac{b}{m}v$$
  $$v=\frac{mg}{b}\left(1-e^{-bt/m}\right)=v_T\left(1-e^{-t/\tau}\right)$$











$\bar{E} = N_A 3/2 k_B T$

$C_{el} = \frac{\partial \bar{E}}{\partial T} = 3/2 N_A R$ ☹

Paul Karl Ludwig Drude
(July 12, 1863-July 5, 1906)

$m\frac{d}{dt}\langle\vec{v}\rangle = q\vec{E} - \gamma\langle\vec{v}\rangle,$

$\frac{d}{dt}\langle\vec{v}\rangle = 0$

$\langle\vec{v}\rangle = \frac{q\tau}{m}\vec{E} = \mu\vec{E},$

$\tau = \frac{m}{\gamma}$

$\vec{J} = \frac{nq^2\tau}{m}\vec{E} = \sigma_0\vec{E}$

$\sigma_0 = \frac{nq^2\tau}{m}$

$k = \frac{1}{3}lvC_V$

$l = v\tau$

$k = \frac{1}{3}v^2\tau C_V$

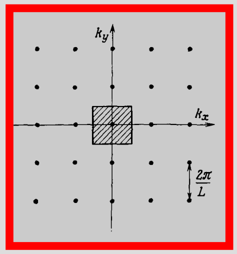
$\frac{k}{\sigma_0} = \frac{1}{3}\frac{mv^2C_V}{nq^2}$

$1/2mv^2 = 3/2k_BT$

$C_V = 3/2nK_B$

Wiedemann and Franz

$\boxed{\frac{k}{\sigma_0} = \frac{3}{2}\left(\frac{k_B}{q}\right)^2 T}$ ☺

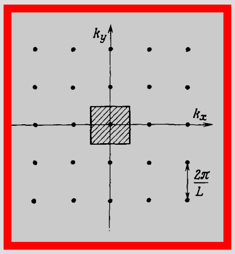


Quasi Free Electrons

Arnold Johannes Wilhelm Sommerfeld
(December 5, 1868 - April 26, 1951)

$$\psi(x, y, z+L) = \psi(x, y, z),$$
$$\psi(x, y+L, z) = \psi(x, y, z),$$
$$\psi(x+L, y, z) = \psi(x, y, z).$$

$$\psi_{\mathbf{k}}(\mathbf{r}) = \frac{1}{\sqrt{V}}e^{i\mathbf{k}\cdot\mathbf{r}};$$
$$\mathcal{E}(\mathbf{k}) = \frac{\hbar^2k^2}{2m},$$



$$\psi_{\mathbf{k}}(\mathbf{r}) = \frac{1}{\sqrt{V}}e^{i\mathbf{k}\cdot\mathbf{r}};$$
$$\mathcal{E}(\mathbf{k}) = \frac{\hbar^2k^2}{2m},$$

$$\frac{\Omega}{(2\pi/L)^3} = \frac{\Omega V}{8\pi^3}$$

$$\Omega = 4/3\pi k_F^3$$

$$N = 2\times 4/3\pi k_F^3 \frac{V}{8\pi^3}$$

$$\frac{N}{V} = 2\times 4/3\pi k_F^3 \frac{1}{8\pi^3}$$

$$n = \frac{k_F^3}{3\pi^2}$$

$$\psi(x, y, z+L) = \psi(x, y, z),$$
$$\psi(x, y+L, z) = \psi(x, y, z),$$
$$\psi(x+L, y, z) = \psi(x, y, z).$$

$$e^{ik_xL} = e^{ik_yL} = e^{ik_zL} = 1$$

$$k_x = \frac{2\pi n_x}{L}, \quad k_y = \frac{2\pi n_y}{L}, \quad k_z = \frac{2\pi n_z}{L}$$

$$E = 2\sum_{k<k_F}\frac{\hbar^2}{2m}k^2$$

$$\frac{E}{V} = \frac{1}{4\pi^3}\int_{k<k_F} d\mathbf{k}\,\frac{\hbar^2k^2}{2m} = \frac{1}{\pi^2}\frac{\hbar^2 k_F^5}{10m} \div N/V = k_F^3/3\pi^2$$

$$\frac{E}{N} = \frac{3}{10}\frac{\hbar^2k_F^2}{m} = \frac{3}{5}\mathcal{E}_F \qquad \frac{E}{N} = \frac{3}{5}k_BT_F$$

$$B = \frac{1}{K} = -V\frac{\partial P}{\partial V} \qquad P = -(\partial E/\partial V)_N$$

$E/N = 3/5N\varepsilon_F \quad \varepsilon_F = \frac{\hbar^2k_F^2}{2m}$

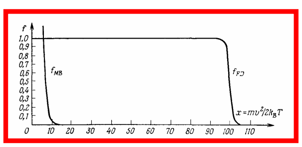
$k_F^3 = 3\pi^2\left(\frac{N}{V}\right)$

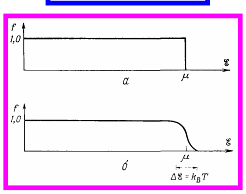
$E = \frac{3}{5}N(3\pi^2)^{2/3}\left(\frac{N}{V}\right)^{2/3}\frac{\hbar^2}{2m}$ $\quad \boxed{E \propto V^{-2/3}}$

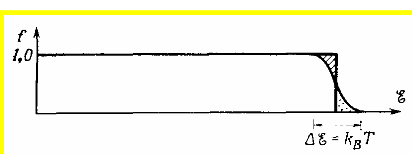
$P = \frac{2}{3}\frac{E}{V}$ $\quad \boxed{P \propto V^{-5/3}}$

$$B = \frac{5}{3}P = \frac{10}{9}\frac{E}{V} = \frac{2}{3}n\mathcal{E}_F$$ ☺

$$f(\mathcal{E}) = \frac{1}{e^{(\mathcal{E}-\mu)/k_BT}+1} \qquad c_v = \gamma T + AT^3$$



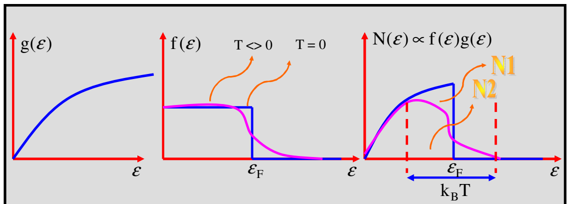




$$u = \int\frac{d\mathbf{k}}{4\pi^3}\mathcal{E}(\mathbf{k})f(\mathcal{E}(\mathbf{k})) \qquad n = \int\frac{d\mathbf{k}}{4\pi^3}f(\mathcal{E}(\mathbf{k}))$$

$$u = \int_{-\infty}^{\infty} d\mathcal{E}\,g(\mathcal{E})\mathcal{E}f(\mathcal{E}) \qquad n = \int_{-\infty}^{\infty} d\mathcal{E}\,g(\mathcal{E})f(\mathcal{E})$$

$$g(\mathcal{E}) = \frac{m}{\hbar^2\pi^2}\sqrt{\frac{2m\mathcal{E}}{\hbar^2}}, \quad \mathcal{E} > 0;$$
$$= 0, \quad \mathcal{E} < 0.$$



N1+N2=N

$$\frac{N1}{N} = \frac{k_B T}{\varepsilon_F} \qquad N1 = N\frac{k_B T}{\varepsilon_F}$$

$$U = N\frac{k_B T}{\varepsilon_F}\, 3/2\, k_B T \qquad C_{el} = \left(\frac{\partial U}{\partial T}\right)_{V,N} = \frac{3Nk_B^2}{\varepsilon_F}T$$

$$\boxed{C_{el} = \gamma T}$$ ☺