SOLID STATE PHYSICS WORKSHOP

(Short) summary of three lectures on

POLARONS

by

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(Short) Summary of three lectures on

POLARONS. (I.C.T.P. Trieste July 1971)

J. Devreese, Univ. Antwerp.

① Optical properties of polarons (WEAK V STRONG COUPLING).

1. Weak coupling [REF 1] [REF 2]

The optical absorption is calculated following [ref 2].

We start from the golden rule for the transition probability for a polaron to go from the groundstate to a scattering state:

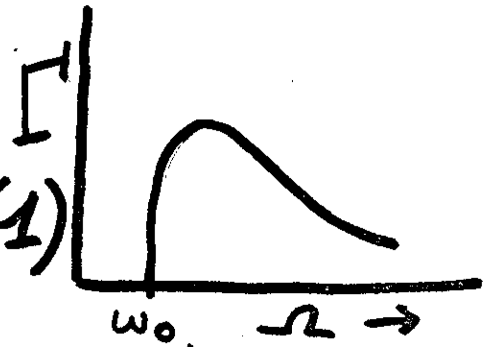
a phonon is emitted
no lattice relaxation

By eliminating intermediate states one obtains the KUBO-FORMULA but for T=0 and one polaron.

Subsequently the Lee Low Pines formalism is used. This formalism is based on two canonical transformations. The first introduces the electron as "reference point." (One moves with the electron) The second takes the lattice deformation into account at weak coupling.

We obtain:

$$\Gamma = \frac{1}{c\epsilon_0 n}\,\frac{2}{3}\,\alpha\,\frac{\sqrt{\Omega-\omega_0}}{\Omega^3} \quad (1)$$



Γ = optical absorption coëfficient
Ω = frequency of the incident light.
ω_0 = long wavelength optical phonon frequency.
α = coupling constant

The derivation given in REF 2 is simple but the result (1) is a special case of results obtained in [ref 1] with highly involved techniques.

It is possible to improve eq (1) so that it is reliable for $\alpha \approx 1$
We obtain:

$$\Gamma = \frac{1}{c\epsilon_0 n}\,\frac{2}{3}\left(\frac{m^*}{m}\right)^{3/2}\alpha\,\frac{\sqrt{\Omega-\omega_0}}{\Omega^3}\, e^{-\gamma_\alpha \frac{m^*}{m}|\Omega-\omega_0|} \quad (2)$$

γ_α is a slowly varying function of α $(0.1 < \gamma < 1)$.

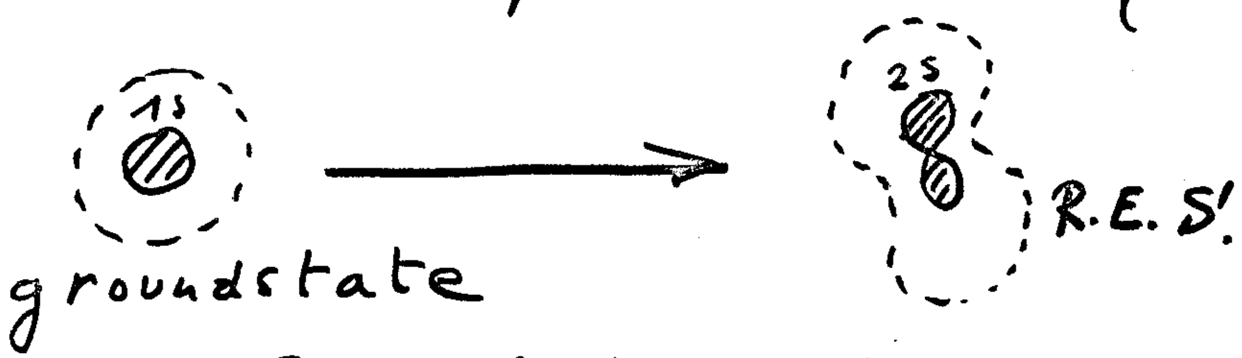
(2) is a limiting case obtained from expressions discussed below

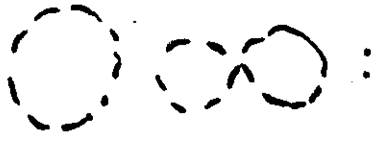
2. Strong coupling. [ref 3][ref 4]

[ref 3] is the main paper; [ref 4] contains mathematical refinements.

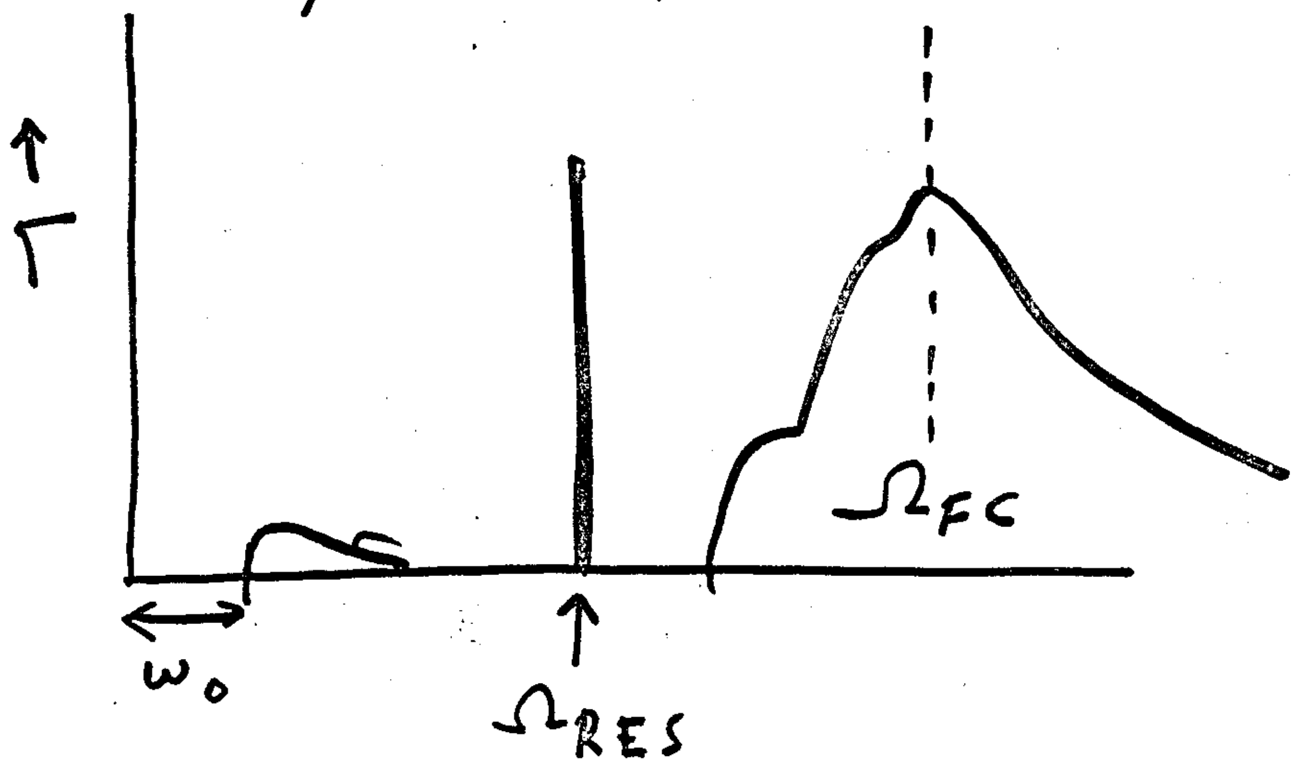
It is argued that <u>internal excitations</u> of polarons play a role at large α. LATTICE RELAXATION can occur for excited states and then one speaks of RELAXED EXCITED STATES: R.E.S.

Pictural representation: (large α)





With golden rule transition probability
from groundstate to R.E.S.
R.E.S. + n phonons
should be calculated.
The lifetime of the R.E.S. is
calculated using Wigner-Weiskopf
theory.
This leads for $\alpha > 6$ to intense
peak for ZERO-PHONON TRANSITION
and complex SIDEBAND STRUCTURE
with maximum at the "FRANCK-CONDON" frequency (<u>no</u> lattice
readaptation)



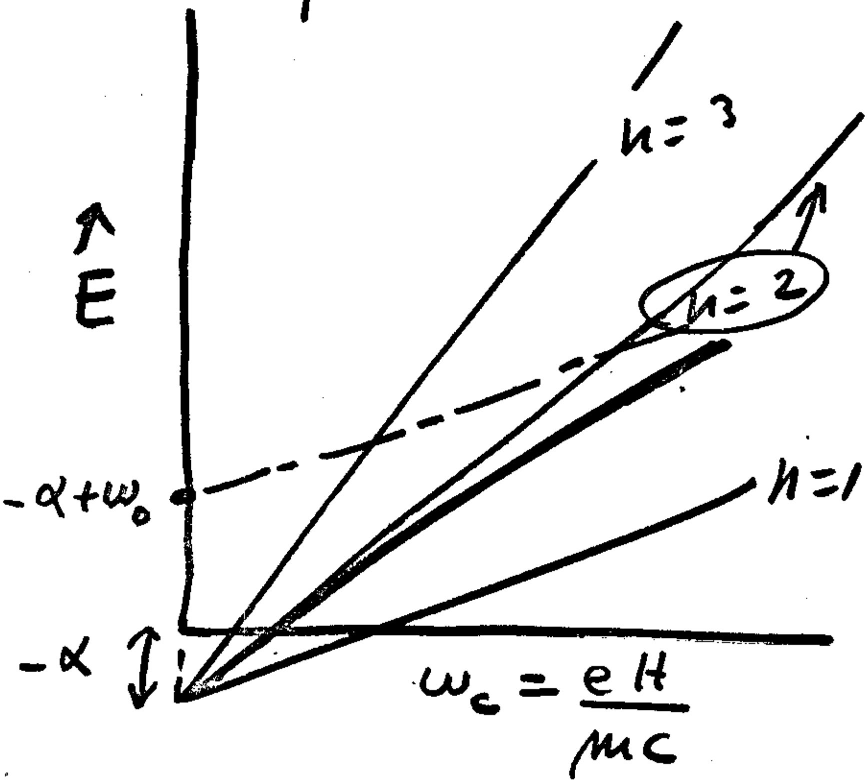
Experiment: Until now only weak
coupling behaviour (eq 1)
seems to have been
observed [REF 5]

② POLARONS in MAGNETIC FIELDS [REF 6, 7]

ELECTRON-PHONON interaction modifies the Landau levels and <u>adds</u> extra levels.

1) Weak coupling (REF 6)

The spectrum becomes:



→ The n=2 level is "pinned" by the scattering state at <u>$-\alpha+\omega_0$</u>.

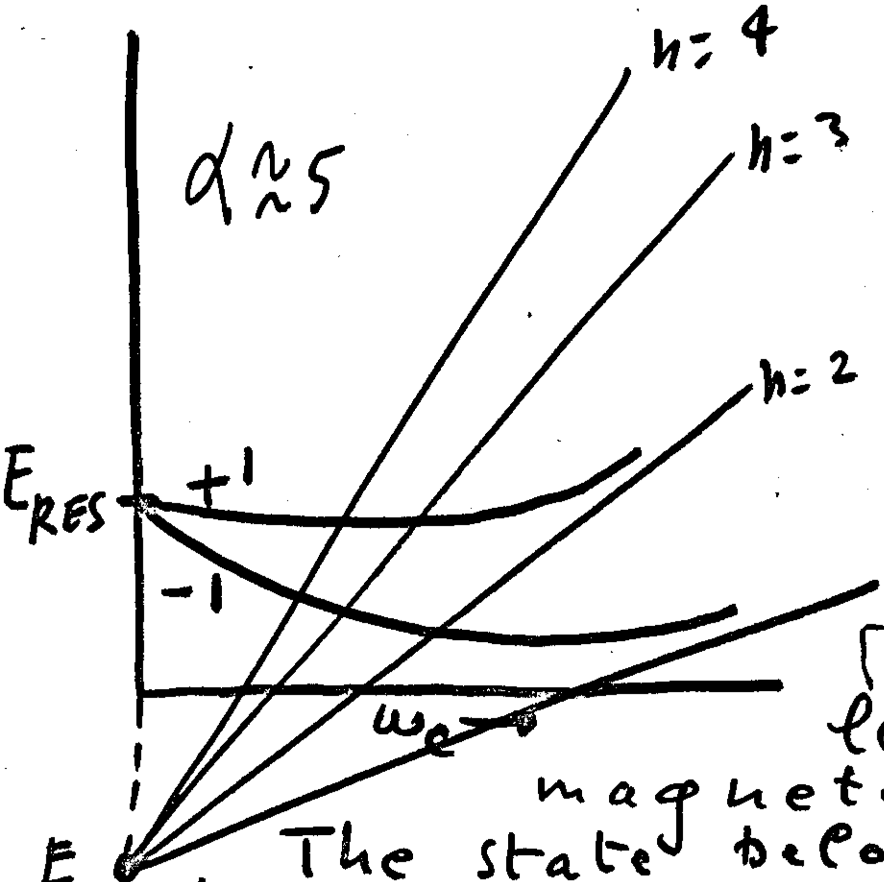
→ The slope of the LANDAU LEVELS is determined by the <u>polaron mass</u>, instead of the bare mass. Brown's [7] measurements are based on this fact. LARSEN, LAX et al. [8] have studied the <u>pinning</u>.

Also R.E.S. modify the LANDAU LEVEL SCHEME.

LEE LOW PINES

In L.L.P. approximation for z-direction || and Product-Ansatz for wave functions ($\Psi = |\text{field}> \varphi_{electr.}$)

we obtain:



There is a Zeeman splitting of RES.

The state belonging to $l_z = +1$ (l_z = angular momentum of the electron) tends to the n=2 Landau level for large magnetic field.

The state belonging to $l_z = -1$ tends to the n=1 Landau level for $H \to \infty$.

Recent calculations have shown that the $l_z = +1$ state gets <u>stabilized</u> if the field increases.

Therefore: HIGH MAGNETIC FIELDS ARE A TOOL TO OBSERVE R.E.S. (PRESUMABLY ONLY IF $\alpha \gtrsim 3$)
EXPER. EVIDENCE: KOBAYASHI (REF 9) observed stabilization of

(3) INTERMEDIATE COUPLING; PATH INTEGRALS.

A short survey of path integral techniques is given. [see 9]

Advantages:
- No operators involved.
- One can rely on classical intuition
- phonons can be exactly eliminated (transformation of many body problem to one-particle problem)
- path integrals might even be calculated by computer.

Disadvantages:
- Until now spin could not be treated.
- Involved mathem.

One can treat exactly with path-integrals:

a) Harmonic oscillator (1948)

b) how progress: Coulomb potential of ref 10, 11, 12.

The only existing intermediate [13]
coupling theory is due to Feynman,
F.H.I.P. [14], Feynman Thornber [15].

It is based on a <u>quadratic</u> approximation.
after the elimination of the phonons one concentrates on the motion of one <u>particle</u>.

One supposes that the electron moves in a quadratic potential.

FHIP calculated:

$$\frac{1}{Z(\Omega)} = \Omega\, G(\Omega)$$

$Z(\Omega)$ = impedance function

harmonic approximation:

$$\frac{1}{Z(\Omega)} = \Omega\, G_0(\Omega)$$

then they go one order further:

$$\frac{1}{Z(\Omega)} = \Omega\,(G_0 + G_1)$$

G_1 is a ~~linear~~ function of $S - S_0$:
the difference between exact and trial <u>action</u>.

FHIP then consider:

$$Z(\Omega) = \frac{1}{\Omega\, G(\Omega)} \approx \frac{1}{\Omega(G_0 + G_1)} \qquad (3)$$

and the "development"

$$Z(\Omega) = \frac{1}{\Omega}\left(\frac{1}{G_0} - \frac{G_1}{G_0^2}\right) \qquad (4)$$

They have no real justification for (4).

From (4) they obtain $\lim_{\Omega \to 0} Z(\Omega) = \frac{1}{\mu}$ (μ = the mobility) and they also plot $\mathrm{Re}\, Z(\Omega)$. $\mathrm{Re}\, Z(\Omega)$ shows structure at FRANCK-CONDON STATES.

It seems, that no lattice relaxation is taken into account.

We calculated [16]

$$\Gamma \sim \mathrm{Re}\, \frac{1}{Z(\Omega)} = \mathrm{Re}\, \frac{\Omega}{\frac{1}{G_0} - \frac{G_1}{G_0^2}} \qquad (5)$$

This leads to cumbersome analytical d numerical work.

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