Fermi Edge singularity (FES) of spin polarized electrons

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Abstract - We study the absorption spectrum of a two-dimensional electron gas (2DEG) in a magnetic field. We find that at low temperatures, when the 2DEG is spin polarized, the absorption spectra, which correspond to the creation of spin up or spin down electrons, differ in magnitude, linewidth, and filling factor dependence. We show that these differences can be explained as resulting from the creation of a Mahan exaction in one case, and of a power law Fermi-edge singularity in the other.

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- Motivation

- Absorption spectrum of a high mobility 2DEG in a magnetic field

- Would 2DEG spin polarization affect FES?

- Opposite spin of photo-excited electron strongly suppresses electron-electron scattering

- In spin polarized 2DEG, the absorption spectra which correspond to the creation of a $|\downarrow>\text{ or } |\uparrow>$ electron differ in magnitude, linewidth and filling factor dependence.
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Motivation

- Coulomb interactions in the optical absorption spectrum of a Fermi sea of electrons
- The response of the electron gas to the sudden creation of the hole attractive potential is manifested in a singularity at the photon energy for which an electron is excited to the Fermi level
- At the threshold energy, absorption is singular

\[ \hbar \omega = E_G + \frac{p_F^2}{2\mu}, \]

- \(E_G\) is the gap energy,
- \(p_F\) is the electron Fermi momentum, and
- \(\mu\) is the electron-hole reduced mass

- absorption intensity decays as \((\omega-\omega_0)^{-\alpha}\),

- \(\alpha\) describes the interaction between the electrons and the deep hole created in the absorption process
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Sample:-

- 20 nm wide QW grown in the middle of the cavity, at a distance of $3\lambda/4$ from the Bragg mirror and the surface, embedded in Al$_{0.38}$Ga$_{0.62}$As barriers

- a Bragg reflector
  - made of 20 pairs of $\lambda/4$ layers of AlAs and Al$_{0.3}$Ga$_{0.7}$As ($\lambda = 800$ nm),

- Bragg reflector and the sample surface form a microcavity in which all wavelengths are back reflected ($R \sim 1$)

- $n^+$ layer serves as a back gate, $n_e$ tuned in $(0.4-3) \times 10^{11}$ cm$^{-2}$

- measured electron mobility $\sim 1 \times 10^6$ cm$^2$ V$^{-1}$ s$^{-1}$

- A tungsten halogen lamp illuminates the sample in a spectral range of 20 nm, centered around the heavy hole
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- Measuring technique:
  - absorption spectrum of a single quantum well
  - very weak white light in a reflection geometry
  - QW located in cavity at an anti-node of a standing wave formed by the optical field
  - circular polarizer analyzes the reflected light
  - experiment performed in two systems:
    - (i) A dilution refrigerator with optical windows (base temperature 40 mK)
    - (ii) A He4 cryostat (1.8 – 4.2K) with a fiber based system for illumination and collection
  - magnetic field applied parallel to the growth direction
    - at positive fields, transitions from the hh band to the lower electron Zeeman spin subband (LZ), σ+
    - at negative field - to the upper electron Zeeman spin subband (UZ) σ−
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Observations

• The calculated reflectivity spectra, assuming typical excitonic parameters of a GaAs QW

• Exciton lineshape is very sensitive to the location of the QW within the cavity

• Inset: reflectivity measurement of an optimized sample at $B = 9$ T

• Reflectivity at the lowest LL energy is $\sim 0.3$
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Observations

- a) absorption spectrum at $B = 0$, $n_e = 1 \times 10^{11}$ cm$^{-2}$.
- At magnetic field, broad FES line splits into discrete LLs.
- b) absorption spectra at $B = 2$ T, $4 \times 10^{10} < n_e < 2.4 \times 10^{11}$ cm$^{-2}$, filling factor range $1 < \nu < 5$. 
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Observations

- c) absorption spectra at $n_e = 1.13 \times 10^{11} \text{ cm}^{-2}$ for both signs of the magnetic field
- d) dashed black line - single particle joint density of states,
  solid black line - FES function
  red line - resulting absorption, $E_F$ is at the center of the 1LL
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Role of the electron spin polarization in the FES

(a) Integrated absorption at the 1LL as a function of filling factor, at constant B

$\nu = 4$ and drop at $\nu < 2$

 dependence of the area under the central peak on $n_e$

spin depolarized 2DEG, ~identical absorption to both Zeeman levels

(b) sum of the two absorption curves is nearly constant
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Role of the electron spin polarization in the FES

Filling factor dependence of the UZ and LZ linewidth (full width at half maximum) at 4.2 K and 70 mK
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- Conclusions
  - At 4.2 K the width of the two lines is identical
    - Identical oscillator strength of two zeeman levels
    - at 70 mK, width of the $\sigma^-$ line drops to 0.3 meV
  - narrowing of the $\sigma^-$ peak occurs only at low temperatures
    - Due to difference in occupation of two levels
Thank you for attention