Excitons

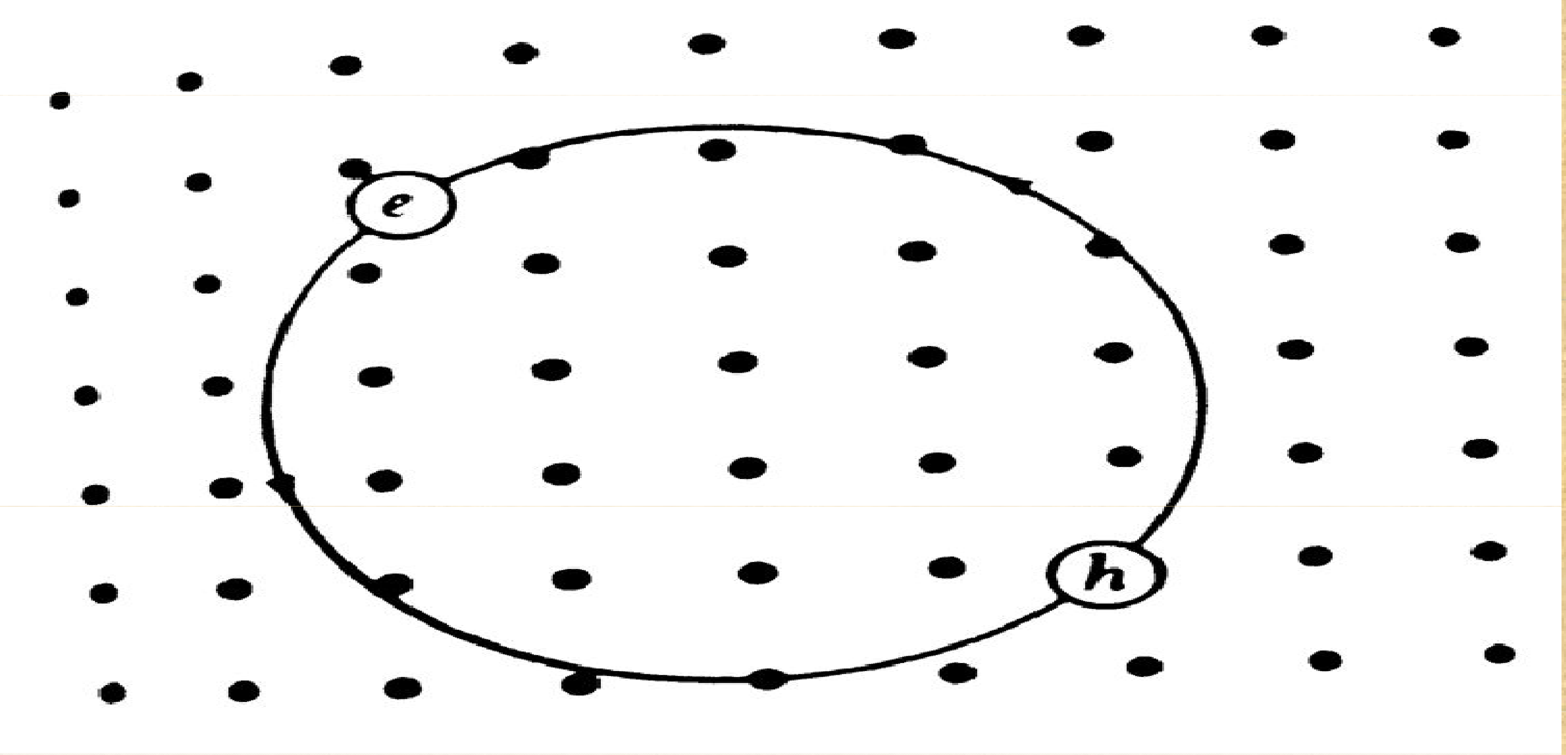
excitons

- Frenkel Excitons
- Alkali Halides
- Molecular crystals
- Weakly bound **(Mott-wannier)** Excitons
- Exciton Condensation into Electron –Hole
- Drops(EHD)

EXCITONS

- An electron and a hole may be bound together by their attractive coulomb interaction , just as an electron is bound to a proton to form a neutral hydrogen atom . the bound electron-hole pair is called an exciton .

  an exciton can move through the crystal and transport energy ; it does not transport charge because it is electrically neutral


e
h

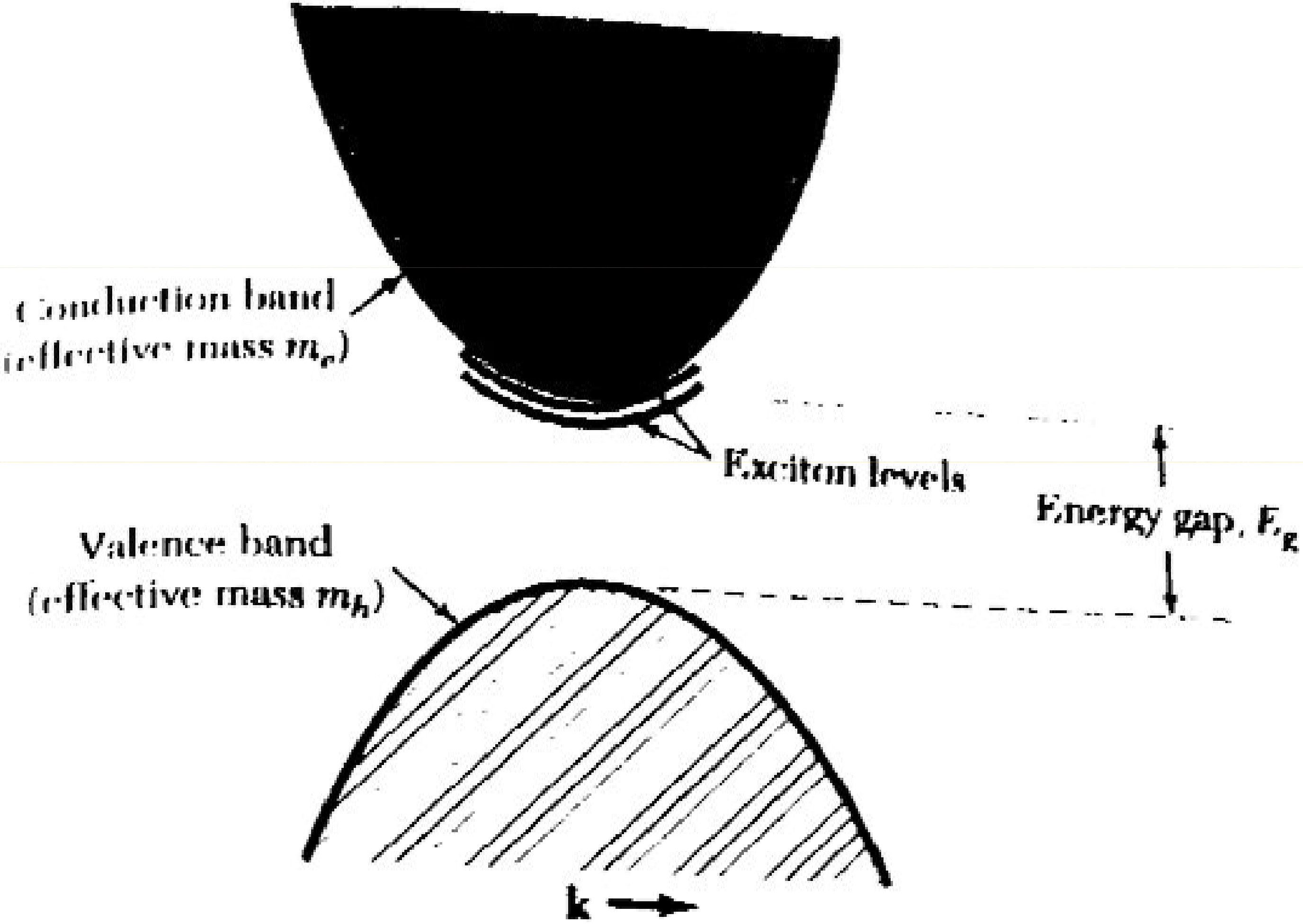
Characteristics of exciton

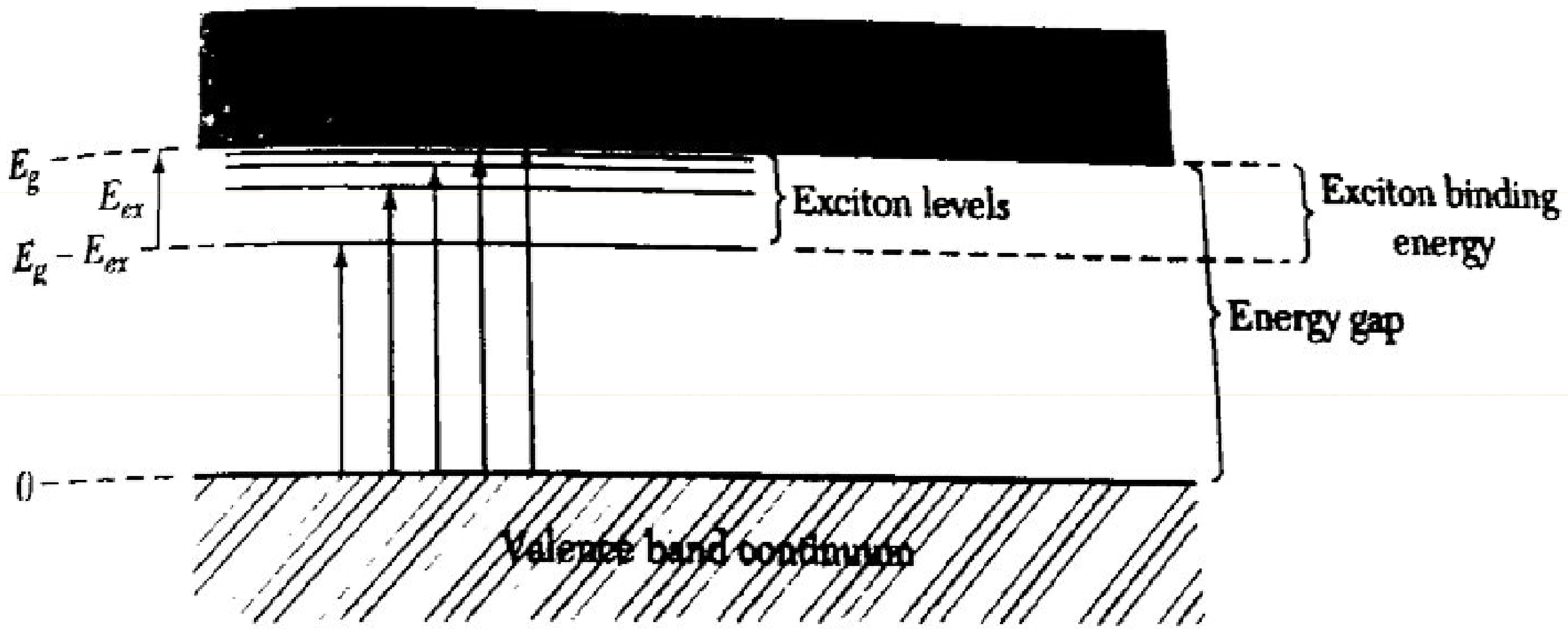
- It is formed in every insulating crystal
- It can form complexes;

EXCITON + EXCITON = BIEXCITON

The binding energy of the exciton can be measured in three ways

- In optical transitions from the valence bond , by the difference between the energy required to create an exciton and the energy to create a free electron & free hole.
- In recombination luminescence, by comparison of the energy of the free electron hole recombination line with the energy of the exciton recombination line.
- By photo-ionization of excitons ,to form free carriers . this experiment requires high concenteration of excitons .


Conduction band
(effective mass m_e)
Exciton levels
Energy gap, E_g
Valence band
(effective mass m_h)
k


E_g
E_{ex}
$E_g - E_{ex}$
0
Exciton levels
Exciton binding energy
Energy gap
Valence band continuum

Excitons in two different approximations

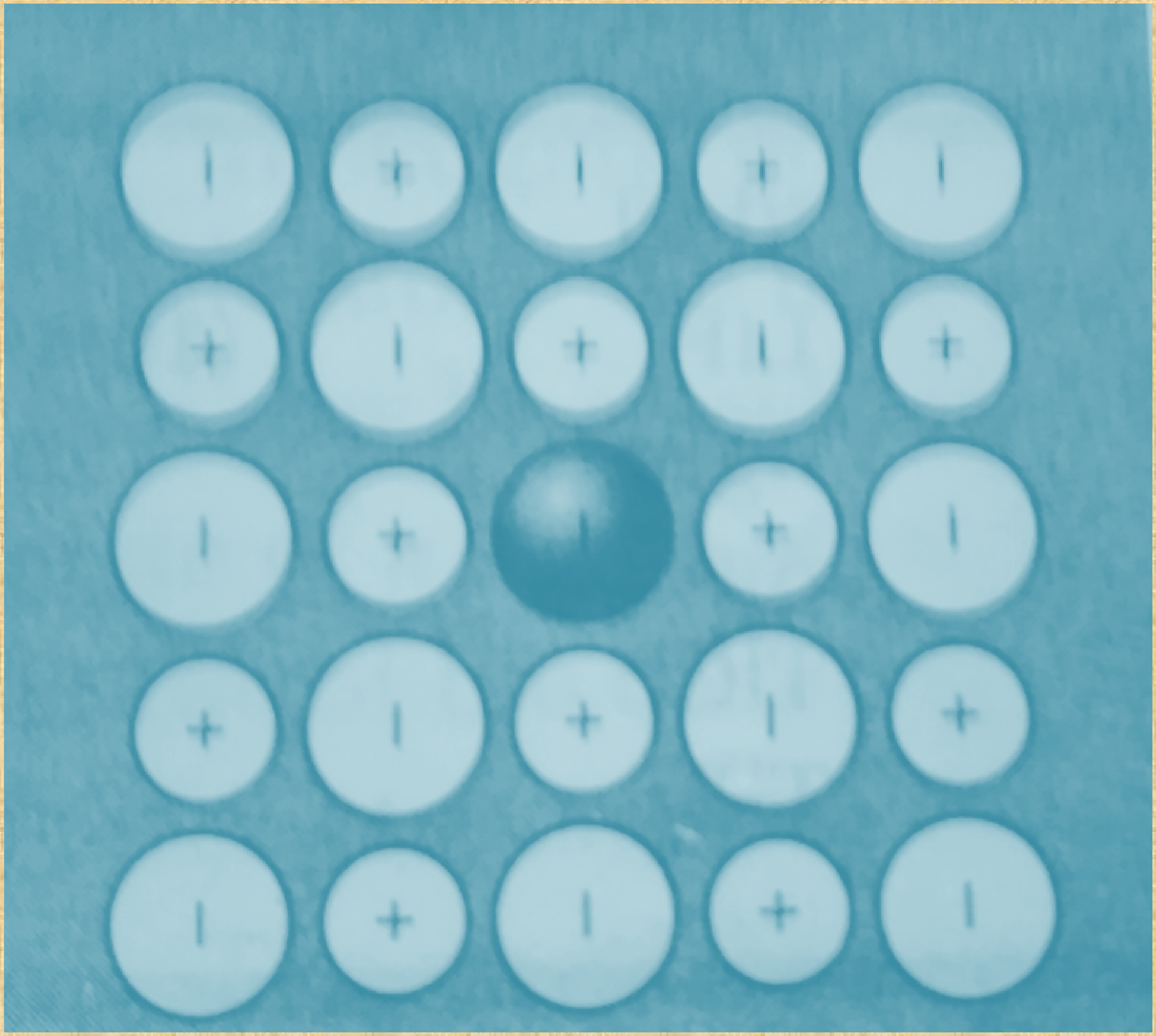
- frenkelexciton
  - small
  - Tightly bound
- Mott & wannier exciton
  - Weakly bound
  - Electron hole separation

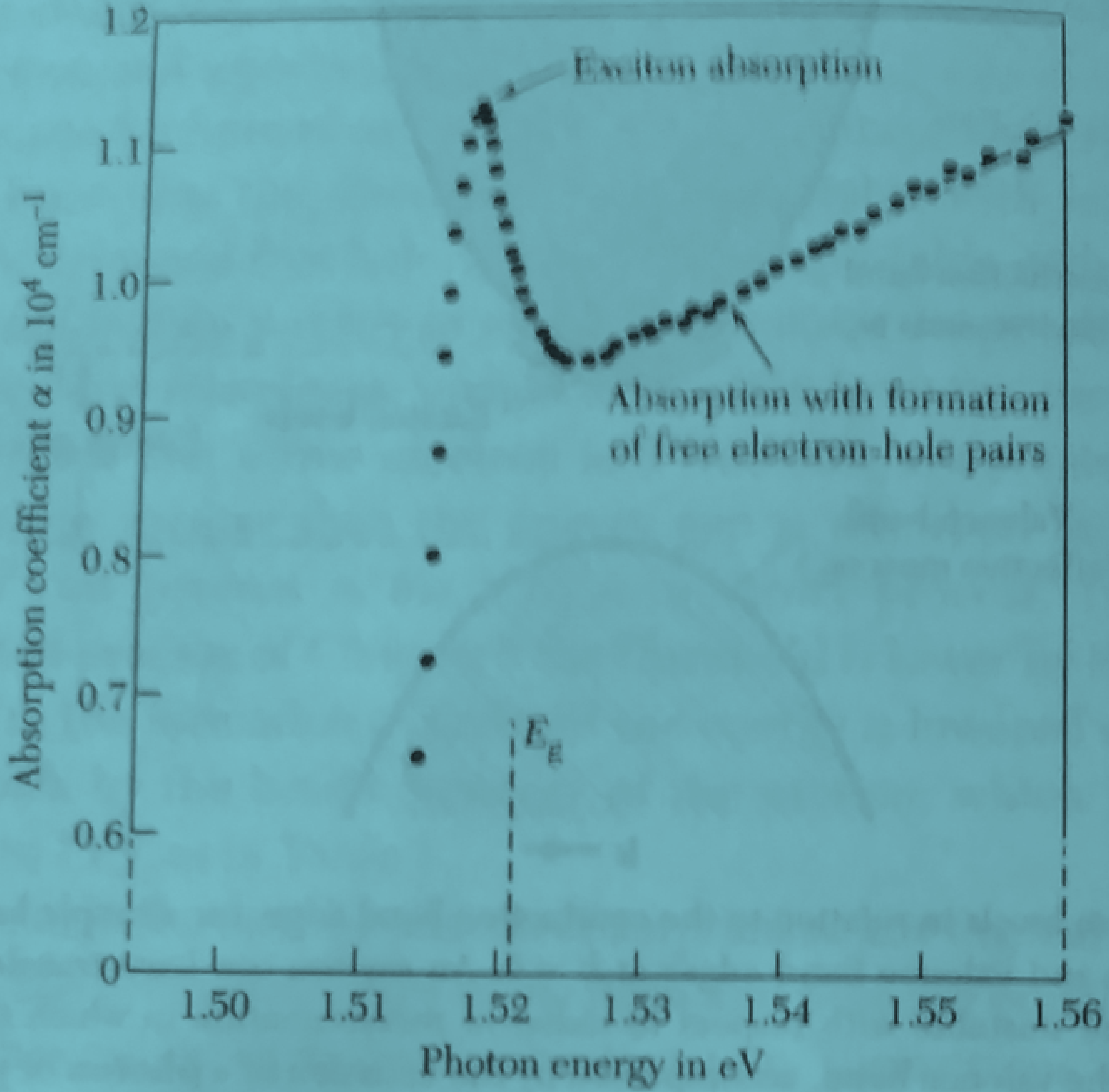
Frenkel exciton

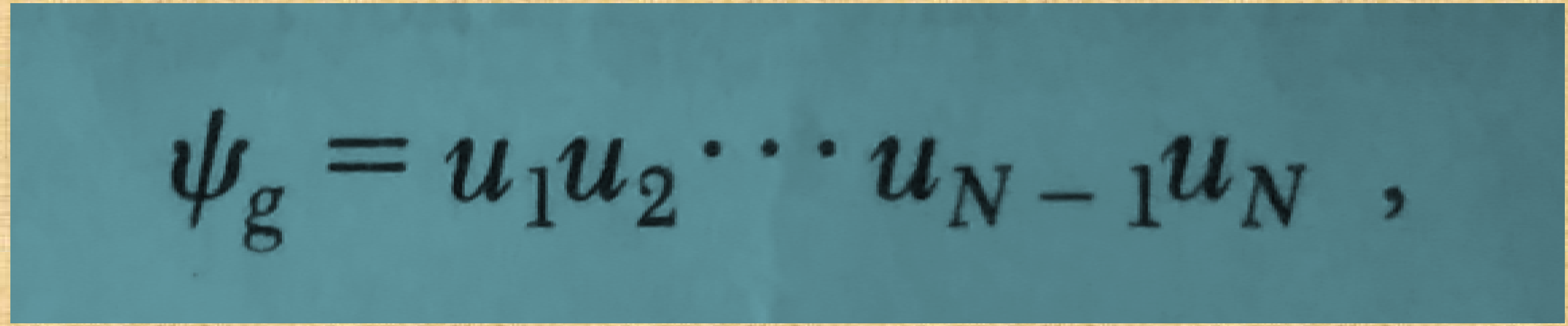
- An excited state of single atom
- Exciton can hop from one atom to another by coupling
- Exciton waves travels through the crystal much as the reversed spin of a magnon travels through the crystal.
- For example krypton….,

  exciton ground state energy=11.7-10.17

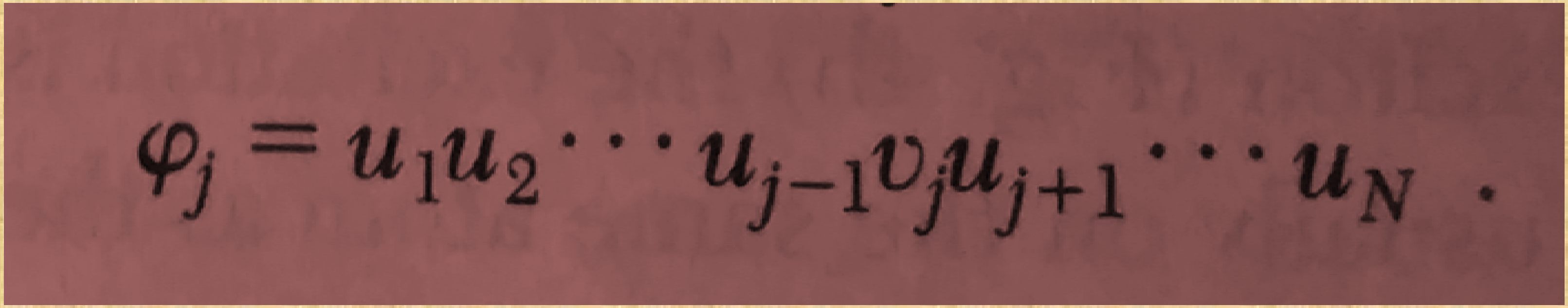
  =1.5 ev



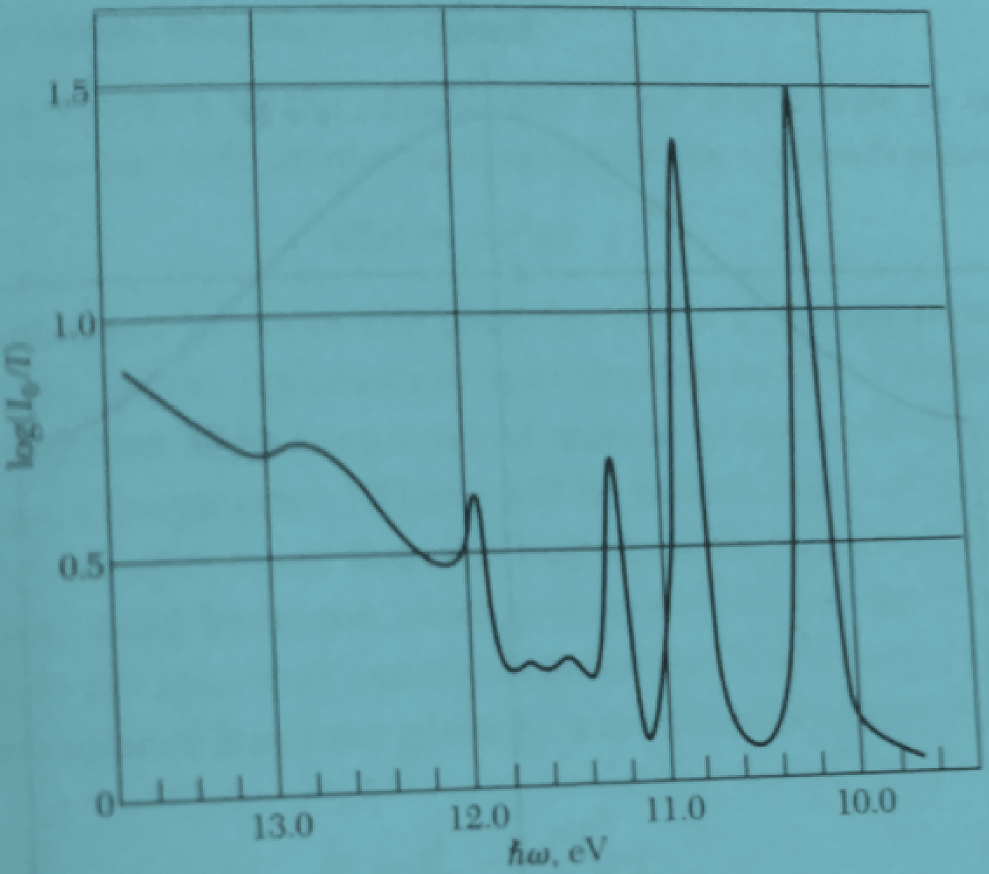

Exciton absorption
Absorption with formation of free electron-hole pairs
E_g
Absorption coefficient α in 10^4 cm^{-1}
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0
1.50
1.51
1.52
1.53
1.54
1.55
1.56
Photon energy in eV



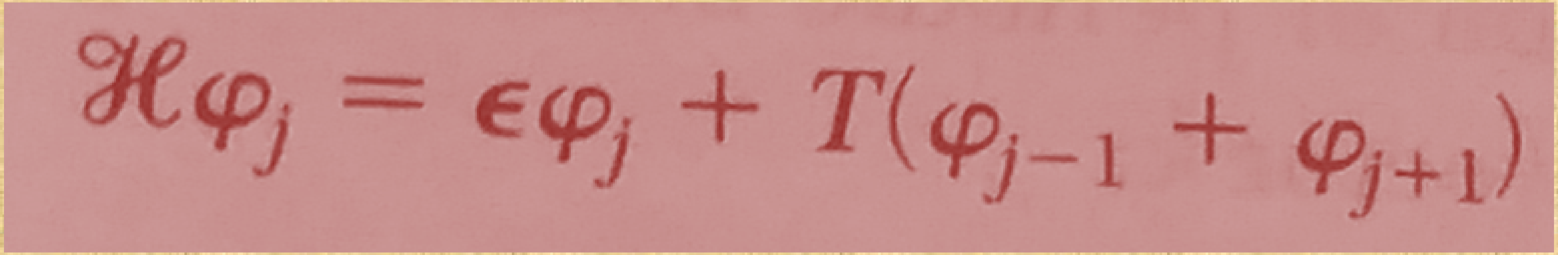
$$\psi_g = u_1 u_2 \cdots u_{N-1} u_N \ ,$$



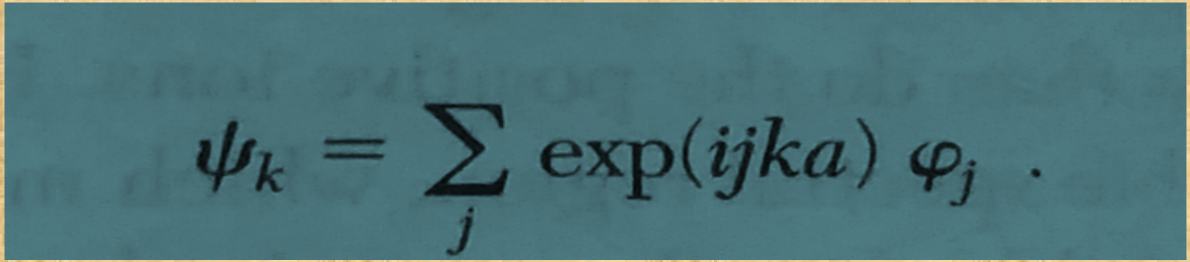
$$\varphi_j = u_1 u_2 \cdots u_{j-1} v_j u_{j+1} \cdots u_N \ .$$



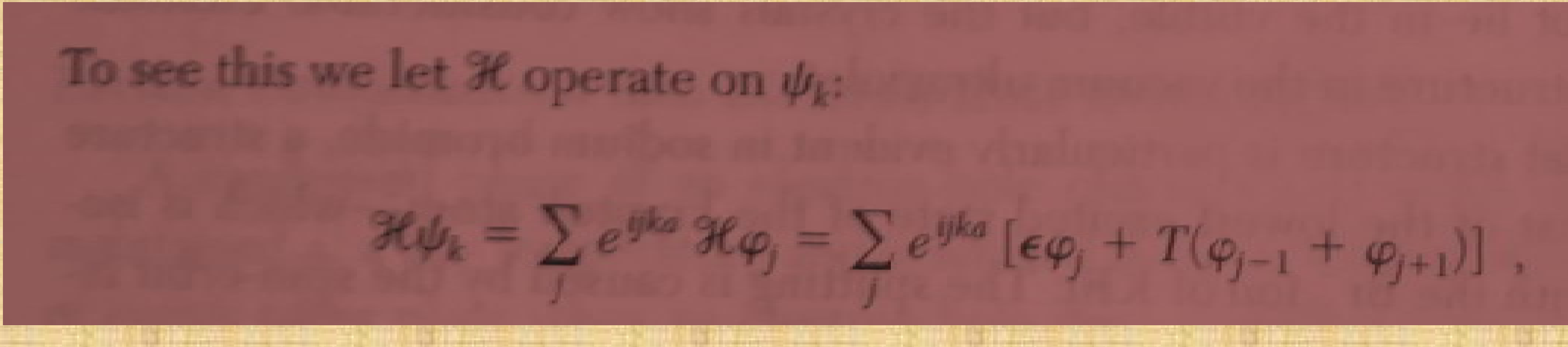
e 8 Absorption spectrum of solid krypton at 20 K. (After G. Baldini.)



$$\mathcal{H}\varphi_j = \epsilon\varphi_j + T(\varphi_{j-1} + \varphi_{j+1})$$

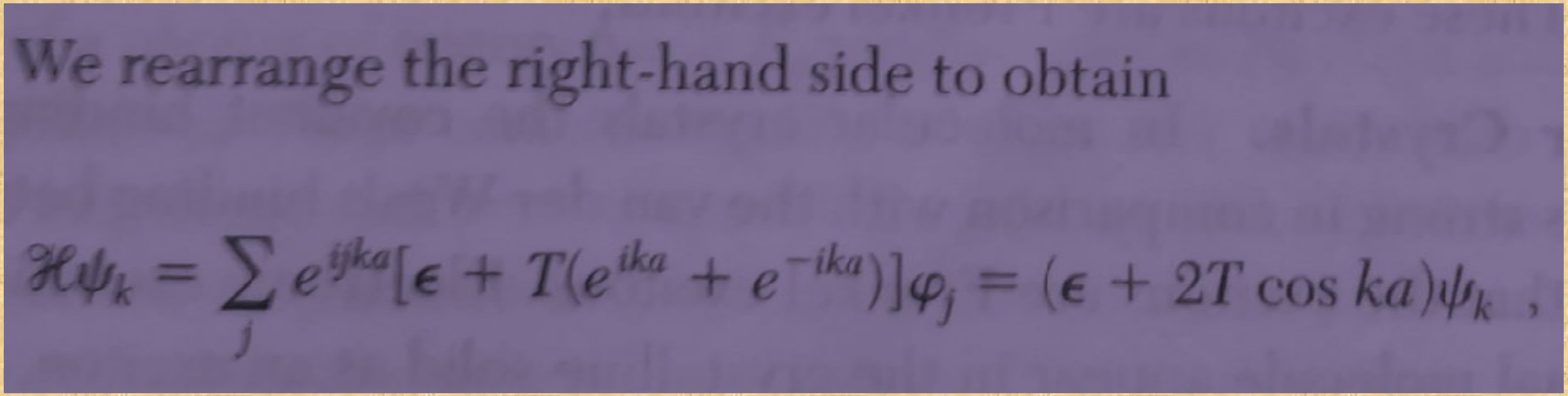


$$\psi_k = \sum_j \exp(ijka)\,\varphi_j \quad .$$



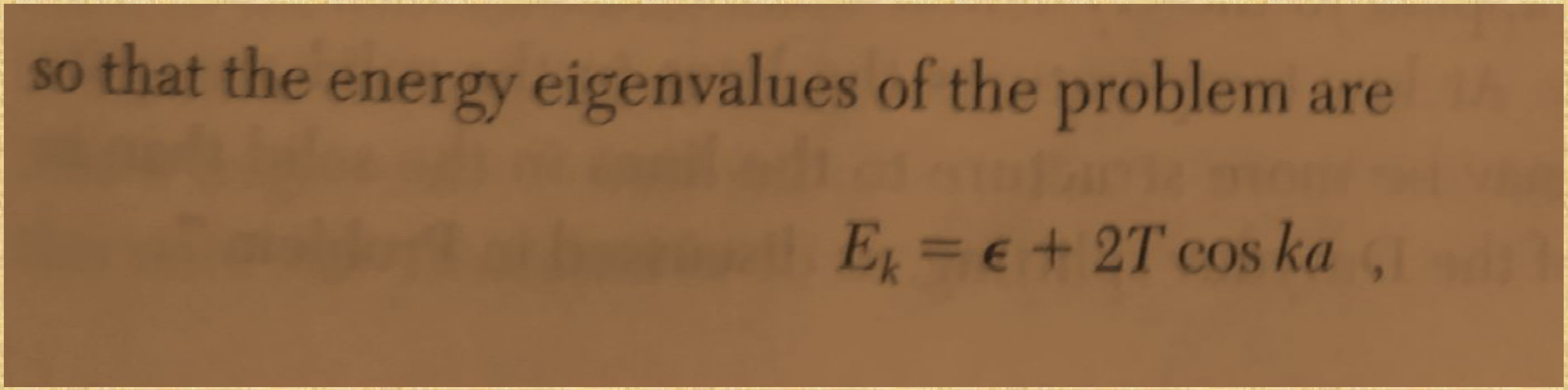
To see this we let $\mathcal{H}$ operate on ψ_k:

$$\mathcal{H}\psi_k = \sum_j e^{ijka}\,\mathcal{H}\varphi_j = \sum_j e^{ijka}\,[\epsilon\varphi_j + T(\varphi_{j-1} + \varphi_{j+1})] \ ,$$



We rearrange the right-hand side to obtain

$$\mathcal{H}\psi_k = \sum_j e^{ijka}[\epsilon + T(e^{ika} + e^{-ika})]\varphi_j = (\epsilon + 2T\cos ka)\psi_k \ ,$$



so that the energy eigenvalues of the problem are

$$E_k = \epsilon + 2T\cos ka \ ,$$

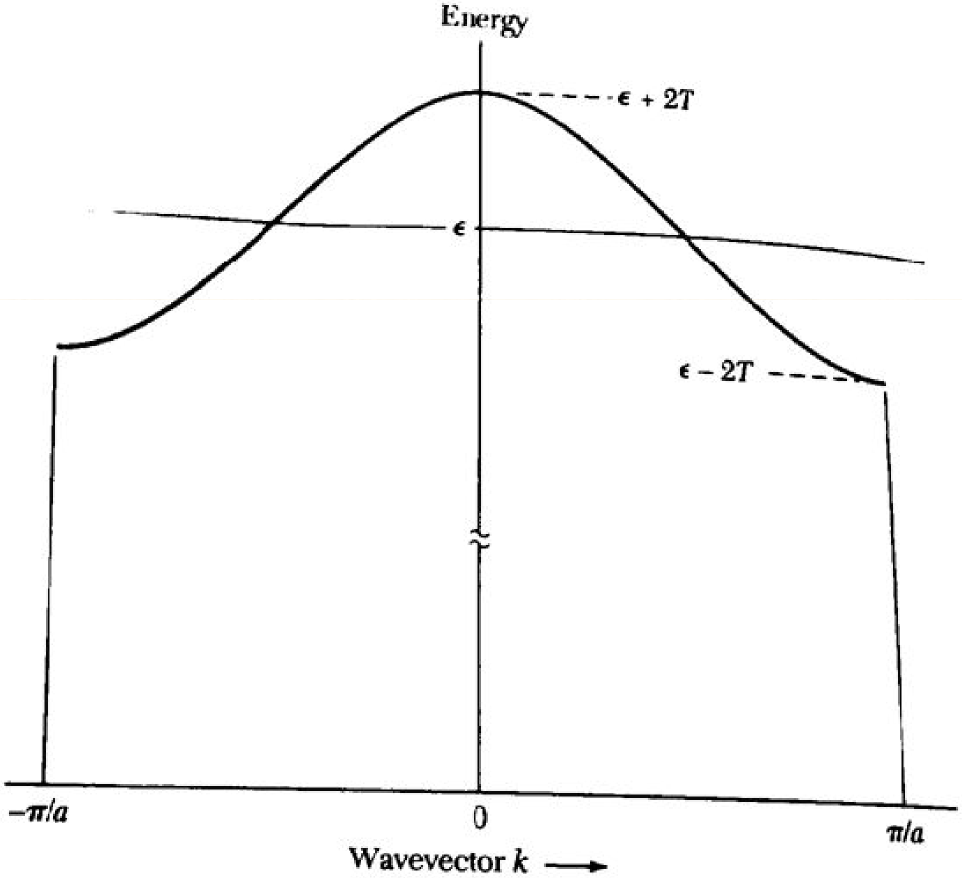


Figure 9 Energy versus wavevector for a Frenkel exciton, calculated with positive ne
neighbor transfer interaction T.

$$k = 2\pi s/Na; \quad s = -\tfrac{1}{2}N, -\tfrac{1}{2}N + 1, \cdots, \tfrac{1}{2}N - 1$$

Alkali halides

- Lowest energy excitons are localized on the negative halogen ions.
- Negative ions < positive ions.
- transparent – in visible spectrum region.
- Energies do not lie in that region.
- Excitonic absorption structure in the vacuum ultra violet.
- Splitting is caused by spin orbit interaction.

Molecular crystals

- The covalent binding is strong within the molecule compared to vanderwaals binding between the molecules.
- Electronic excitation lines of an molecule appear in the crystalline solid with little shift in frequency.
- At low temperature the lines in the solid are sharp , but there will be more lines due to davydov splitting

Weakly bound excitons

- The electron & hole attract each other by the coulomb potential,

$$U(r) = -e^2/\epsilon r$$

$$E_n = E_g - \frac{\mu e^4}{2\hbar^2\epsilon^2 n^2} .$$

Here n is the principal quantum number and μ is the reduced mass:

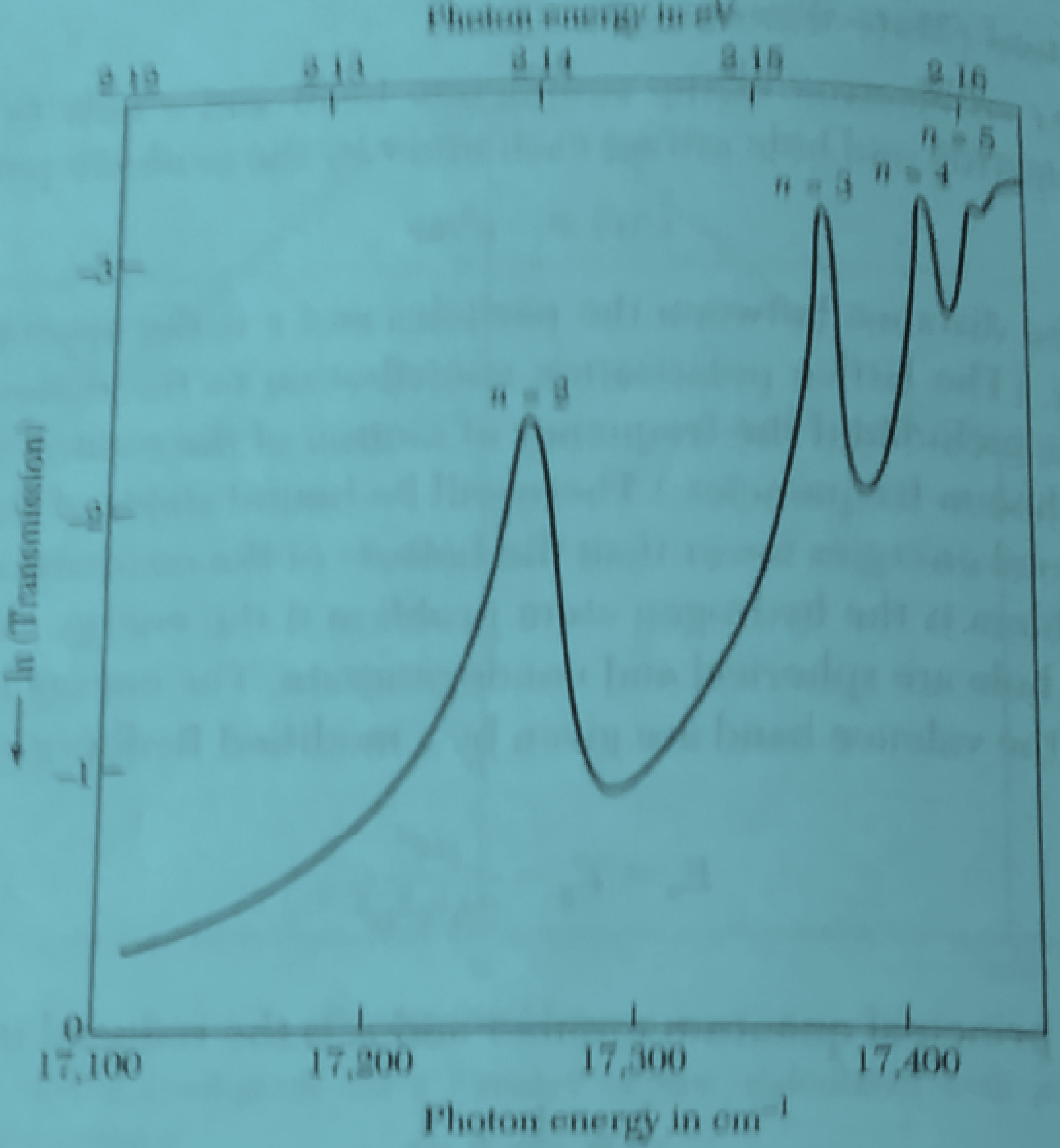
$$\frac{1}{\mu} = \frac{1}{m_e} + \frac{1}{m_h} ,$$

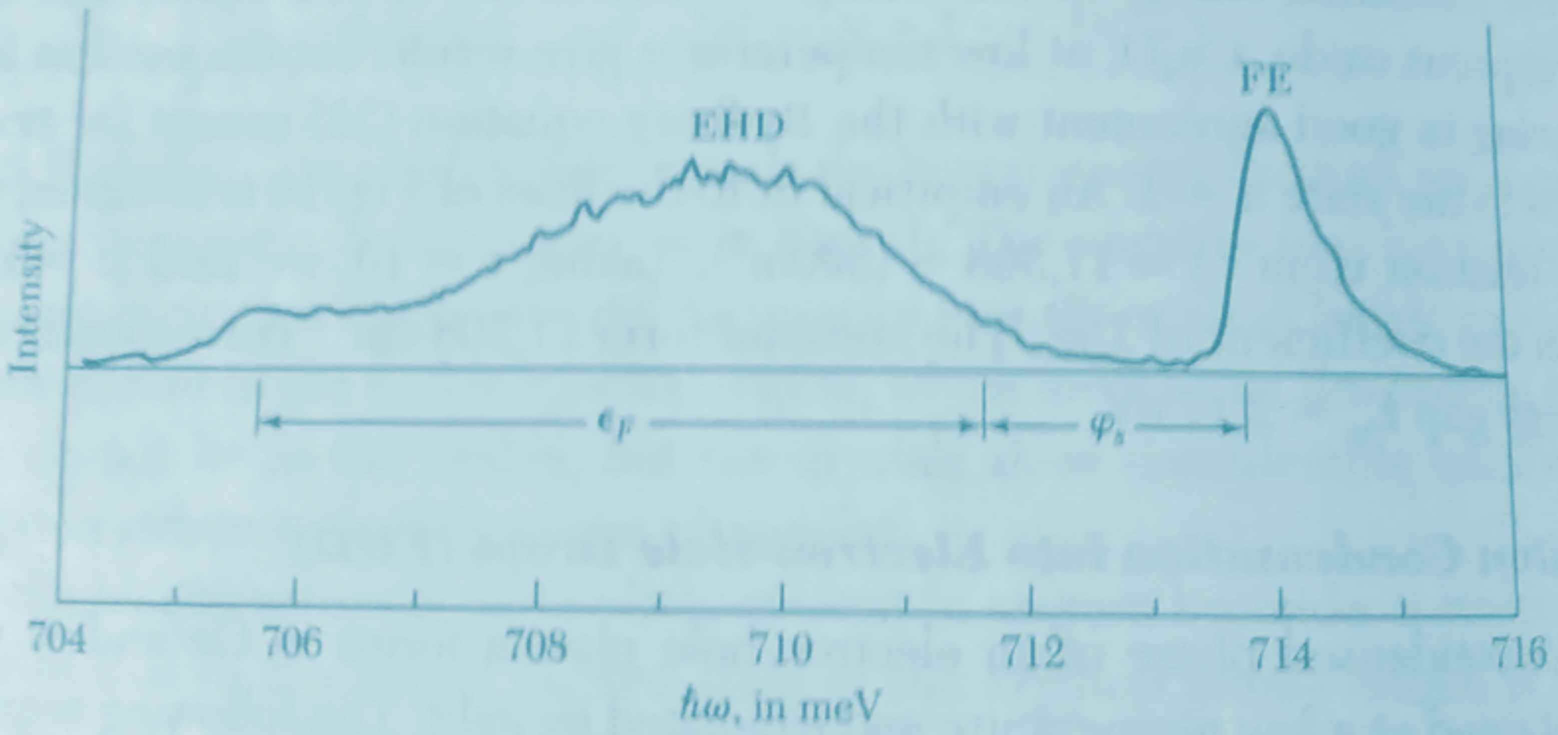
Taking E=10 & μ=0.7m from the coefficient of 1/n^2 . the constant term is 17,508 cm ^-1 ,corresponding to an energy gap Eg = 2.17 eV

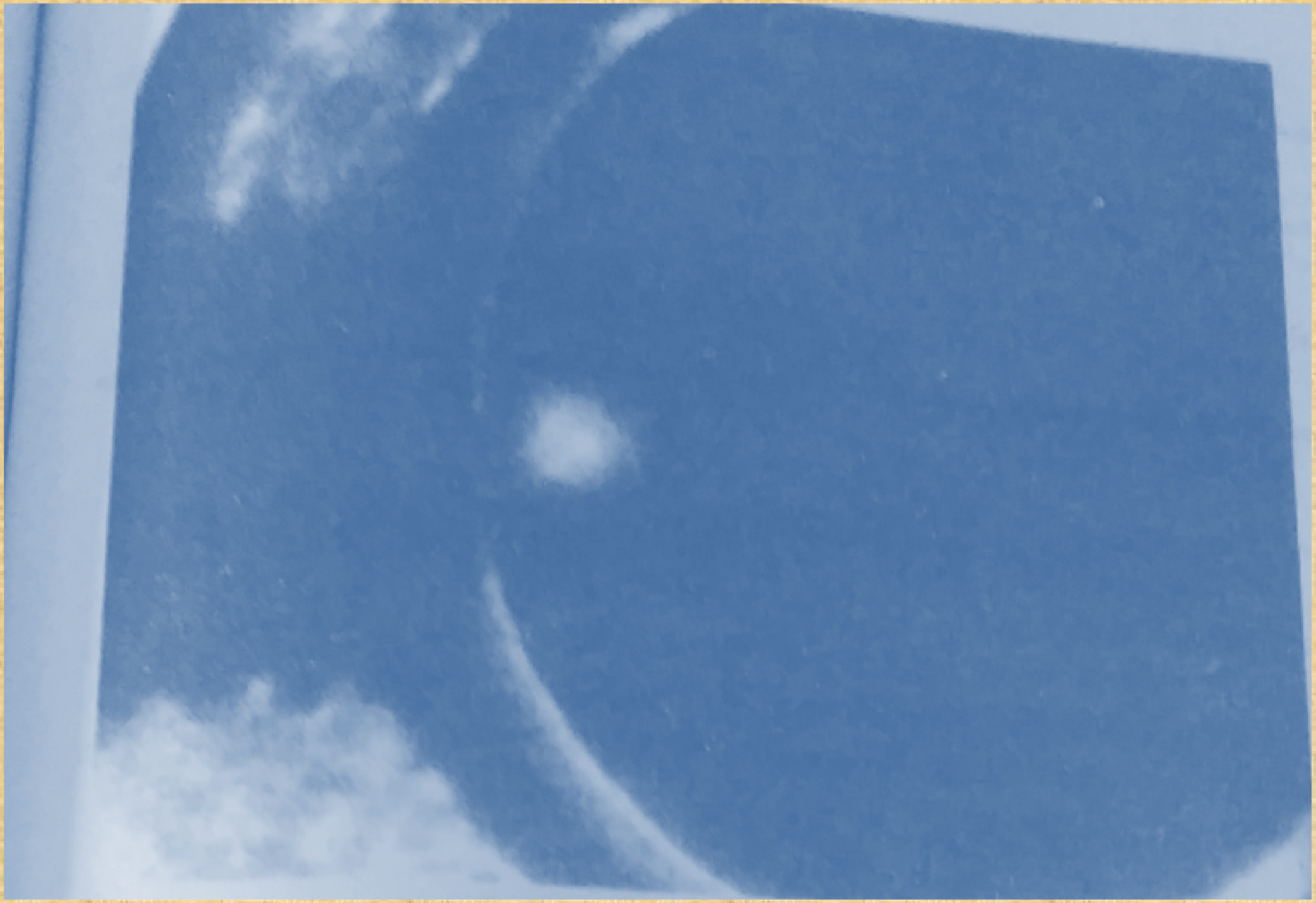
Exciton condensation into electron hole drops (EHD)

- at low temperature & irradiated by light

  Ge & Si .
- In Ge ,the absorption of photon of free energy produces a free electron and free hole with high efficiency.
- Lifetime -8 µs
- Drop lifetime -40 µs
- In strained Ge as long as 600µs


Photon energy in eV
2.12
2.13
2.14
2.15
2.16
n = 2
n = 3
n = 4
n = 5
ln (Transmission)
0
1
2
3
17,100
17,200
17,300
17,400
Photon energy in cm^{-1}


FE
EHD
Intensity
ϵ_F
φ_s
704
706
708
710
712
714
716
$\hbar\omega$, in meV



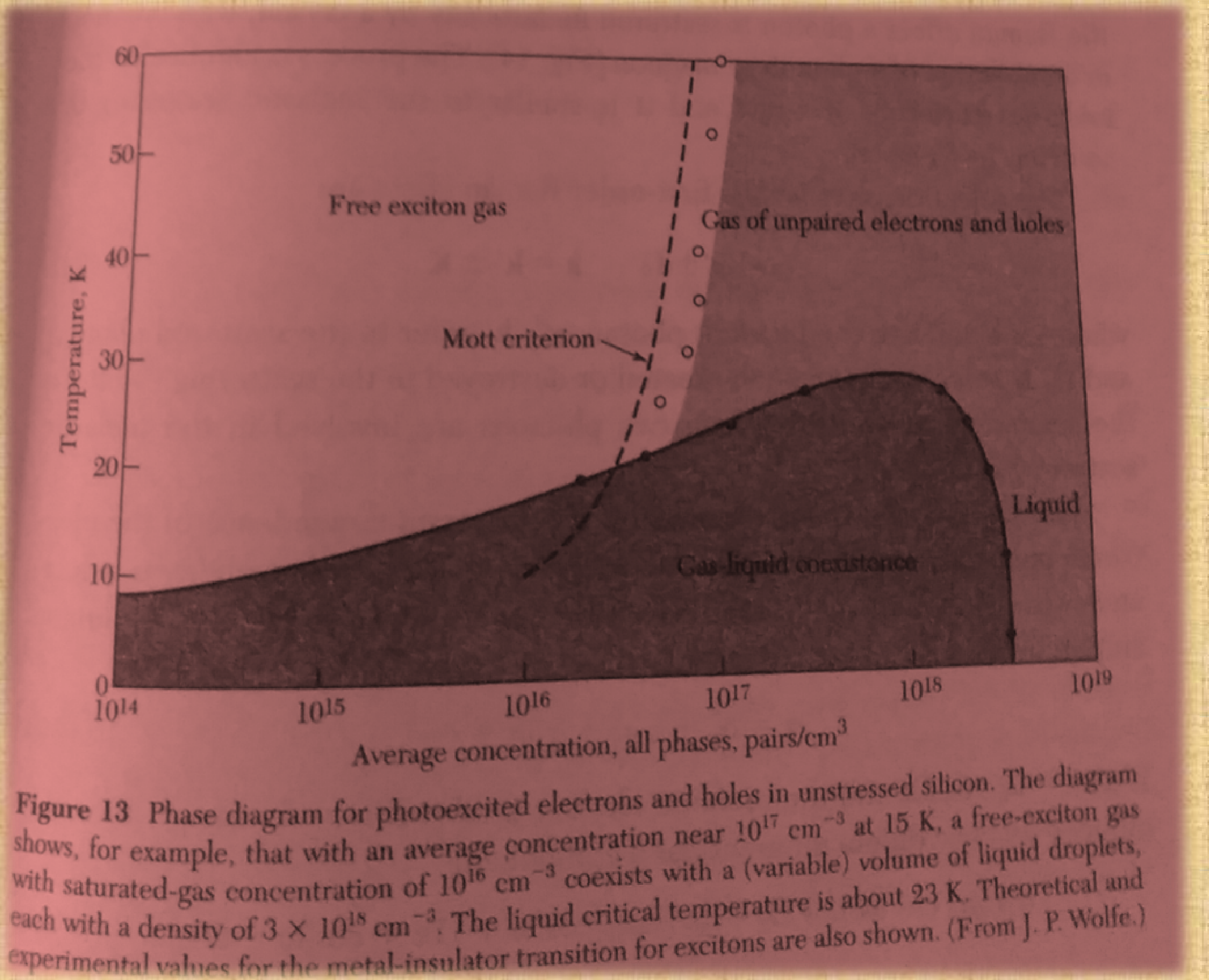


Figure 13 Phase diagram for photoexcited electrons and holes in unstressed silicon. The diagram shows, for example, that with an average concentration near 10^{17} cm^{-3} at 15 K, a free-exciton gas with saturated-gas concentration of 10^{16} cm^{-3} coexists with a (variable) volume of liquid droplets, each with a density of 3×10^{18} cm^{-3}. The liquid critical temperature is about 23 K. Theoretical and experimental values for the metal-insulator transition for excitons are also shown. (From J. P. Wolfe.)

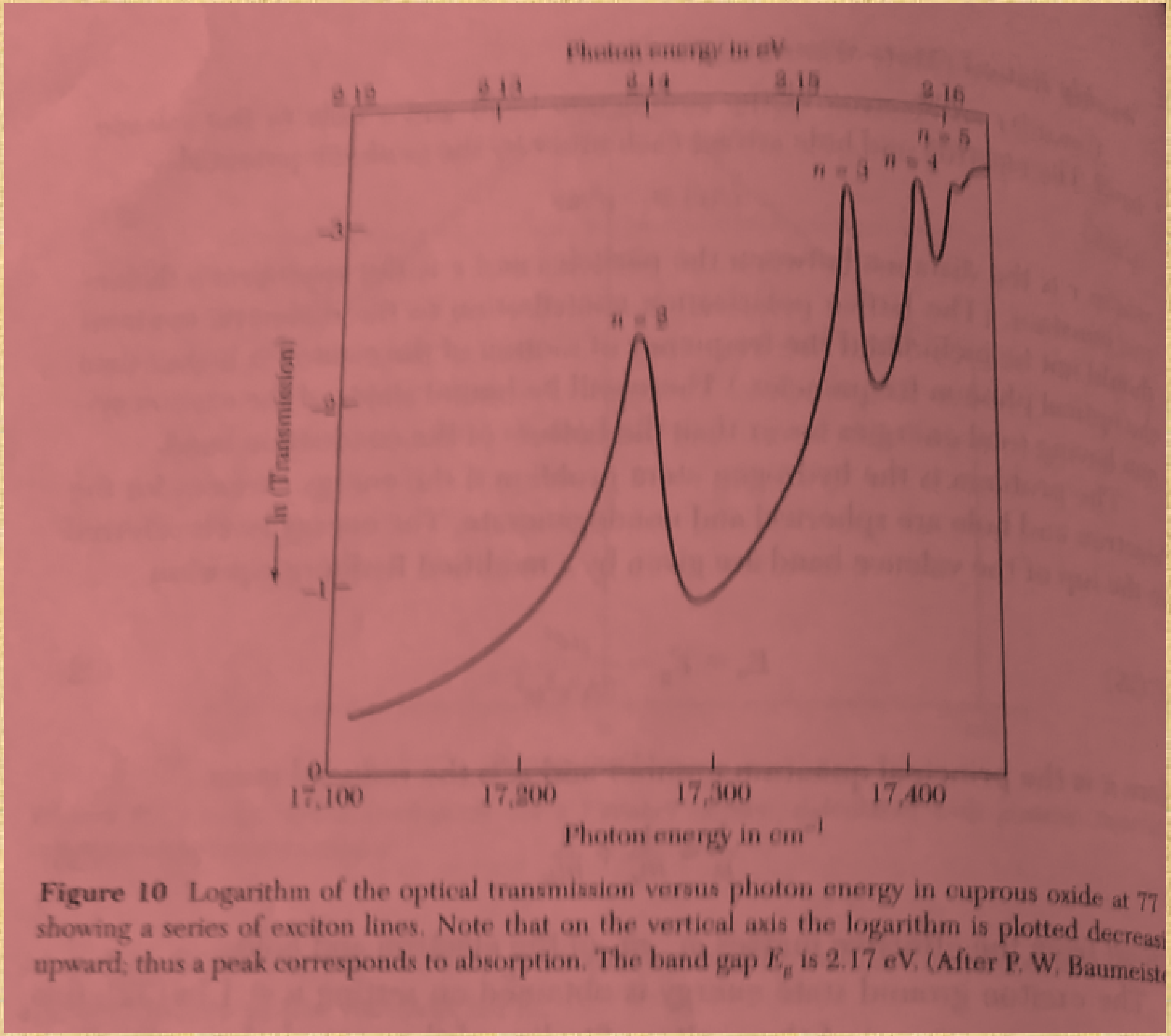


Figure 10 Logarithm of the optical transmission versus photon energy in cuprous oxide at 77 showing a series of exciton lines. Note that on the vertical axis the logarithm is plotted decreasi upward; thus a peak corresponds to absorption. The band gap E_g is 2.17 eV. (After P. W. Baumeiste

- Within the drop the excitons dissolve into a degenerate fermi gas of electrons and holes , with metallic properties this state was predicted by L.V.Keldysh.
- At low pressure , the exciton gas is insulating .
- At high pressure , the exciton gas breaks up into a conducting plasma of unpaired electron and hole.
- The transition from exciton to the plasma is an example of mott transition.