固体物理

一. 02 晶向 ⟨110⟩ 晶面密勒指数 $\propto(\frac{1}{r},\frac{1}{s},\frac{1}{t})$

05 倒易点阵 $\vec a_i\cdot\vec b_j \in 2\pi N$ $\vec b_i = 2\pi\frac{\vec a_j\times\vec a_k}{\Omega}$ 体心 $\xLeftarrow{\text{倒格子}}$ 面心.

$\vec K_h = h\vec b_1 + k\vec b_2 + l\vec b_3$ 与晶面 (h,k,l) 垂直. 晶面间距 $\frac{2\pi}{|\vec K_h|}$

06 $2d_{hkl}\sin\theta = n\lambda$ 原子散射因子 $f(\vec K)=\int \rho(\vec r) e^{i\vec K\cdot\vec r} d\vec r$ $\vec K = \vec k - \vec k_0$

几何结构因子 $F=\sum_{j=1}^{n} f_j e^{i\vec K\cdot\vec R_j}$ $R_j = x_j\vec a_1 + y_j\vec a_2 + z_j\vec a_3$, $\vec K = \vec G_{HKL}$

$F_{HKL} = \sum_j^n f_j[\cos 2\pi(Hx_j+Ky_j+Lz_j) + i\sin 2\pi(Hx_j+Ky_j+Lz_j)]$

二. 07 体变模量 $K=-V\frac{dp}{dV} = (V\frac{d^2U}{dV^2})_{V_0}$ $W=-U(r_0)$

马德隆能 $\frac{q^2}{4\pi\varepsilon_0 r}\sum\frac{(-1)^{n_1+n_2+n_3}}{\sqrt{n_1^2+n_2^2+n_3^2}}$

勒纳德-琼斯势 $u(r)=4\varepsilon(\frac{\sigma^{12}}{r^{12}}-\frac{\sigma^6}{r^6})$ $U=2N\varepsilon[A_{12}\frac{\sigma^{12}}{r_0^{12}} - A_6\frac{\sigma^6}{r_0^6}]$

由 $\frac{\partial U(r)}{\partial r}\Big|_{r_0}=0$, $U(r_0) = -N\varepsilon\frac{A_6^2}{2A_{12}}$

三 09 一维单原子链 $m\frac{d^2u_n}{dt^2} = \beta(u_{n+1}+u_{n-1}-2u_n)$ $Ae^{i(\omega t - naq)}$ $\omega = 2\sqrt{\frac{\beta}{m}}|\sin\frac{aq}{2}|$ $q=\frac{2\pi}{\lambda}$

相 $v_p=\frac{\omega}{q}$ 群 $v_g=\frac{d\omega}{dq}$

10 $u_n = \sum_q u_{nq} = \sum_q A_q e^{i(\omega t - naq)} = \frac{1}{\sqrt{Nm}}\sum_q \sqrt{Nm}A_q e^{i\omega t} e^{-inaq} = \frac{1}{\sqrt{Nm}}\sum_q Q_q e^{-inaq}$

$T = \sum_n^N \frac12 m\dot u_n^2 = \frac12\sum_{i=1}^{3N}\dot Q_i^2$ $V=\frac{\beta}{2}\sum_{n=1}^{N}(u_n^2+u_{n-1}^2-2u_nu_{n-1}) = \frac12\sum^{3N}\omega_i^2Q_i^2$

$L=T-V$ $p_i=\frac{\partial L}{\partial\dot Q_i}=\dot Q_i$ $H=\frac12\sum p_i^2+\omega_i^2Q_i^2$ $\Rightarrow$ $\ddot Q_i+\omega_i^2Q_i=0$ $Q_i = A\sin(\omega_i t-\delta)$

$u_n=\frac{1}{\sqrt{Nm}}\sum_q Q_q e^{-inaq}$ $Q_q=\sqrt{\frac{m}{N}}\sum_{n=1}^{N} u_n e^{inaq}$

09 一维双原子链 $m\frac{d^2u_{2n}}{dt^2}=\beta(u_{2n+1}+u_{2n-1}-2u_{2n})$ $M\frac{d^2u_{2n+1}}{dt^2}=\beta(u_{2n+2}+u_{2n}-2u_{2n+1})$

$u_{2n}=Ae^{i(\omega t-2naq)}$ $u_{2n+1}=Be^{i(\omega t-(2n+1)aq)}$ $\Rightarrow \omega_\pm^2=\frac{\beta(M+m)}{Mm}(1\pm\sqrt{1-\frac{4Mm}{(M+m)^2}\sin^2 aq})$

态密度 $g(\omega)d\omega=dn$ $dn=\frac{V}{(2\pi)^3}dV_q$ $dV_q=\iint_{S_\omega} dS_q dq_n$ $d\omega=|\nabla_q\omega(q)|dq_n$

$g(\omega)=\frac{V}{(2\pi)^3}\iint_{S_\omega}\frac{dS_q}{|\nabla_q\omega(q)|}$

11 热容 Einstein 模型 $E_i=(\bar n+\frac12)\hbar\omega$ 3N个格波 $\Rightarrow \bar E=\frac{3N\hbar\omega_E}{e^{\frac{\hbar\omega_E}{k_BT}}-1}$ $C_V=\frac{\partial\bar E}{\partial T}=3Nk_B(\frac{T_E}{T})^2\frac{e^{\frac{T_E}{T}}}{(e^{\frac{T_E}{T}}-1)^2}$

Debye 模型 弹性波 $g(\omega)=\frac{3V\omega^2}{2\pi^2v_s^3}$ 线性 $\omega=v_sq$ $\int_0^{\omega_D}g(\omega)d\omega=3N \Rightarrow \omega_D=\sqrt[3]{6\pi^2n}\,v_s$

$\bar E=\int_0^{\omega_D}\frac{\hbar\omega}{e^{\frac{\hbar\omega}{k_BT}}-1}g(\omega)d\omega = 9Nk_BT(\frac{T}{T_D})^3\int_0^{\frac{T_D}{T}}\frac{x^3}{e^x-1}dx$ $C_V=\frac{\partial\bar E}{\partial T}=9Nk_B(\frac{T}{T_D})^3\int_0^{\frac{T_D}{T}}\frac{x^4e^x}{(e^x-1)^2}dx$

二维 $g(\omega)=\frac{S\omega}{2\pi v_s^2}$? 一维 $g(\omega)=\frac{1}{v_s}\cdot\frac{L}{\pi}$?

13 格林爱森参数 $\gamma=-\frac{d\ln\omega}{d\ln V}$ $\alpha=\frac{\gamma}{K}\frac{C_V}{V}$

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四 15 Drude模型 $n = N_A \frac{2\rho_m}{A}$ $\sigma = \frac{ne^2\tau}{2m\bar{v}}$ $\kappa = \frac{1}{3}C_v v \bar{l}$ $\frac{\kappa}{\sigma} = \frac{3}{2}(\frac{k_B}{e})^2 T$

Sommerfeld $E_k = \frac{\hbar^2}{2m}(k_x^2 + k_y^2 + k_z^2)$ $Z(E) = N$ $N(E) = \frac{d\frac{Z(E)}{V}}{dE} = \frac{(2m)^{\frac{3}{2}}}{2\pi^2\hbar^3} \cdot E^{\frac{1}{2}}$

$2 \cdot \frac{4\pi k_F^3}{3} \cdot \frac{V}{(2\pi)^3} = N \Rightarrow k_F = \sqrt[3]{3\pi^2 n}$ $E_F = \frac{\hbar^2 k_F^2}{2m}$ $T_F = \frac{E_F}{k_B}$ $N(E_F^0) = \frac{3}{2}\frac{n}{E_F}$

$U_0 = \int_0^{E_F^0} E N(E) dE = \frac{3}{5} n E_F^0$

16 $C = C_e + C_V = \frac{\pi^2}{2} N_A k_B \frac{T}{T_F} + \frac{12}{5}\pi^4 N_A k_B (\frac{T}{T_D})^3$ $T_C: C_e = C_V$ 时 $T_C = \sqrt{\frac{5T_D^3}{24\pi^2 T_F}}$

$v = \frac{\hbar \Delta k}{m} = -\frac{e\varepsilon\tau}{m}$ $j = nev = \frac{ne^2\tau}{m}\varepsilon = \sigma\varepsilon$

$\kappa_e = \frac{1}{3} C_e v \bar{l} = \frac{1}{3}(\frac{\pi^2}{2} N_A k_B \frac{T}{T_F})(v_F)(v_F \cdot \tau_F) = \frac{\pi^2 n k_B^2 T}{3m} \tau_F$ $\frac{\kappa}{\sigma} = \frac{\pi^2}{3}(\frac{k_B}{e})^2 T = LT$

$W = V_0 - E_F$ $V_{AB} = V_A - V_B = \frac{1}{e}(W_B - W_A)$

五 17 绝热 平均场 周期场 近似 $\psi_k(r) = e^{ik\cdot r} u_k(r)$ $\psi_k^{(0)} = \frac{1}{\sqrt{L}} e^{ik\cdot r}$ $E_k^{(0)} = \frac{\hbar^2 k^2}{2m}$

周期微扰使能量高的更高，低的更低

18 紧束缚 $E(k) = \varepsilon_s - J_0 - J_1 \sum_{R_s 近邻} e^{-ik\cdot R_s}$

19 课程论文 20 带底 $N(E) = \frac{(2m^*)^{\frac{3}{2}}}{2\pi^2\hbar^3} E^{\frac{1}{2}}$ 带顶 $\frac{(2m^*)^{\frac{3}{2}}}{2\pi^2\hbar^3}(E_c - E)^{\frac{1}{2}}$ $2\cdot\frac{L}{(2\pi)^3}\cdot N$ $N(E) = \frac{1}{4\pi^3}\oint \frac{ds}{|\nabla_k E|}$

第六 22 有效质量张量 $[\frac{1}{m^*}] = \frac{1}{\hbar^2}[\frac{\partial^2 E}{\partial k_\alpha \partial k_\beta}]$ 对角化对应主轴方向

$T = \frac{2\pi/a}{eE/\hbar}$ (~~~~带顶带底的周期) 电场

23 $\hbar\frac{dk}{dt} = -ev(k)\times B$ 磁场 回旋运动 回旋频率 $\omega_c = \frac{2\pi eB/\hbar}{\oint_{E=const} \frac{dE}{|v_\perp|}} = \frac{eB}{m^*}$ $\Delta\frac{1}{B} = \frac{2\pi e}{\hbar}\frac{1}{A_F}$ A_F为费米面极值截面积

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2.22 赵瑾 zhaojin@ustc. staff.ustc.edu.cn/~zhaojin
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绪论 研究对象 发展历程 研究方法 相关教材
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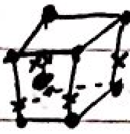
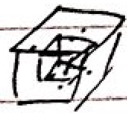
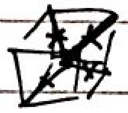
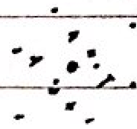
《黄昆》 Ashcroft・Mermin solid state physics
周期性结构中波的传播
谢华 15555433213 周二交作业 30/20/50

2.25 晶体 周期性排列 晶格 原胞：最小周期性重复单元 晶胞全复单元
Wigner-Seitz原胞：中垂线分割 体积 $\Omega = \vec{a}_1 \cdot (\vec{a}_2 \times \vec{a}_3)$ 惯用晶胞
基元 看课件 配位数?
简立方 体心立方 面心立方 简单六角
晶列 晶向 晶向指数 晶面指数(密勒指数) 六角的指数?

晶体的对称性 点群 旋转 C_n 反演 $C_i = S_2$
2.29 3.1 反映 $m = S_2$ 旋转反演 S_n D_n: C_n + 加入一个n个适合的二次轴 T:四面体 O:八面体
h: 垂直主轴的对称面 v 含主轴的对称面
d: 垂直主轴的两个二次轴的平分面 对称面
对称操作 描述 $\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} & & \\ & & \\ & & \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$
32种点群
晶体 C_2 C_3 C_4 C_6 螺旋轴 滑移面
晶体宏观物理性质具有点群的性质
3.3 Real crystal structures
堆积 占空比
简立方 52% (Po) 体心立方 68% 碱金属 Li Na K
紧密堆结构 ABAB hcp 镁 Mg ABCABC fcc 面心立方 Cu
简单晶格：每个原子等价(晶体粒子) 复式晶格
金刚石 34%
bcc：体心?

NaCl  (面心立方→2(00)) ~~Ni~~ CsCl  闪锌矿结构 ZnS 面心立方 → $\frac{1}{4}\frac{1}{4}\frac{1}{4}$

ZnS 纤锌矿  hcp ↑ $0,0,\frac{3}{8}$ 萤石 CaF_2 Ca面心，F 

Cu_2O  $CaTiO_3$ 

复杂合金结构

晶体表面结构   表面重构

(2×2) $\sqrt{2}\times\sqrt{2}\ R45^\circ$

准晶   非晶

$\boxed{3.8}$ 倒易点阵 布里渊区 COS

平移操作算符 $T(\vec{R}_l)f(\vec{r}) = f(\vec{r}+\vec{R}_l)$

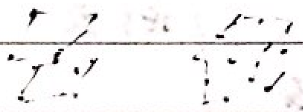
$\Rightarrow e^{i\vec{G}\cdot\vec{R}_l}=1$ $n(\vec{r}) = \sum n_G e^{i\vec{G}\cdot\vec{r}}$ $\vec{R}_l$ 格矢 $\vec{G}$ 倒格矢

$R=(n_1,n_2,n_3)\ \vec{a}_1,\vec{a}_2,\vec{a}_3$ $\vec{a}_i\cdot\vec{b}_j = 2\pi\delta_{ij}$

$G=(m_1,m_2,m_3)\ \vec{b}_1,\vec{b}_2,\vec{b}_3$ $\vec{R}\cdot\vec{G} = 2\pi(n_1m_1+n_2m_2+n_3m_3) = 2\pi m$

$\vec{b}_i = \vec{a}^i\cdot 2\pi$ 正点阵和倒易点阵互易

体心的倒易点阵为面心点阵

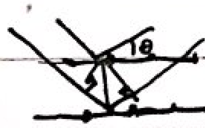


倒格矢垂直晶面（密勒指数的晶面）

$K_h = h_1\vec{b}_1+h_2\vec{b}_2+h_3\vec{b}_3$ 晶面间距 $d=\frac{2\pi}{|K_h|}$

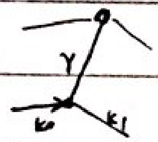
布里渊区：连中垂线，第一布里渊区：中垂线 $\vec{R}_l\cdot\vec{G} = \frac{1}{2}G^2$，$\vec{G}$为倒格矢

$\boxed{3.10}$ 晶体衍射的几何理论 Cob

 $2d_{hkl}\sin\theta = n\lambda$  $\Rightarrow \vec{R}_l\cdot(\vec{k}_0-\vec{k}_1) = 2\pi n \Rightarrow \vec{k}_0-\vec{k}_1 = \vec{G}$

$(\Rightarrow \vec{k}_0\cdot\vec{G} = \frac{1}{2}G^2)$

原子散射因子



$\vec{K} = \vec{k} - \vec{k}_0$ $f(\vec{K}) = \int \rho(\vec{r}) e^{i\vec{K}\cdot\vec{r}} d^3\vec{r}$

几何结构因子

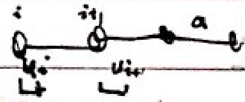
3.15 晶体的结合 (2)

3.17 (2)

3.22 (4) 第三章 晶格振动

声子 $\omega = \frac{\hbar k^2}{2m}$

一维原子链振动



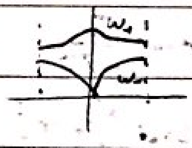
$F = m\ddot{u}_n = \beta(u_{n+1} + u_{n-1} - 2u_n)$ 周期边界

$U_{nq} = Ae^{i(\omega t - naq)}$ $q = \frac{2\pi}{\lambda}$ 代入 $\Rightarrow$ $-m\omega^2 = 2\beta(\cos aq - 1)$

$\omega = 2\sqrt{\frac{\beta}{m}}\left|\sin\frac{1}{2}aq\right|$ $q \in (-\frac{\pi}{a}, \frac{\pi}{a})$ 第一布里渊区内的波矢

3.24

一维双原子链



$\mu = \frac{Mm}{M+m}$

模式密度 态密度 $g(\omega) = \frac{dn}{d\omega}$ $\omega(q) \sim \omega(q) + d\omega(q)$ 之间 $dn = \frac{V}{(2\pi)^3} dV_q$

$g(\omega) = \frac{V}{(2\pi)^3} \iint \frac{dS_q}{\nabla_q \omega(q)}$

$U_n = \sum_q U_{nq} = \sum_q A_q e^{i\omega t - naq} = \frac{1}{\sqrt{Nm}} \sum \underbrace{\sqrt{Nm} A_q e^{i\omega t}}_{Q_q} e^{-inaq}$

$T = \frac{1}{2}\sum^{N} \dot{Q}_i^2$ $V = \frac{1}{2}\sum \omega^2 Q_i^2$ $H = \cancel{\frac{1}{2}\sum Q_i p_i}\ \frac{1}{2}\sum p_i^2 + \omega_i^2 Q_i^2$

$\ddot{Q}_i + \omega_i^2 Q_i = 0$ $Q_i = A\sin(\omega_i t - \delta)$ $Q_q = \sqrt{\frac{m}{N}} \sum_n U_n e^{inaq}$

3.24 CP11

3.31 C12 离子晶体的红外光学性质

4.5 C13 非简谐效应 C14

4.12 C15 金属自由电子论

真空：$\omega = \frac{\hbar k^2}{2m}$

金属的性质 $J = \sigma E$ $LT = \frac{K}{\sigma}$ $L = \frac{K}{\sigma T} = \frac{\pi^2}{3}\left(\frac{k_B}{e}\right)^2$

Drude模型：看作理想气体

唯一变量：电子密度 $n = N_A \times \frac{Z \rho_m}{A}$ 典型值 $10^{29}/m^3$

4.19 C16 金属交流导电率

电子在电场作用下的经典运动方程

$$m\frac{dv}{dt} = -eE - \frac{mv}{\tau}$$ $\vec{E} = E_0 e^{-i\omega t}$ 电子漂移速度 $v_d = v_{d0} e^{-i\omega t}$

$$\Rightarrow \vec{v_d} = \frac{-eE\tau}{m(1-i\omega\tau)}$$

$$J = -ne\vec{v_d} = \frac{ne^2\tau}{m(1-i\omega\tau)}\vec{E}$$

由 $J = \sigma\vec{E}$ $\sigma = \frac{\sigma_0}{1-i\omega\tau}$ $\sigma_0 = \frac{ne^2\tau}{m}$ $\sigma = \sigma' + i\sigma''$

$$\sigma' = \frac{\sigma_0}{1+\omega^2\tau^2} \quad \sigma'' = \frac{\sigma_0\omega\tau}{1+\omega^2\tau^2}$$

$\nabla\times H = \varepsilon_0\varepsilon_i\frac{\partial E}{\partial t} + \vec{j}$ 金属 $\varepsilon_i = 1$ $j = \sigma E = \frac{\sigma}{-i\omega}\frac{\partial E}{\partial t}$

$\nabla\times H = \underbrace{\left(\varepsilon_0 + i\frac{\sigma}{\omega}\right)}_{\varepsilon}\frac{\partial E}{\partial t}$ $\varepsilon_r = \frac{\varepsilon}{\varepsilon_0} = 1 + i\frac{\sigma}{\varepsilon_0\omega}$

$$\varepsilon_r = \varepsilon_r' - i\varepsilon_r'' = \left(1 - \frac{\sigma_0\tau}{\varepsilon_0(1+\omega^2\tau^2)}\right) + i\frac{\sigma_0}{\varepsilon_0\omega(1+\omega^2\tau^2)}$$

测量反射率R 吸收系数 α

$\tilde{n} = \sqrt{\varepsilon_r} = n + ik$ $\begin{cases} R = \frac{(n-1)^2 + k^2}{(n+1)^2 - k^2} \\ \alpha = 2\frac{\omega}{c}k \end{cases}$

等离子体频率 $\omega_p^2 = \frac{ne^2}{\varepsilon_0 m}$ $\varepsilon_r = \left(1 - \frac{\omega_p^2\tau^2}{1+\omega^2\tau^2}\right) + i\frac{\omega_p^2\tau}{\omega(1+\omega^2\tau^2)}$

$\omega\tau \ll 1$ $\varepsilon_r \approx i\varepsilon_r''$ $|n| \approx |k| = \left|\frac{\varepsilon_r''}{2}\right|^{\frac{1}{2}} = \sqrt{\frac{\sigma_0}{2\varepsilon_0\omega}}$

$\delta = \frac{c}{\omega k} = \sqrt{\frac{\varepsilon_0 c^2}{2\sigma_0\omega}}$ 吸收区

高频区 ε_r 简化成实数 $\omega < \omega_p$ $\varepsilon_r < 0$ $n \approx 0$ $R \approx 1$ 反射区

$\omega > \omega_p$ $0 < \varepsilon$ $k \approx 0$ $\alpha R < 1$ $\lambda_p = \frac{2\pi c}{\omega_p}$

$\omega = \omega_p$ R 垂直下降

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$b_i = 2\pi \frac{\vec{a}_j \times \vec{a}_k}{\Omega}$ $2d_{hkl}\sin\theta = n\lambda$ $f(\vec{k}) = \int \rho(r) e^{i\vec{k}\cdot\vec{r}} d\vec{r}$ $k = \vec{k} - \vec{k}_0$

$F_{HKL} = \sum f_j e^{i\vec{K}\cdot\vec{R}_j} = f_a \sum \cos(H_x, K_y, L_z) + f_a \sum \sin(H_x, K_y, L_z)$

$K = -V\frac{dp}{dV} = \left(V\frac{d^2U}{dV^2}\right)_{V_0}$ $W = -U(r_0)$

$\frac{q}{4\pi\varepsilon_0 d^2} \sum \frac{(-1)^{n_1+n_2+n_3}}{\sqrt{n_1^2+n_2^2+n_3^2}}$ $U(r) = 4\varepsilon\left(\frac{\sigma^{12}}{r^{12}} - \frac{\sigma^6}{r^6}\right)$ $2N\varepsilon\left[A_{12}\frac{\sigma^{12}}{r_0^{12}} - A_6\frac{\sigma^6}{r_0^6}\right]$

$U(r_0) = -N\varepsilon\frac{A_6^2}{2A_{12}}$ $Ae^{i(\omega t - naq)}$ $2\sqrt{\frac{\beta}{m}}\left|\sin\frac{aq}{2}\right|$

$\omega_\pm^2 = \frac{\beta(m+M)}{Mm}\left(1 \pm \sqrt{1 - \frac{4Mm}{(m+M)^2}\sin^2 aq}\right)$

$g(\omega)d\omega = dn = \frac{V}{(2\pi)^3}dV_q$ $d\omega = \nabla_q\omega(q) dq_n$

$g(\omega) = \frac{V}{(2\pi)^3}\iint \frac{dS_\omega}{|\nabla_q\omega(q)|}$ $\bar{E} = \frac{3N\hbar\omega_E}{e^{\frac{\hbar\omega_E}{k_BT}} - 1}$ $~~C_V = \frac{\partial E}{\partial T} = 3Nk_B\left(\frac{T_E}{T}\right)^2~~$

$C_V = 3Nk_B\left(\frac{T}{T_E}\right)^2 \frac{e^{\frac{T_E}{T}}}{\left(e^{\frac{T_E}{T}} - 1\right)^2}$

$\frac{V}{(2\pi)^3} 4\pi q^2 dq = dn = \frac{V}{(2\pi)^3} 4\pi \frac{\omega^2 d\omega}{V_s^3} = dn$

$3\frac{V\omega^2}{2\pi^2 V_s^3} d\omega = dn$

$\int_0^{\omega_D} \frac{3V\omega^2 d\omega}{2\pi^2 V_s^3} = 3N$ $\frac{V\omega_D^3}{2\pi^2 V_s^3} = 3N$ $\omega_D = \sqrt[3]{6n\pi^2}\, V_s$

$\hbar\omega_D = k_BT_D$ $\hbar k_D = m v_0$ $\frac{\omega_D}{V_s} = q_D$

$\bar{E} = 9Nk_BT\left(\frac{T}{T_D}\right)^3 \int^{\frac{T_D}{T}} \frac{x^3}{e^x - 1} dx$ $C_V = 9Nk_B\left(\frac{T}{T_D}\right)^3 \int^{\frac{T_D}{T}} \frac{x^4 e^x}{(e^x - 1)^2} dx$

$\gamma = -\frac{d\ln\omega}{d\ln V}$ $\alpha = \frac{\gamma}{K}\frac{C_V}{V}$ $\gamma = -\frac{d\ln\omega}{d\ln V}$ $\alpha = \frac{\gamma}{K}\frac{C_V}{V}$

$n = N_A\frac{Z\rho_m}{A}$ $\sigma = \frac{ne^2\bar{\tau}}{2m}$ $k = \frac{1}{3}C_V\bar{v}\bar{l}$ $\frac{k}{\sigma} = 3\left(\frac{k_B}{e}\right)^2 T$

$E_k = \frac{\hbar^2 k^2}{2m}$ $VN(E)dE = dN$ $N(E) = \frac{(2m)^{\frac{3}{2}}}{2\pi^2\hbar^3} E^{\frac{1}{2}}$

$(3\pi^2 n)^{\frac{1}{3}}$ $N(E_F^0) = \frac{3n}{2E_F^0}$ $U_0 = \int_0^{E_F^0} E\, N(E)dE = \frac{3}{5}NE_F^0$

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$C_e = \frac{\pi^2}{2} N_A k_B \frac{T}{T_F}$ $C_V = \frac{12}{5}\pi^4 N_A k_B \left(\frac{T}{T_D}\right)^3$

$v = \frac{\hbar k}{m} = -\frac{e\varepsilon\tau}{m}$ $j = nev = \frac{ne^2\tau}{m}\varepsilon$

$\kappa_e = \frac{1}{3} C_e \bar{v}\bar{l} = \frac{1}{3} \cancel{\frac{12}{5}\pi^4 N_A k_B \left(\frac{T}{T_D}\right)^3} \left(\frac{\pi^2}{2} N_A k_B \frac{1}{T_F}\right)(v_F)(v_F \tau_F)$. $\frac{\kappa}{\sigma} = \frac{\pi^2}{3}\left(\frac{k_B}{e}\right)^2 T$

$w = v_0 - E_F^0$ $V_{AB} = \frac{(w_A - v_B)}{e}$

$\varepsilon_s - J_0 - J_1 \sum e^{-i\vec{k}\cdot\vec{R}_s}$

$N(E) = 2 \cdot \frac{1}{V} \frac{V}{(2\pi)^3} \iint \frac{ds}{|\nabla_k E|}$ $\left[\frac{1}{m^*}\right] = \frac{1}{\hbar^2}\left[\frac{\partial^2 E}{\partial k \partial k}\right]$

$T = \frac{2\pi/a}{e\varepsilon/\hbar}$ $\hbar\frac{dk}{dt} = q v \times B$

$\hbar v = e\varepsilon$ $\frac{eV}{d}$

$\frac{2\pi/a}{e\varepsilon/\hbar}$ $E = \frac{d}{5}$

$\hbar k \quad e\varepsilon t$

$\hbar \frac{k}{t} = e\varepsilon$

$\omega_c = \frac{2\pi e B}{\hbar \oint \frac{dk}{|v_\perp|}}$ $\frac{eB}{m^*}$ $\sigma \frac{1}{B} = \frac{2\pi e}{\hbar A_F}$

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$\boxed{4.21}$ C17 能带理论

$\boxed{4.26}$

$\boxed{5.3}$ C19 • .. .. ..

5.1 5.6 C20

? 二维矩形晶格，x y方向晶格常数 a b

(1) 用紧束缚方法求出 s态电子能态密度

5.2

总结