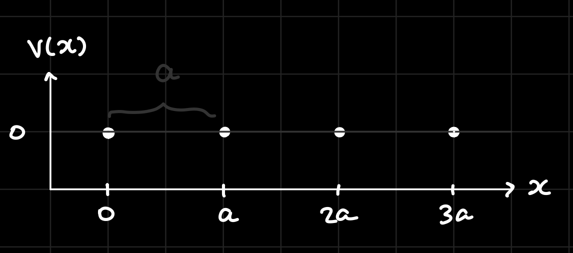
fermi energy = chemical potential
(E_F)

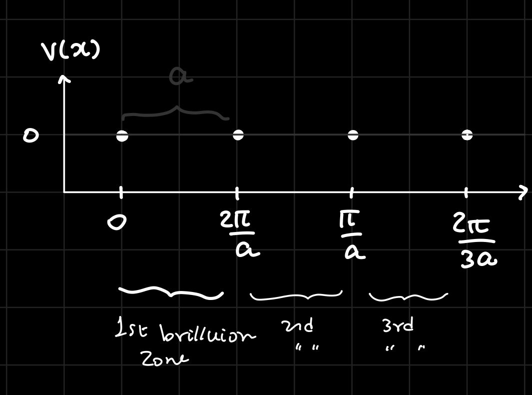
the probability that a particle has energy (E) $\Big\{ f(E) = \dfrac{1}{1+e^{\left(\frac{E-E_f}{k_bT}\right)}}$

PE of e⁻ in crystal

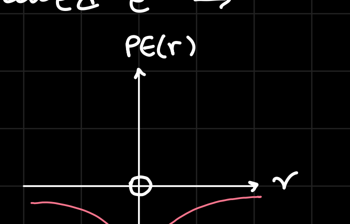


for 1d → $aa^* = 2\pi \Rightarrow a^* = \frac{2\pi}{a}$

in k space → we have brillouin zone



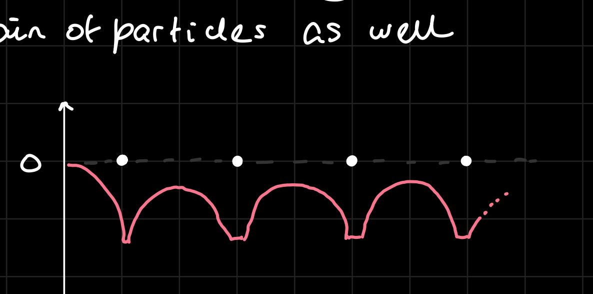
for one isolated e⁻ →



• exponentially varying

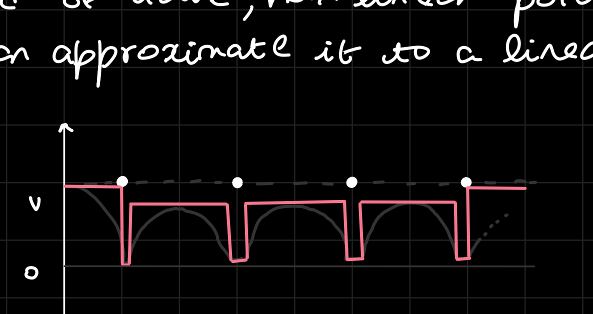
how about we add another e⁻?

and we can have a long chain of particles as well



PE inside the crystal is periodic with period 'a'

instead of above, non-linear potential, we can approximate it to a linear potential.



BLOCH THEOREM

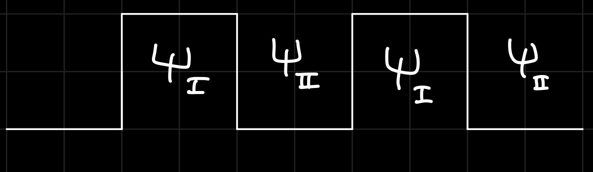
for a general crystal: $\boxed{\psi(x) = e^{ikx}u(x)}$

where u(x) = periodic just like potential function
and hence $u(x) = u(x+a)$ where a is the potential's periodicity

note: The amplitude is now a periodic function instead of a constant

alternatively → $\psi(x+a) = e^{ika}\psi(x)$
where, $k = \frac{2\pi}{a}$ (periodic)

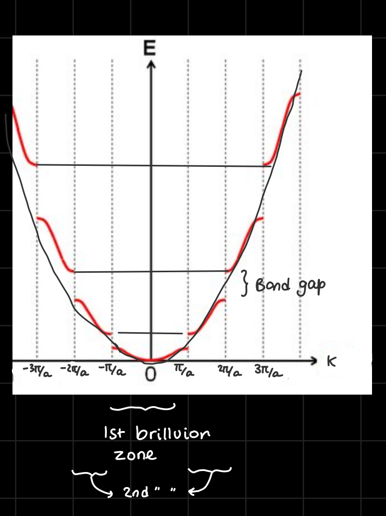
KRONIG-PENNEY MODEL



Solution: D.A. Neeman pg 63-70

E-K relation →

$ka = \pm n\pi$



initial assumption, continuous graph

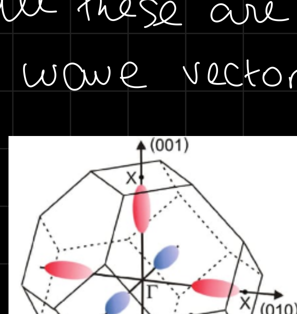
as soon as we bring periodicity, we observe the band gap

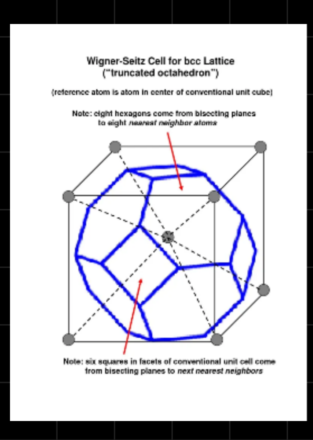
at some energies, band gap is so less that we cannot distinguish between valence band & conduction band.

wave vector ≡ momentum

In a wigner-seitz cell,
center point of the hexagonal face ≡ L
center point of the square face ≡ X
center point of the cell = γ (gamma)

all these are wave vectors





for Silicon
we observe the Emin of conduction band at K = X
i.e. the center of the square face of the wigner seitz cell.

we achieve highest Energy level in valence band at k = γ, center the wigner cell

and hence, band gap = E(X) − E(γ)

for Si,

for Ge,

→ also called energy band valleys

Energy band structure gives relation between E and K (momentum space)

Energy band diagram gives relation between E and x (real dimension)

for silicon, (lattice parameter) $a = 5.54 \text{Å}$ ≡ lattice const
for germanium, $a = 5.68 \text{Å}$

in case of germanium, we have a similar E-K relation with the exception that the Emin for the conduction band is at x = L (center pt of hexagonal face)

for silicon, we have 6 valleys (minima condition) for conduction band E_{min}.
CBmin at every center point of a square face of the wigner cell

and 8 valleys for germanium

Since we have larger # of valleys, e⁻ will flow "more" in case of Ge and hence more current

Si and Ge are indirect band gap semiconductor
↳ CBmin and VBmax are not at the same momentum point

for Si, particle moves in momentum axis and then changes energy to move from $CB_{min} \to VB_{max}$

LEDs use direct band gap semiconductor
↳ not loosing energy when transitioning from VB → CB. eg} GaAs

DBGS very useful in optical electronic devices.

GaAs

k: const

Si