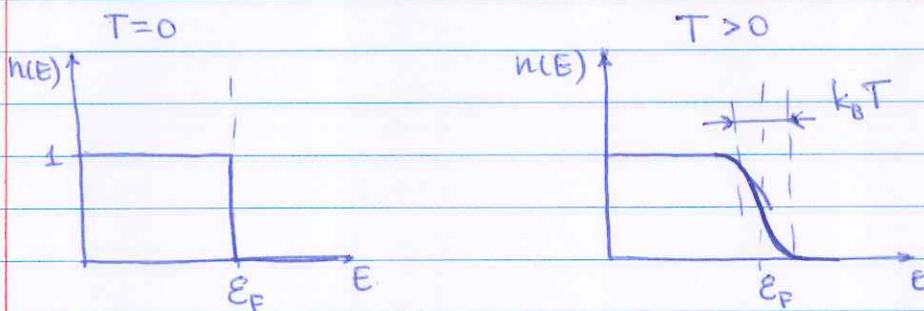


Quantum description of conductivity (cont)

Classical Drude model - electrons are treated as an ideal gas

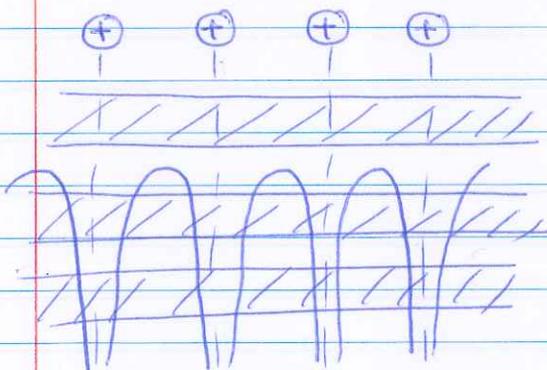
↓
+ ~~classical~~ Pauli exclusion principle

↓
Fermi energy ; Fermi-Dirac electron distribution



At $T=0$ electrons occupy all low-energy notional states \rightarrow if any of electrons needs to change direction, it will have to acquire enough energy to occupy an empty state above Fermi energy, since all states below E_F are occupied already.

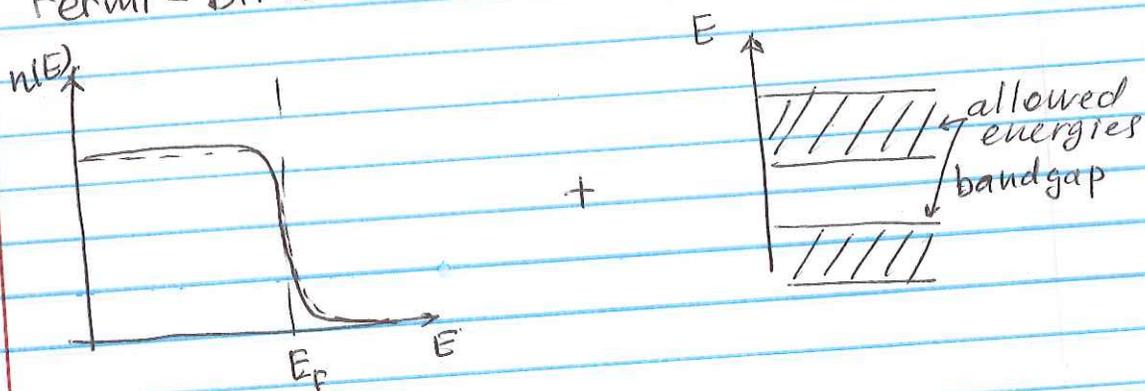
+ Band structure - electrons are not really free



electrons are waves, delocalized, with energy band structure
 \rightarrow ranges of kinetic energy are allowed (bands)
 \rightarrow some ranges are forbidden (band gaps)

periodic potential

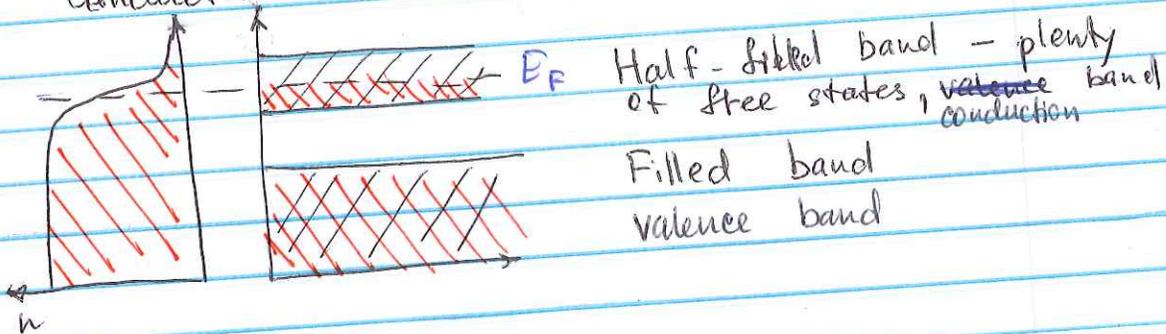
Fermi-Dirac distribution + band structure



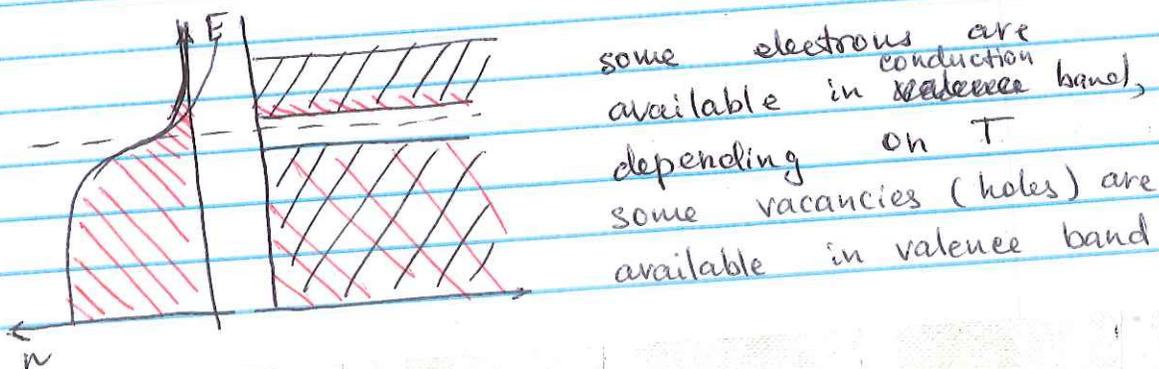
Insulators



Conductors



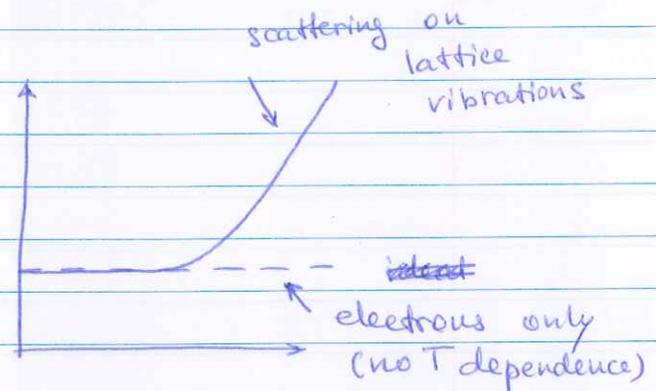
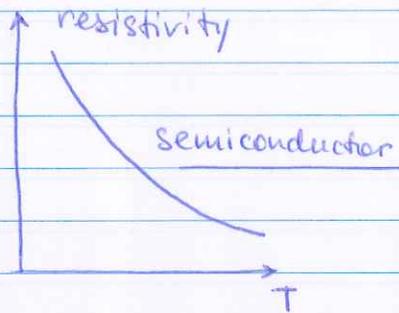
Semiconductors



The actual band level structure depends on the crystal structure.

<VO₂ slides>

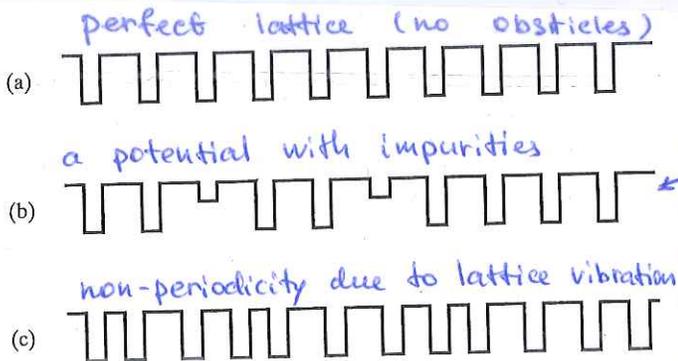
Temperature dependence



Ideally periodic potential - electrons scatter only on defects

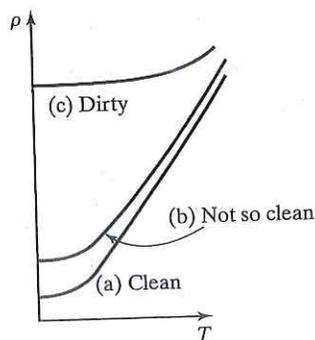
(quantum interference → 100% constructive)

Higher temperature - the lattice can vibrate, breaking the perfect interference, increasing resistance

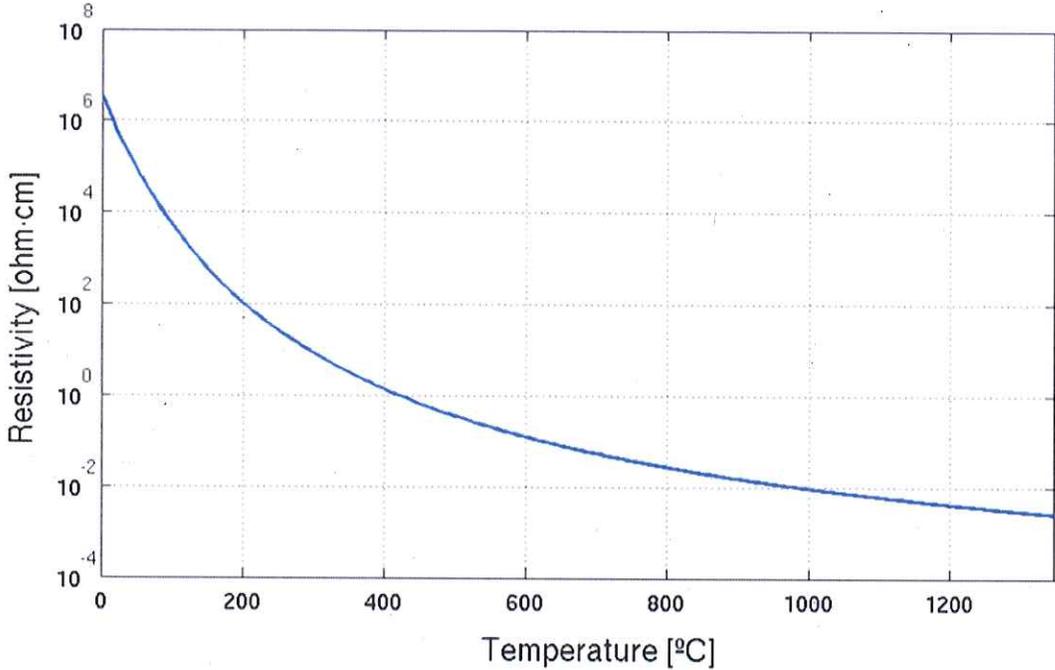


Resistance does not depend on temperature

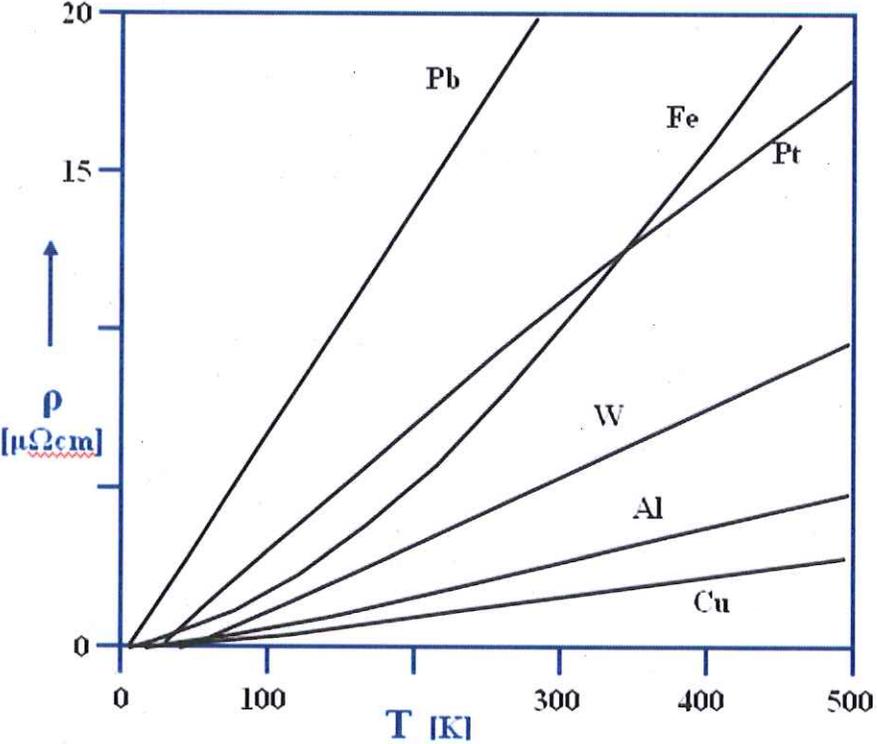
Higher T → more vibrations → higher resistance



Silicon resistivity as a function of temperature

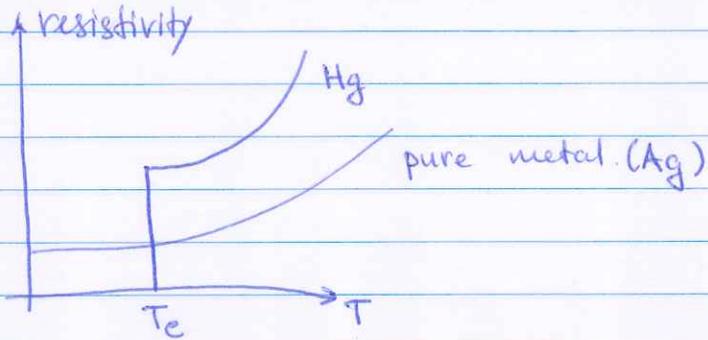


Temperature dependence of resistivity for various metals



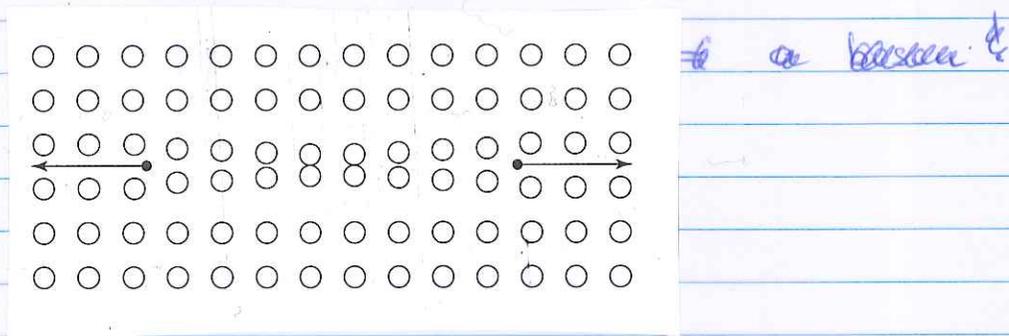
Super conductivity

Some metals lose electrical resistance completely below certain critical temperature



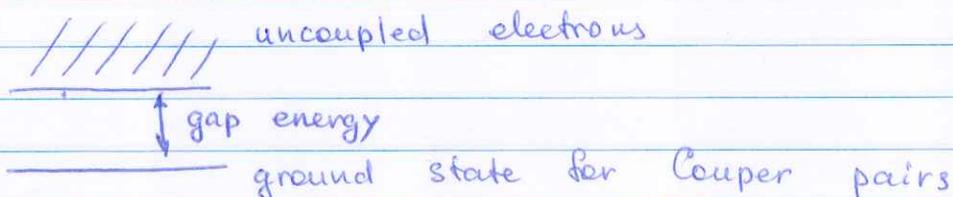
The BCS Theory of Superconductivity

Via interaction with lattice the electrons can form Cooper pairs



fermion + fermion = boson!

No Pauli exclusion principle for bosons, so all pairs can be brought to the same ground state



To break a Cooper pair by a collision, enough energy must be transferred to "bridge" the gap. So ~~it~~ at really low temperatures collisions will not provide sufficient energy to do that. So collisions become impossible \rightarrow electrons move without resistance!