Last time

- Raman effect (Fox 10.5)
- Metals (Fox 7)
- Semiconductors (Fox 3)

Today

- Remainder semiconductors (Fox 3)

Semiconductors in a magnetic field

- At high enough fields: quantization of orbits and energy

$$E_n = \left(n + \frac{1}{2}\right)\hbar\omega_c$$

- For $B=B_z$: $$E_n^v(k_z) = -\left(n + \frac{1}{2}\right)\hbar\frac{eB}{m_h^*} - \frac{\hbar^2 k_z^{v\,2}}{2m_h^*}$$

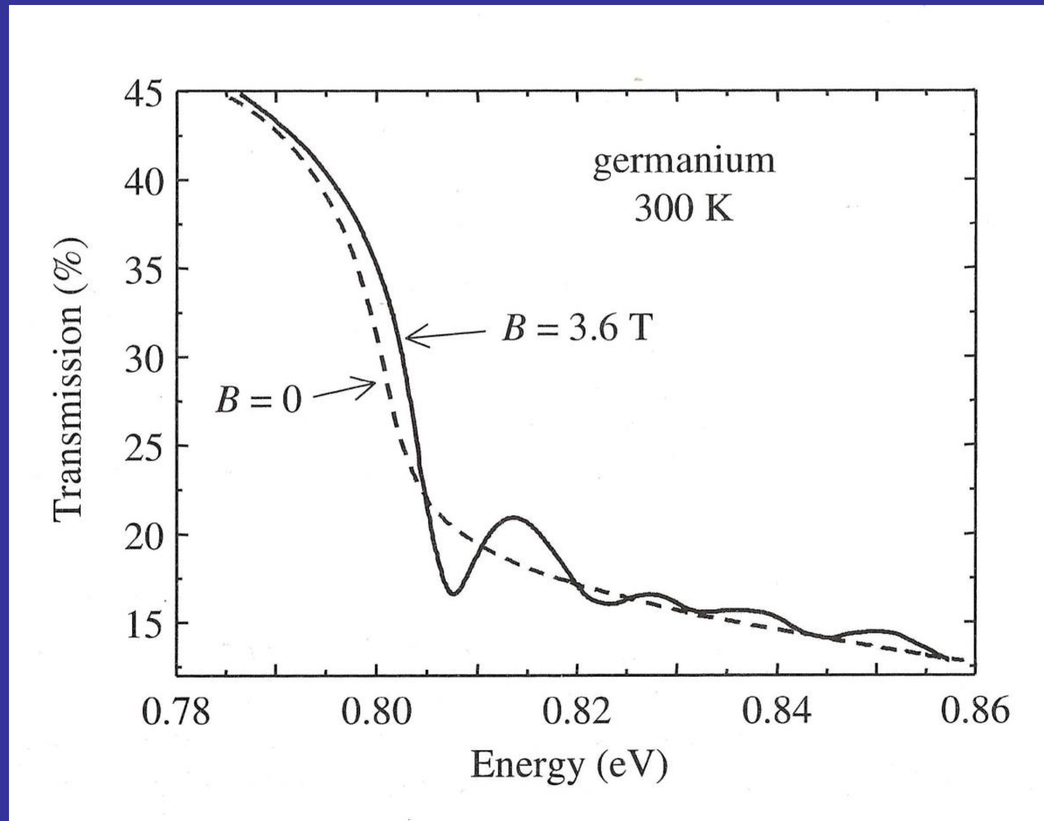
$$E_n^c(k_z) = E_g + \left(n + \frac{1}{2}\right)\hbar\frac{eB}{m_e^*} + \frac{\hbar^2 k_z^{c\,2}}{2m_e^*}$$

$$\hbar\omega = E_g + \left(n + \frac{1}{2}\right)\hbar\frac{eB}{\mu} + \frac{\hbar^2 k_z^2}{2\mu}$$

- Strong absorption for $k_z=0$
  ➔ equidistant peaks in absorption spectrum $\hbar\omega = E_g + \left(n + \frac{1}{2}\right)\hbar\frac{eB}{\mu}$

- Absorption edge shift in magnetic field $\Delta = \hbar\frac{eB}{2\mu}$

Ge in a magnetic field



PHYSICAL REVIEW VOLUME 108, NUMBER 6 DECEMBER 15, 1957

Oscillatory Magneto-Absorption in Semiconductors*

SOLOMON ZWERDLING, BENJAMIN LAX, AND LAURA M. ROTH
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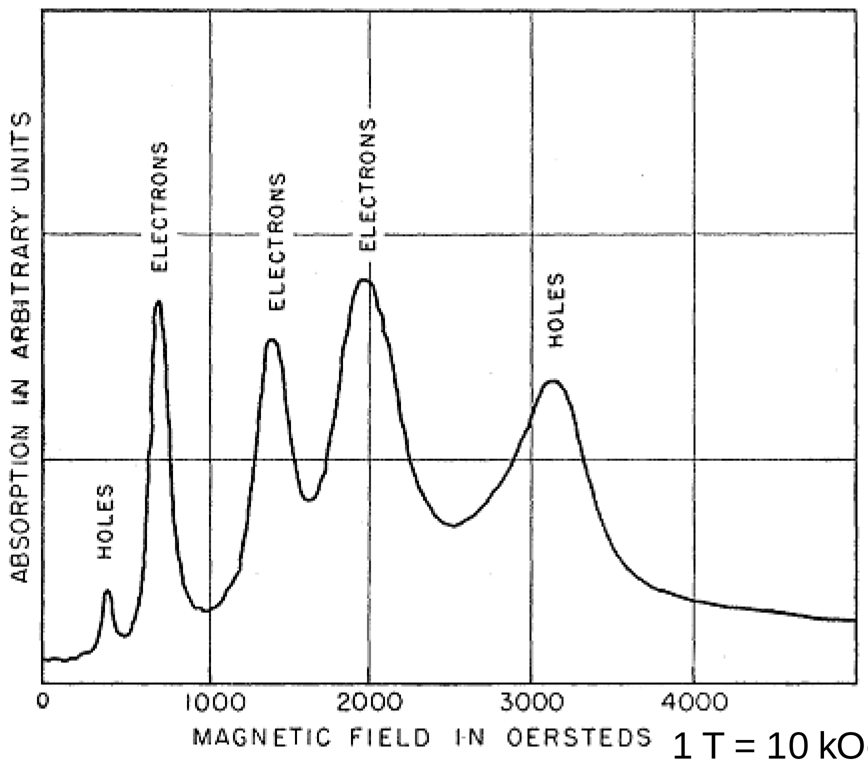
(Received August 30, 1957)

Cyclotron resonance



1 T = 10 kOe

FIG. 2. Typical cyclotron resonance results in germanium near 24 000 Mc/sec and 4°K: direct copy from a recorder trace of power absorption *vs* static magnetic field in an orientation in a (110) plane at 60° from a [100] axis.

- Transitions with $\Delta n = 1$
- 24000 Mc/sec ~ 1 meV
- Energy fixed, scan B

$$\omega_c = \frac{eB}{m^*} \Rightarrow \text{ determine effective mass}$$

Cyclotron Resonance of Electrons and Holes in Silicon and Germanium Crystals

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(Received December 16, 1954)

Wannier-Mott Excitons

- Conduction band: electrons with mass m_e^*
- Valence band: holes with mass m_h^*
- Hydrogen problem with very light 'proton' in a screened environment

  - Screening: $e^2 \rightarrow e^2 / \varepsilon_r$
  - Reduced mass: $m_e \rightarrow \mu = \left[\frac{1}{m_e} + \frac{1}{m_h}\right]^{-1}$

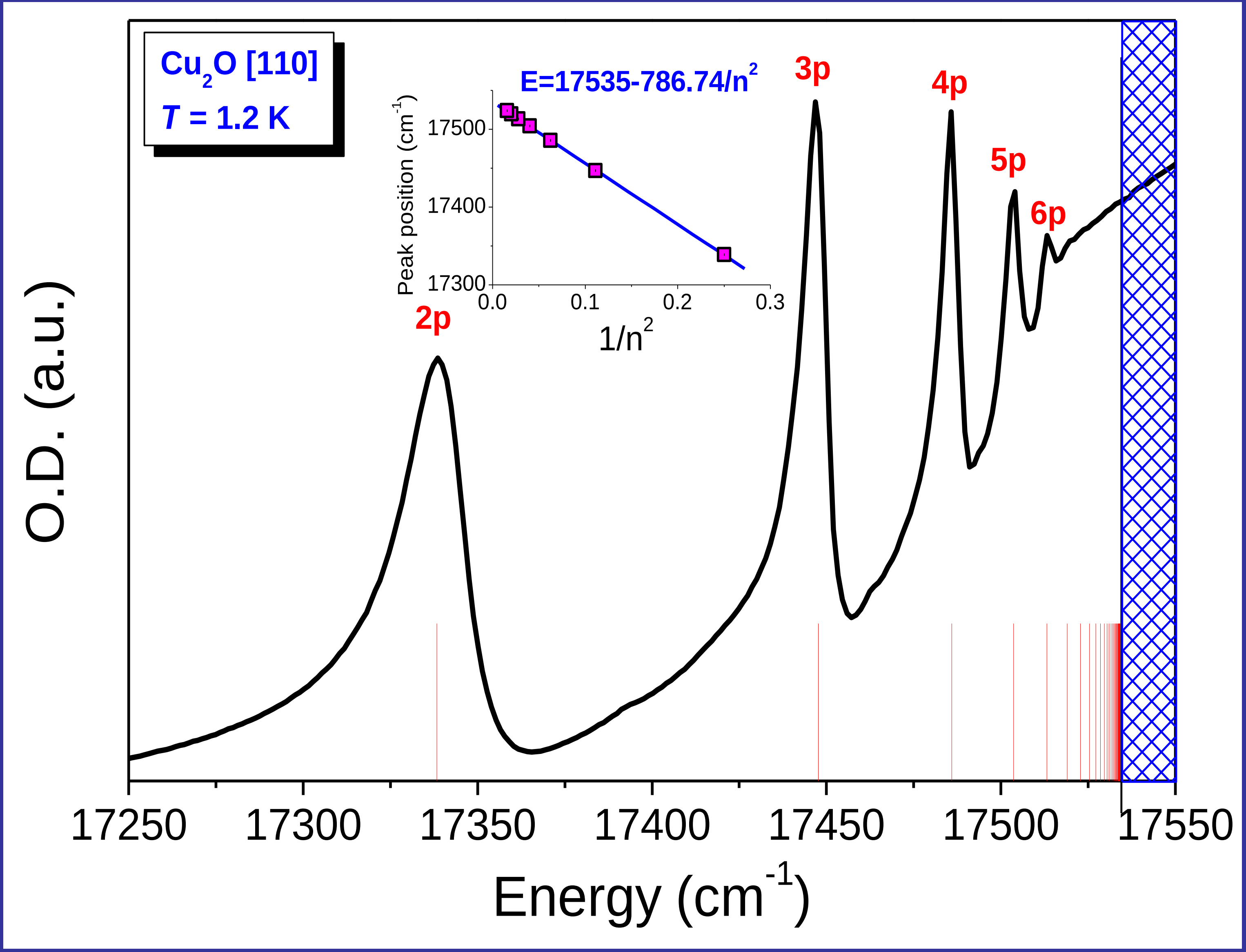
$$H = \frac{p_e^2}{2m_e} + \frac{p_p^2}{2m_p} - \frac{e^2}{|r_e - r_p|} \quad \Rightarrow \quad H = \frac{p_e^2}{2m_e^*} + \frac{p_h^2}{2m_h^*} - \frac{e^2}{\varepsilon_r |r_e - r_h|}$$

$$a_{ex} / a_H = \frac{m_e}{\mu} \varepsilon_r \approx 20$$

$$E_{ex} / E_H = \frac{\mu}{m_e} \frac{1}{\varepsilon_r^2} \approx \frac{1}{144}$$

	Hydrogen	Cu_2O
Bohr radius	0.53 Å	10.6 Å
Binding E_1	13.6 eV	94 meV

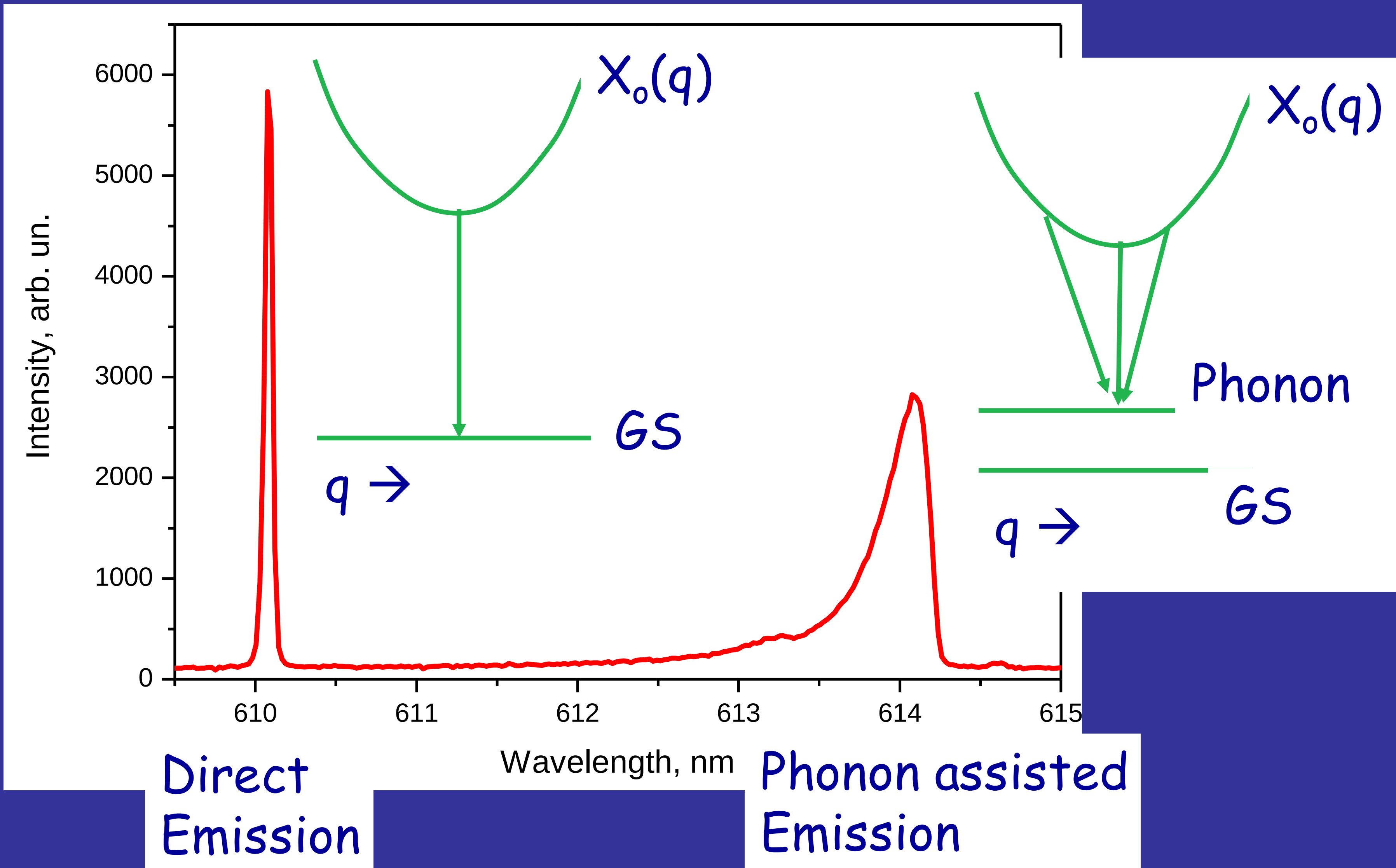
Excitons in Cu_2O (absorption)



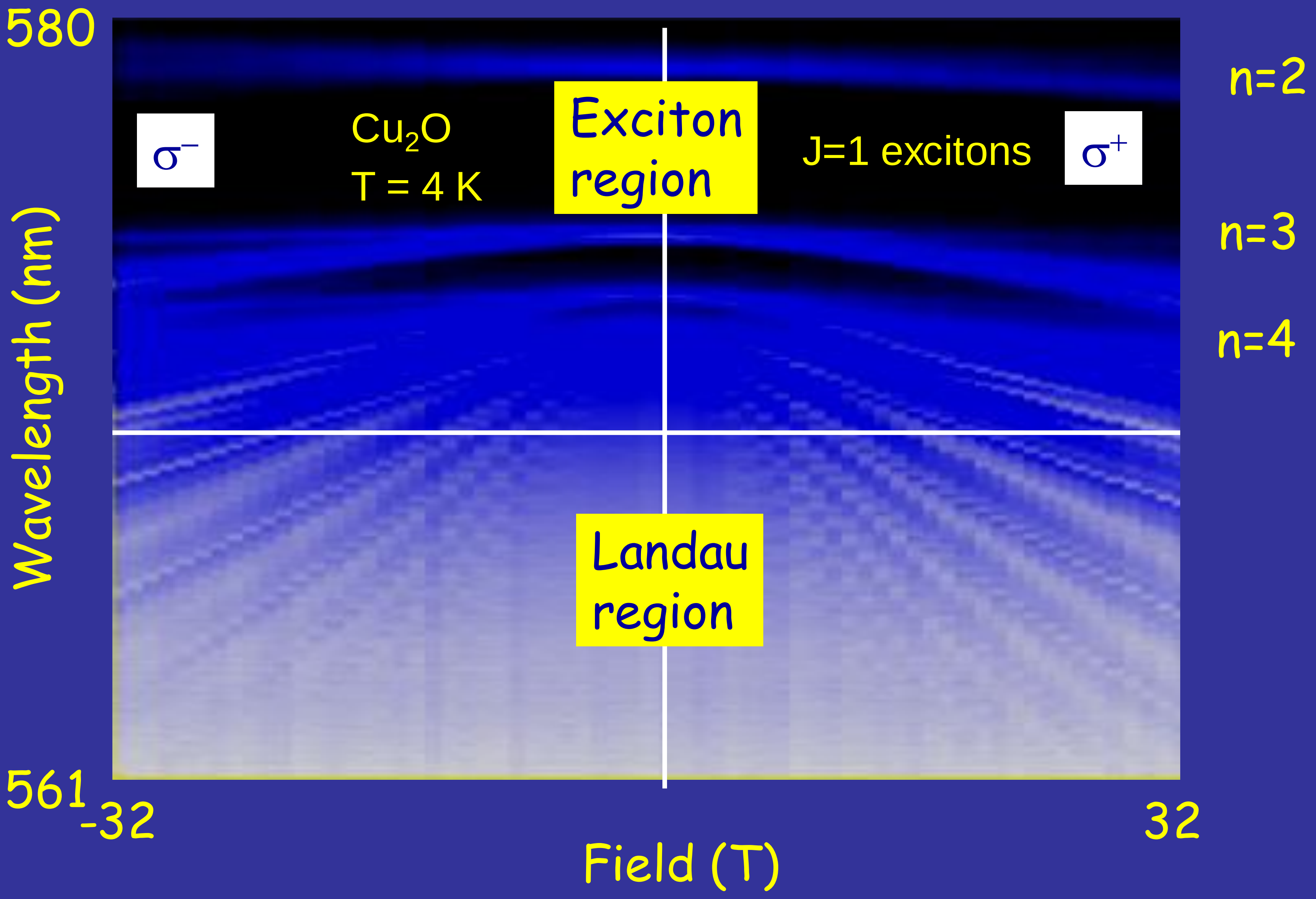
Lyman series

$$E(n) = \frac{E_0}{n^2}$$

Cu_2O Emission



Magneto-absorption of excitons



Excitons in KBr

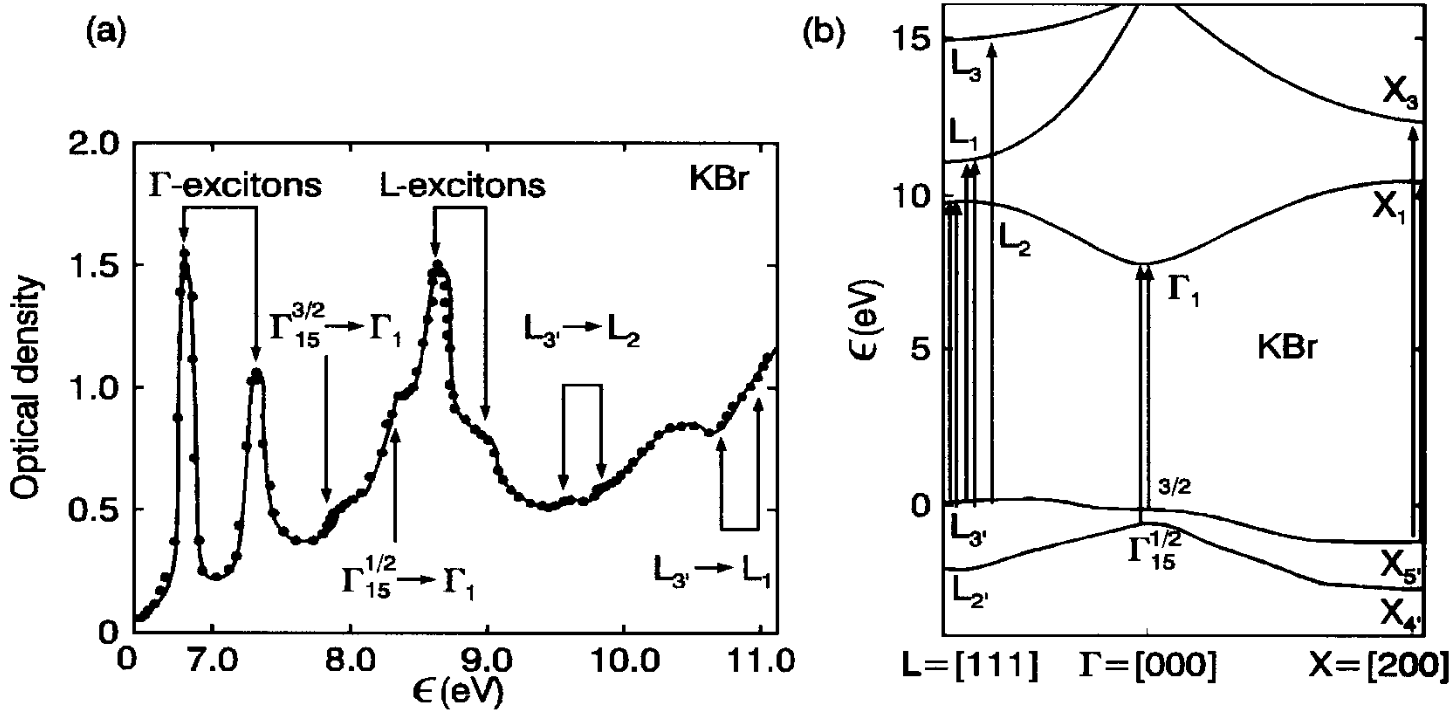


Fig. 7.7. Optical density for KBr measured at 80 K (**a**) and band structure for the corresponding lattice (**b**); after [7.11].

PHYSICAL REVIEW VOLUME 116, NUMBER 5 DECEMBER 1, 1959

Ultraviolet Absorption of Alkali Halides*

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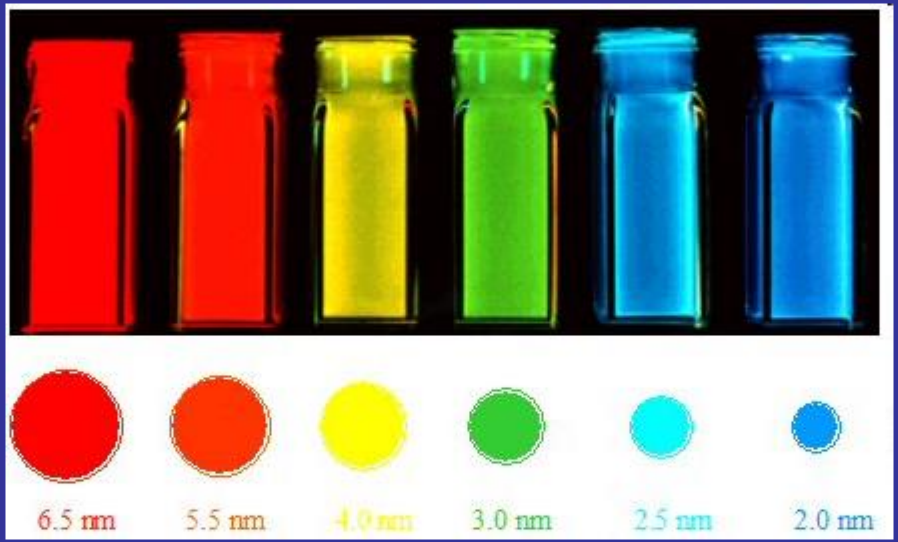
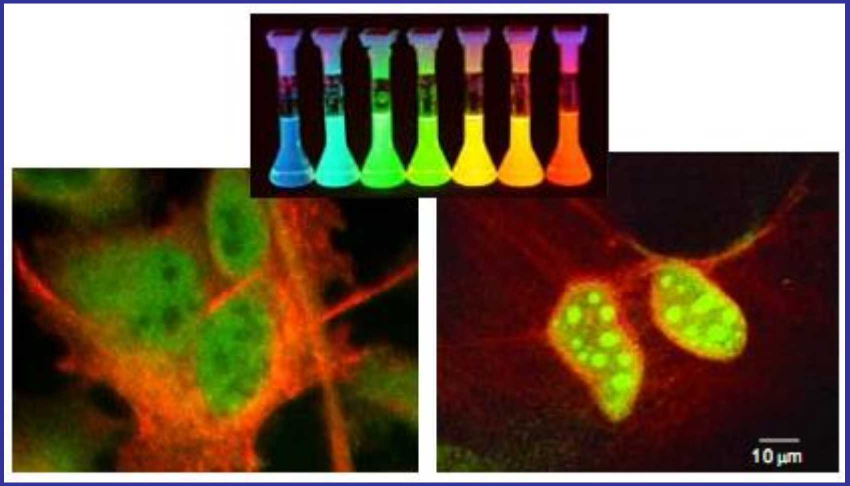
(Received May 27, 1959; revised manuscript received August 19, 1959)

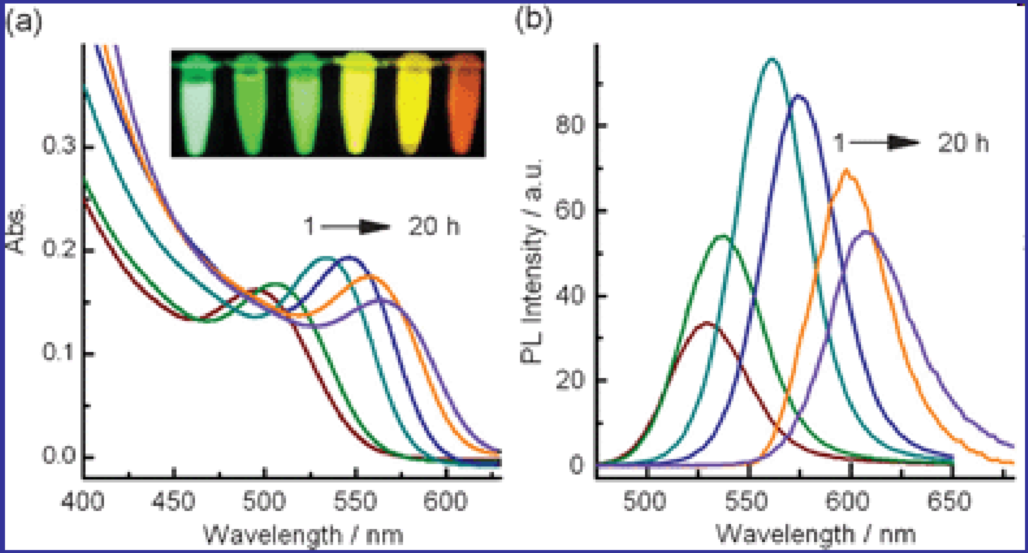
Nano Crystals

CdSe nanocrystals



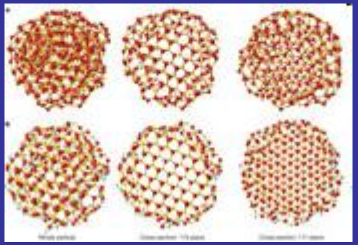


CdTe nanocrystals



- Bio labeling
- Displays
- Solar cells
- Photonic crystals
- MRI enhancement
- …

Nano Crystals



Bandgap CdTe: 1.56 eV (direct)

Bulk → emission at 795 nm

Small particle: confinement energy (particle in a box)

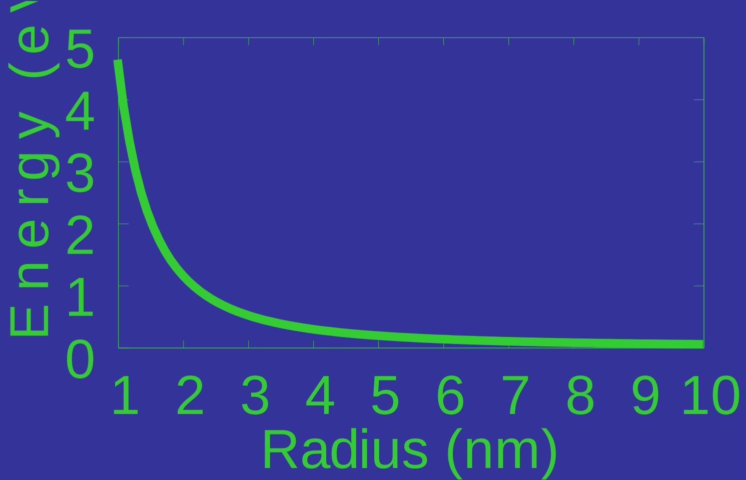
$$E = E_g + \frac{\hbar^2 \pi^2}{2 \mu R^2}$$

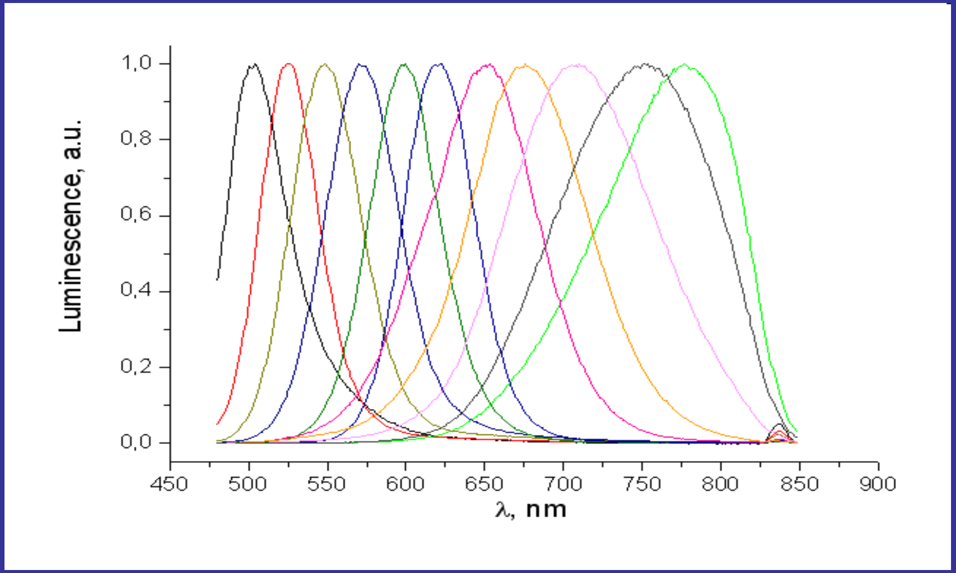
CdTe: $m_e^* \approx 0.1\, m_0$, $m_h^* \approx 0.44\, m_0$ $\Big\} \; \mu \approx 0.08\, m_0$

2 nm particles: Confinement 1.15 eV

E = 1.56 + 1.15 = 2.71 eV Corresponds to 475 nm

For 3 nm: 600 nm





Exercises

- Derive the wave equation
- 1.8; 1.12; 1.19
- Derive the response function of a Lorentz oscillator
- 2.3; 2.6;
- 3.13
- 6.3, 6.18
- 7.1, 7.6, 7.7