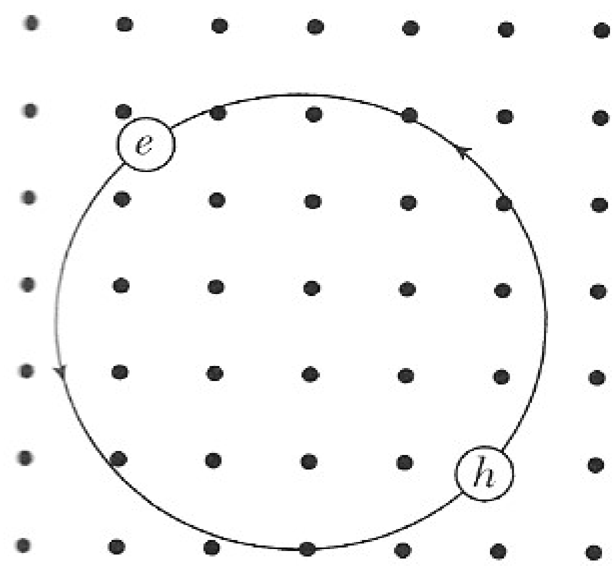
# Excitons, Polarons

# Excitons

Bound state of an electron and a hole in a semiconductor or insulator

**Mott Wannier excitons**

(like positronium)




Hydrogenic model

$$E_{n,K} = E_g - \frac{\mu^* e^4}{32\pi^2\hbar^2\varepsilon^2\varepsilon_0^2 n^2} + \frac{\hbar^2 K^2}{2\left(m_h^* + m_e^*\right)}$$

# Mott-Wannier Excitons

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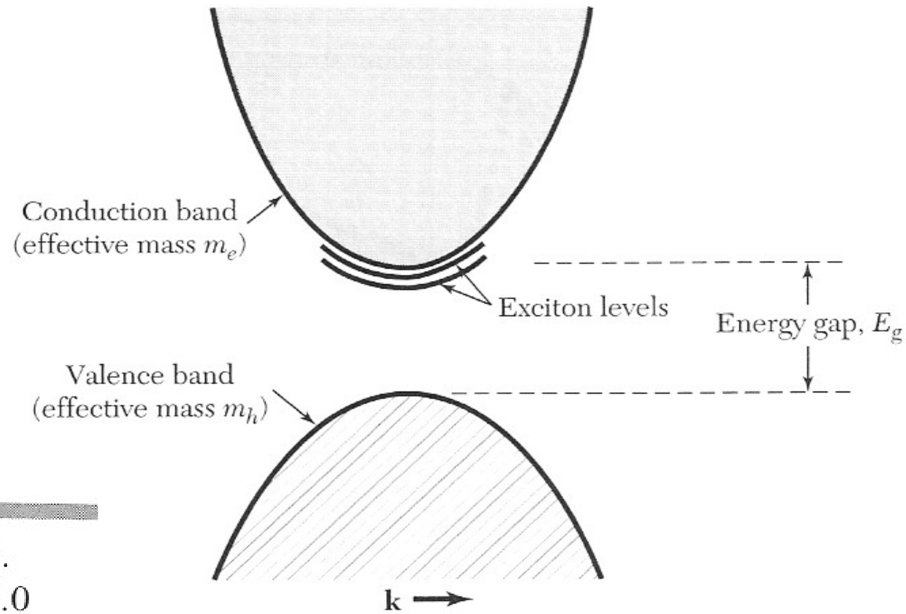
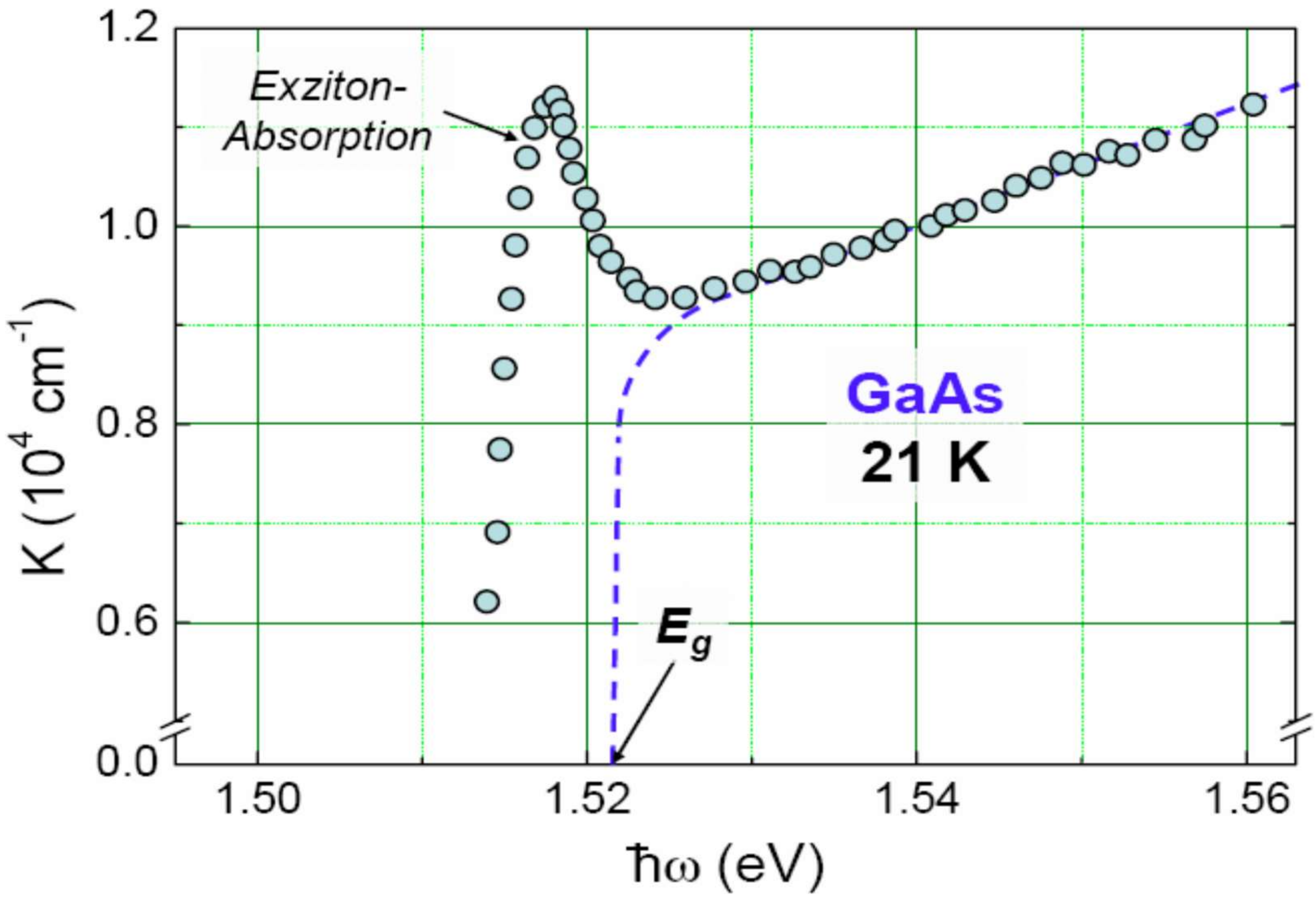
**Table 1 Binding energy of excitons, in meV**

| | | | |
|---|---|---|---|
| Si | 14.7 | BaO | 56. |
| Ge | 4.15 | InP | 4.0 |
| GaAs | 4.2 | InSb | (0.4) |
| GaP | 3.5 | KI | 480. |
| CdS | 29. | KCl | 400. |
| CdSe | 15. | KBr | 400. |




Kittel

# Excitons



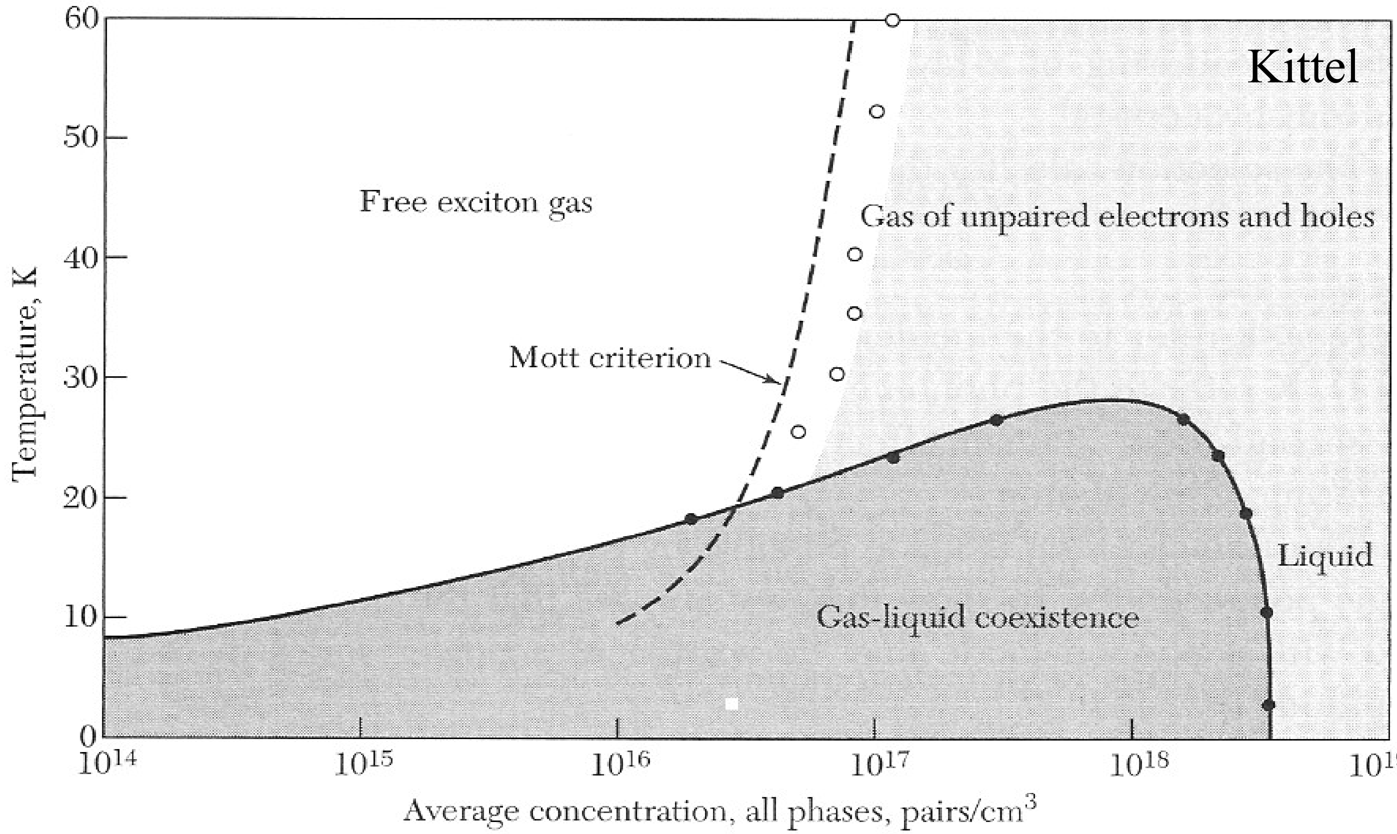

Gross & Marx

# Excitons

Biexcitons $H_2$?

Metallic plasma droplets

Observe with an infrared camera




Phase diagram for photoexcited electrons and holes in unstressed silicon.

See: C. D. Jeffries, Electron-Hole Condensation in Semiconductors, Science 189 p. 955 (1975).

# Frenkel Excitons

A Frenkel exciton is localized on an atom or molecule in a crystal.

The band gap of solid krypton is 11.7 eV. Lowest atomic transition in the solid is 10.17 eV.

Excitons transport energy but not charge. Frenkel excitons are occur in organic solar cells, organic light emitting diodes, and photosynthesis.

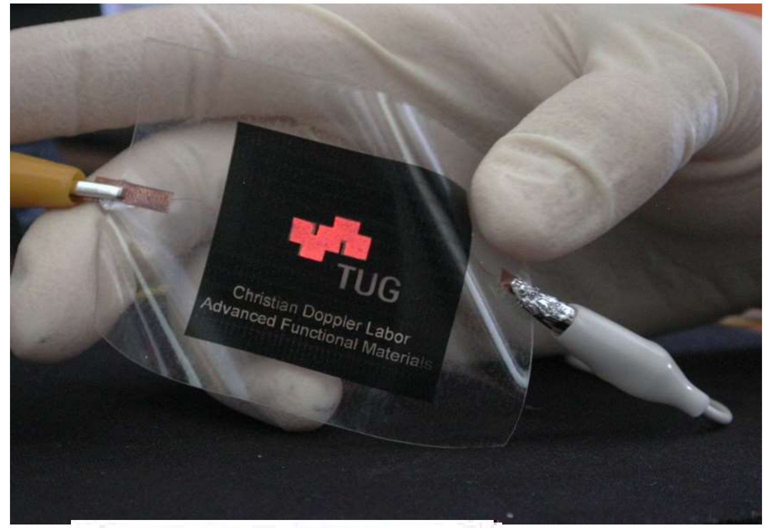
# Organic Light Emitting Diodes (OLEDs)

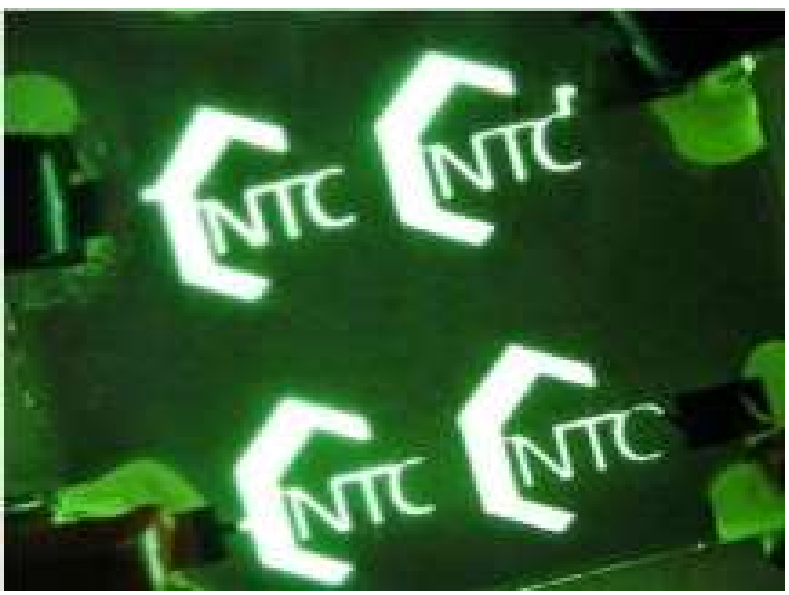
| |
|---|
| Aluminum cathode |
| Electron transport layer |
| Emission layer |
| Hole transport layer |
| ITO anode |
| Glass |

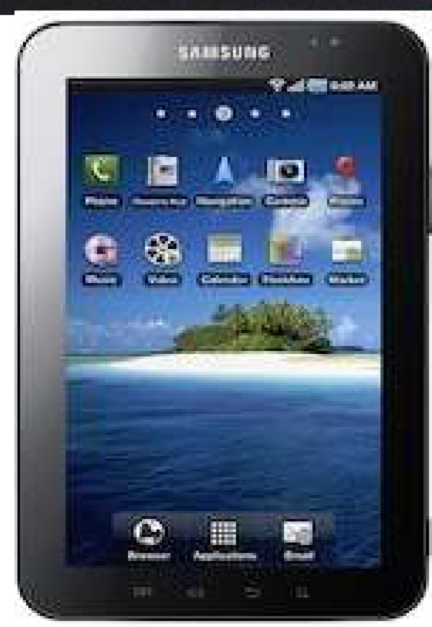
Cathode is typically a low work function material Al, Ca - injects electrons

Anode is typically a high work function material ITO - injects holes

# OLEDs

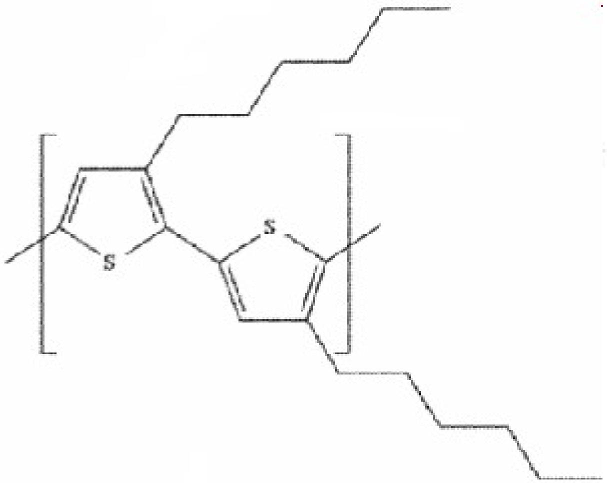



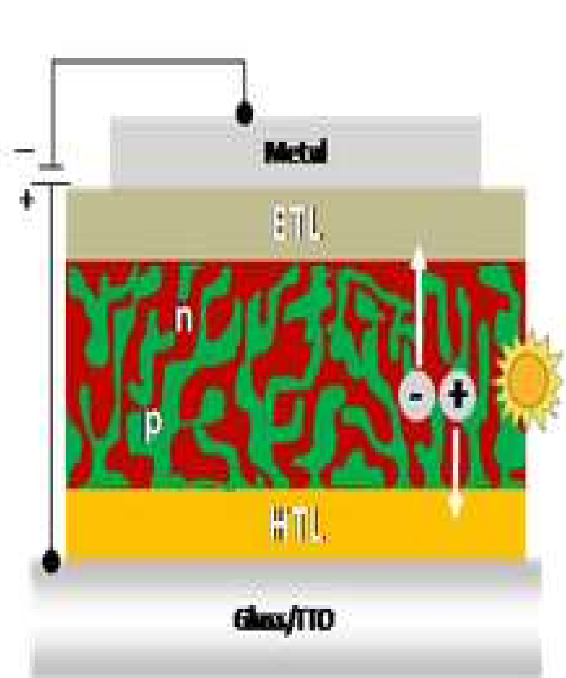



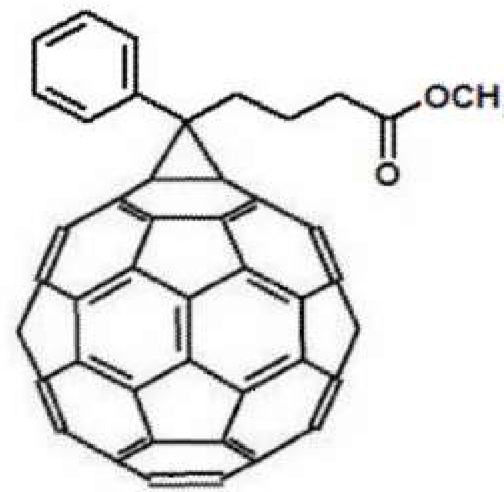

Galaxy Tab

# Organic solar cells




P3HT donor



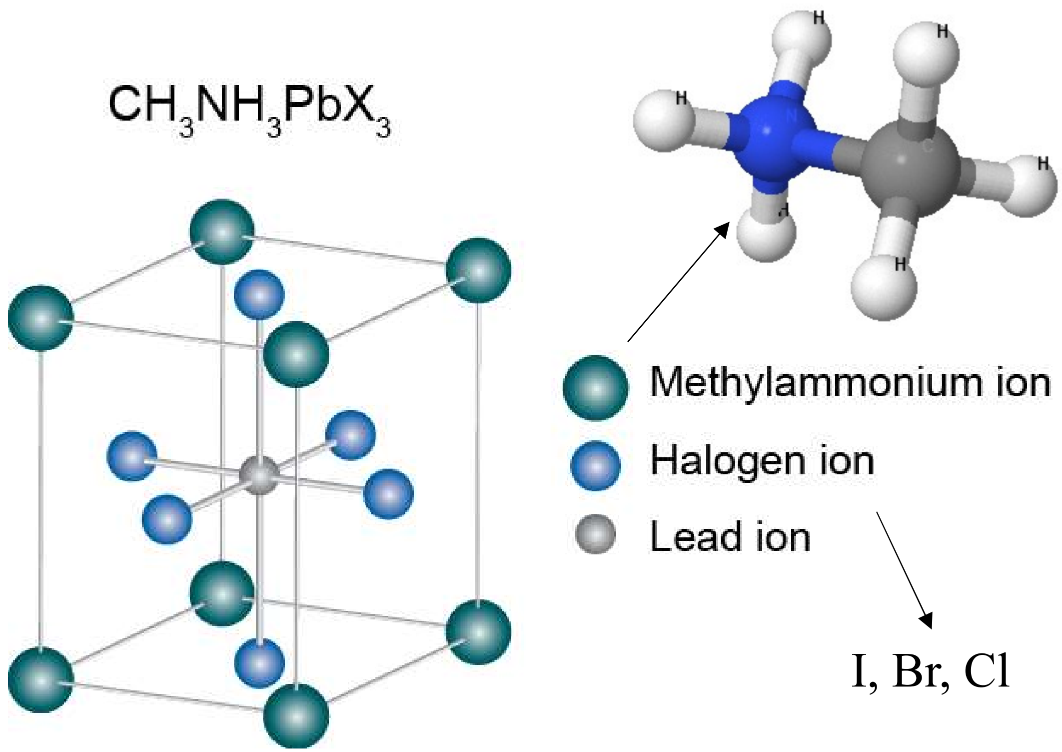

PCBM acceptor

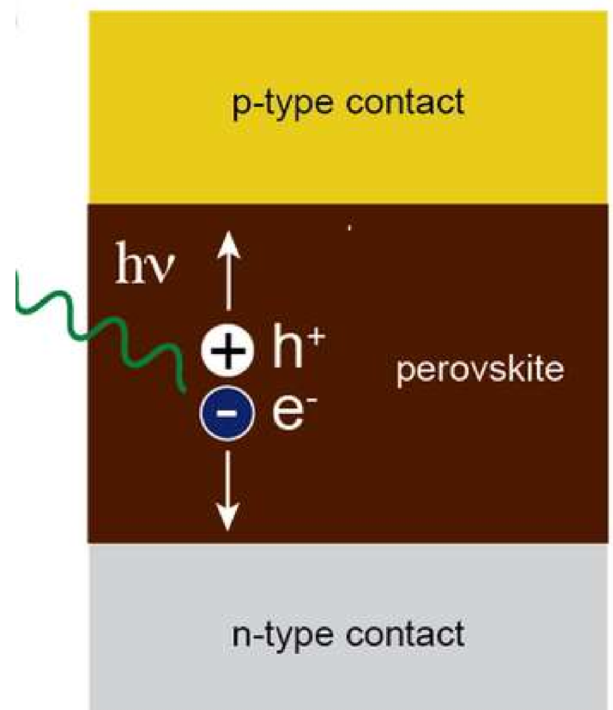
Excitons in polymers: a monomer is in an excited states and this moves down the chain.

https://www.uni-ulm.de/nawi/nawi-oc2/forschung/ag-organische-halbleiter-und-farbstoffe-fuer-die-photovoltaik.html?print=1

# Perovskite solar cells

$CH_3NH_3PbX_3$



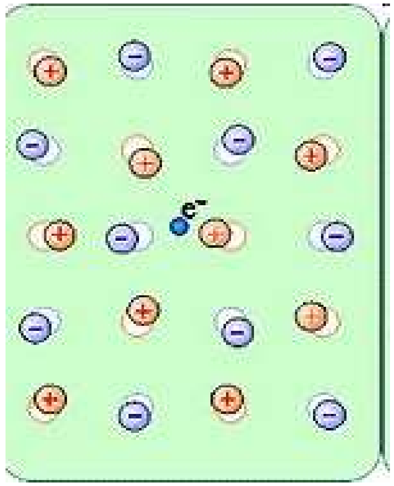




Efficiency ~ 22%

https://en.wikipedia.org/wiki/Perovskite_solar_cell

# Polarons

A polaron is a quasiparticle consisting of an electron and an ionic polarization field. The electron density is low so the screening by electrons can be neglected.

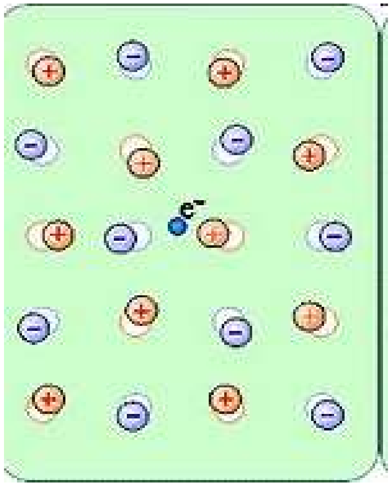



Electronic charge is partially screened by lattice ions. This is a charge - phonon coupling.

# Large polaron (Fröhlich polaron)

The spatial extent of the polaron is much larger than the lattice constant.

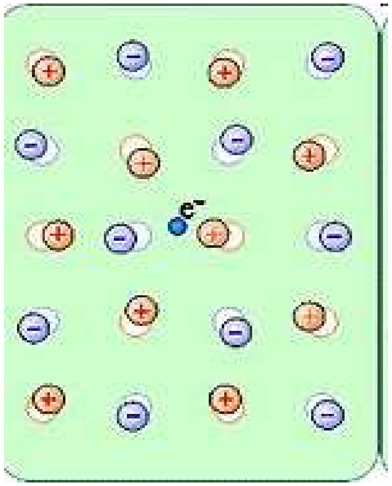
Large polarons typically form bands.




Electrons move in bands with a large effective mass (432 $m_e$ for NaCl)

# Small polaron (Holstein polaron)

For a small polaron, the polarization is about the size of the lattice contant.




Small polaron - Holstein Hamiltonian - electrons are localized and hop (thermally activated or tunneling). Small polarons often form in organic material. In soft materials the energy for making a distortion is smaller.

# Bipolarons

Two polarons can bind together to form a bipolaron (a quasiparticle).

Elastic strain is reduced by sharing the polarization field.

Bipolarons have integral spin $\rightarrow$ they are bosons.

It is possible that the condensation of bipolarons could lead to superconductivity