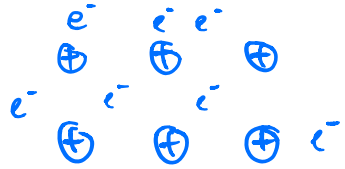
KOVINE

$R(T)$ naraščа s T

Delno zapolnjen valenčni pas. Elektronski plin / tekočina.

1) MODEL PROSTIH ELEKTRONOV

- upoštevamo šibko vezane valenčne elektrone

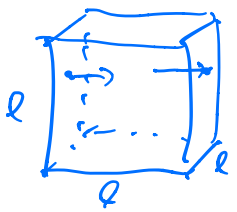


- razmazanemo ⊕ naboje

Celota električno nevtralna.

- zanemarimo Coulombski odboj

⇒ Delimo plin delcev, ki se med seboj sploh ne čutijo.



$V = \ell^3$

$\psi(x,y,z) = \psi(x+\ell, y, z)$

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$\psi = \frac{1}{\sqrt{V}} e^{i\vec{k}\cdot\vec{r}}$

$\int_V |\psi|^2 dV = 1$

1. $E = ?$
2. $k = ?$

$k^2 = k_x^2 + k_y^2 + k_z^2$

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

$\psi(x) = \psi(x+\ell)$ $\quad \psi = \frac{1}{\sqrt{\ell}} e^{ikx}$

$\frac{1}{\sqrt{\ell}} e^{ikx} = \frac{1}{\sqrt{\ell}} e^{ikx+ik\ell} = \frac{1}{\sqrt{\ell}} e^{ikx} e^{ik\ell}$ $\quad \Rightarrow e^{ik\ell} = 1$

$k_x l = 2\pi n_x \Rightarrow k_x = \frac{2\pi}{l} n_x \quad n_x = 0,1,2,\ldots \quad n \in \mathbb{Z}$

$k_y l = 2\pi n_y \quad k_y = \frac{2\pi}{l} n_y \quad n_y = 0,1,2,\ldots$

n_z

$N = N_A \sim 10^{23} \qquad E = \frac{\hbar^2}{2m_e}\left(\frac{2\pi}{l}\right)^2 (n_x^2 + n_y^2 + n_z^2) \rightarrow |\vec{n}|$

(n_x, n_y, n_z)

$(0,0,0)$ ↑↓

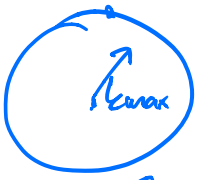
$(0,0,1)$ ↑↓ $\quad (0,1,0)$ ↑↓ $\quad (1,0,0)$ ↑↓

$(2,0,0) \quad (0,2,0), \ldots$

$\leftarrow (1,1,0), \ (1,0,1), \ (0,1,1)$ $\quad n_z$

$n \rightarrow 1 \qquad k \rightarrow \left(\frac{2\pi}{l}\right)^3 = \frac{(2\pi)^3}{V}$

$\frac{N}{2} \frac{(2\pi)^3}{V} = \frac{4\pi k_{max}^3}{3}$



$k_{max} = k_F$

Fermijev valovni vektor

$k_F = (3\pi^2 n)^{1/3} \qquad n = \frac{N}{V}$ (stevilčna) gostota elektronov

E_F: Fermijeva energija

$$E_F = \frac{\hbar^2}{2m_e}(3\pi^2 n)^{2/3}$$

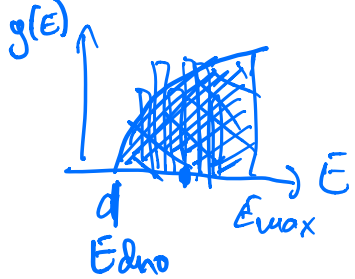
Fermijeva hitrost: $v_F = \frac{\hbar k_F}{m_e}$

Cu: $1\,cm^3 \quad n = 8{,}45 \cdot 10^{22}\,cm^{-3} \quad E_F = 7\,eV \quad v_F = 1{,}6 \cdot 10^6\,m/s = 0{,}005c$

degeneriran plin, Fermijev plin $\qquad T = 100\,000\,K$

kalij, natrij, rubidij

2) GOSTOTA STANJ



$$\frac{dN(E_{max})}{dE_{max}} = g(E_{max})$$

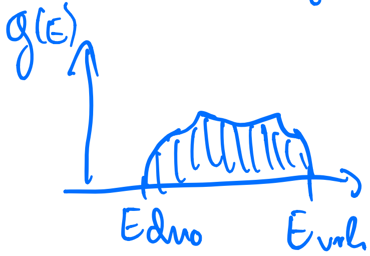
$$N(E_{max}) = \int_0^{E_{max}} g(E)\,dE$$

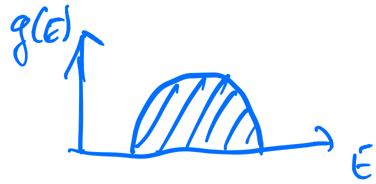
$$E = \frac{\hbar^2}{2m_e}\left(\frac{3\pi^2}{V}\right)^{2/3} N^{2/3}$$

$$N = E^{3/2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2}\frac{V}{3\pi^2} \qquad \frac{dN}{dE} = c\,E^{1/2}$$

$$g(E) = c\sqrt{E - E_{dno}}$$

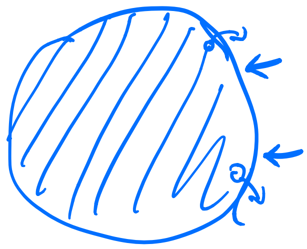
Velja splošno v 3D.





približek (za 3D)

3) FERMI-DIRACOVA PORAZDELITEV

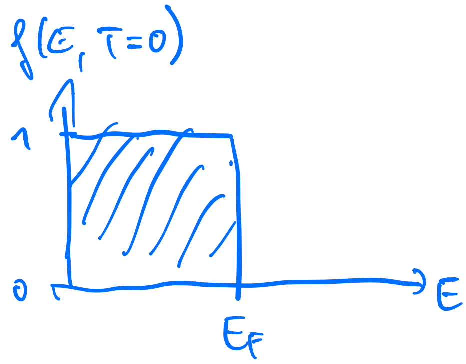


Fermijevo morje $E \le E_F$

Fermijeva površina $E = E_F$

Paulijeva prepoved: porazdelitvena funkcija $0 \le f(E) \le 1$

↳ kolikšno je neko stanje dejansko zasedeno



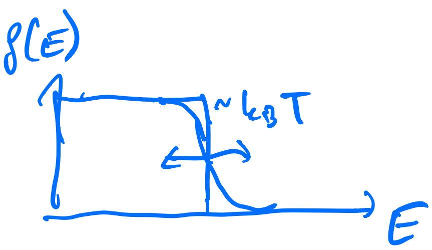
(1926)

$$f(E,T) = \frac{1}{1 + e^{(E-\mu)/k_B T}}$$

μ : kemijski potencial

$k_B = 1{,}38 \cdot 10^{-23}\ \mathrm{J/K}$ $\quad T\ [\mathrm{K}]$

$$\mu(T) = \begin{cases} E_F & T = 0 \\ E_F + \dots & T > 0 \end{cases}$$



$$N(T) = \int_{-\infty}^{\infty} g(E)\, f(E,T)\, dE$$

$$k_B T_{soba} \sim \frac{1}{40}\ \mathrm{eV} = 0{,}025\ \mathrm{eV} \qquad \frac{k_B T_{soba}}{E_F} \sim \frac{1}{100}$$

4. GIBANJE ELEKTRONA V ZUNANJEM POLJU

$E(k)$ disperzijska zveza $\quad \omega = \frac{1}{\hbar} E(k)$

$v_g = \frac{d\omega}{dk} \qquad v = \frac{1}{\hbar}\frac{dE(k)}{dk}$

$$a = \frac{dv}{dt} = \frac{dv}{dk}\frac{dk}{dt} = \frac{1}{\hbar}\frac{d^2E}{dk^2}\frac{dk}{dt}$$

$p = \hbar k \qquad \frac{dp}{dt} = F \qquad F = q(\vec{E} + \vec{v}\times\vec{B})$

$$\hbar\frac{dk}{dt} = F = \hbar^2 a \cdot \frac{1}{d^2E/dk^2} = m^* a \qquad m^* = \frac{\hbar^2}{d^2E/dk^2}$$

$$\boxed{F = m^* a}$$

1. Prosti elektron: $E(k) = \frac{\hbar^2 k^2}{2m_e} \qquad E' = \frac{\hbar^2 k}{m_e} \qquad E'' = \frac{\hbar^2}{m_e} \qquad \boxed{m^* = m_e}$

2. o–o–o–o Približek šibke vezi: $E = \varepsilon - 2t\cos(ka)$

$E' = 2ta\sin(ka)$

$E'' = 2ta^2\cos(ka)$

$$m^* = \frac{\hbar^2}{2ta^2}\frac{1}{\cos(ka)} \qquad \cos(ka) = 1 - \frac{k^2a^2}{2}$$

$$\approx \frac{\hbar^2}{2ta^2}\left(1 + \frac{k^2a^2}{2}\right) \qquad \frac{1}{1-x} \approx 1+x$$

m^* upošteva kristalno mrežo.

6. OHMOV ZAKON

$U = RI \rightarrow \quad j = \sigma E$

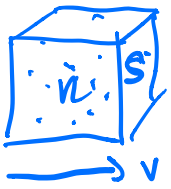
- gostota toka $j = \frac{I}{S}$
- električno polje $E = \frac{U}{l}$
- specifična prevodnost.

$\varsigma = \rho = 1/\sigma$

7. DIFUZIJSKO PREVAJANJE

Vpadnost $= \frac{qE}{m^*}\tau$ $\quad q$: naboj vsakega delca

$\boxed{j = nvq}$



$Q = It = (Sln)\cdot q$

$l = vt \qquad I = jS$

$j \cancel{S} t = Sln q = \cancel{S} v t n q$

$j = n\frac{q^2E}{m^*}\tau = \sigma E \Rightarrow \boxed{\sigma = n\frac{q^2\tau}{m^*}}$