FYS3410 - Vår 2010 (Kondenserte fasers fysikk)

http://www.uio.no/studier/emner/matnat/fys/FYS3410/index-eng.xml

Based on Introduction to Solid State Physics by Kittel

Course content

- Periodic structures, understanding of diffraction experiment and reciprocal lattice
- Crystal binding, elastic strain and waves
- Imperfections in crystals: point defects and diffusion
- Crystal vibrations: phonon heat capacity and thermal conductivity
- Free electron Fermi gas: density of states, Fermi level, and electrical conductivity
- Electrons in periodic potential: energy bands theory classification of metals, semiconductors and insulators
- **Semiconductors: band gap, effective masses, charge carrier distributions, doping, pn-junctions**
- Metals: Fermi surfaces, temperature dependence of electrical conductivity

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FYS3410 lecture schedule and exams: Spring 2010

M/18/1/2010:	Introduction and motivation. Periodicity and lattices	2h
W/20/1/2010:	Index system for crystal planes. Crystal structures	1h
M/25/1/2010:	Reciprocal space, Laue condition and Ewald construction	2h
W/27/1/2010:	Brillouin Zones. Interpretation of a diffraction experiment	1h
M/01/2/2010:	Crystal binding, elastic strain and waves	2h
W/03/2/2010:	Elastic waves in cubic crystals; defects in crystals	1h
M/08/2/2010:	Defects in crystals; case study - vacancies	2h
W/10/2/2010:	Diffusion	1h
M/15/2/2010:	Crystal vibrations and phonons	2h
W/17/2/2010:	Crystal vibrations and phonons	1h
M/22/2/2010:	Lattice heat capacity: Dulong-Petit and Einstein models	2h
W/24/2/2010:	Phonon density of states (DOS) and Debye model	1h
M/01/3/2010:	General result for DOS; role of anharmonic interactions	2h
W/03/3/2010:	Thermal conductivity	1h
M/08/3/2010:	Free electron Fermi gas in 1D and 3D – ground state	2h
W/10/3/2010:	Density of states, effect of temperature – FD distribution	1h
M/15/3/2010:	Heat capacity and thermal conductivity of FEFG	2h
W/17/3/2010:	Repetition	1h
22/3/2010:	Mid-term exam	

M/12/4/2010:	**Drude model and the idea of energy bands**	**2h**
W/14/4/2010:	**Nearly free electron model; Kronig - Penny model**	**2h**
M/19/4/2010:	**no lectures**	
W/21/4/2010:	**Empty lattice approximation; number of orbitals in a band**	**2h**
M/26/4/2010:	**Semiconductors, effective mass method, intrinsic carriers**	**2h**
W/28/4/2010:	**Impurity states in semiconductors and carrier statistics**	**2h**
M/03/5/2010:	**p-n junctions and heterojunctions**	**2h**
W/05/5/2010:	**surface structure, surface states, Schottky contacts**	**1h**
M/10/5/2010:	**Metals and Fermi surfaces**	**2h**
W/12/5/2010:	**no lectures**	
W/19/5/2010:	**no lectures**	
W26/5/2010:	**Repetition**	**2h**
27-28/5/2010:	**Final Exam (sensor: Prof. Arne Nylandsted Larsen at the Aarhus University, Denmark, http://person.au.dk/en/anl@phys.au.dk)**	

Lecture 22: Semiconductors, effective mass method, intrinsic carriers

- **Repetion: Energy band structure and filling of the bands**
- **Interesting properties of semiconductors**
- **Effective mass method**
- **Intrinsic carrier concentration in semiconductors**

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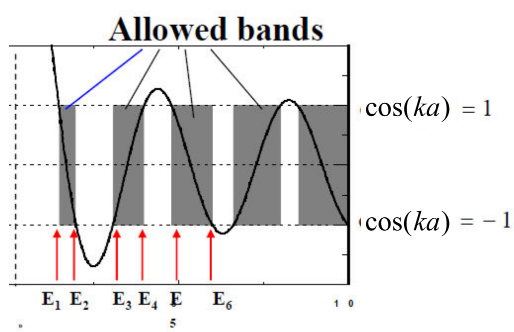
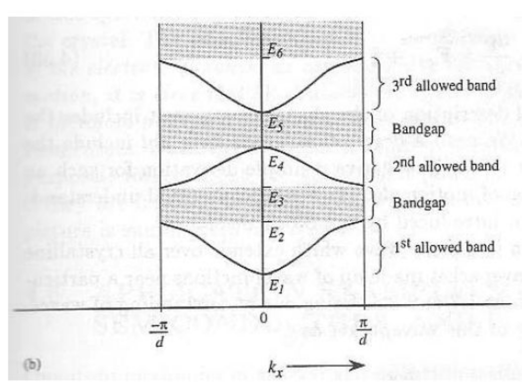
Energy band structure and filling of the bands: origin of the bands

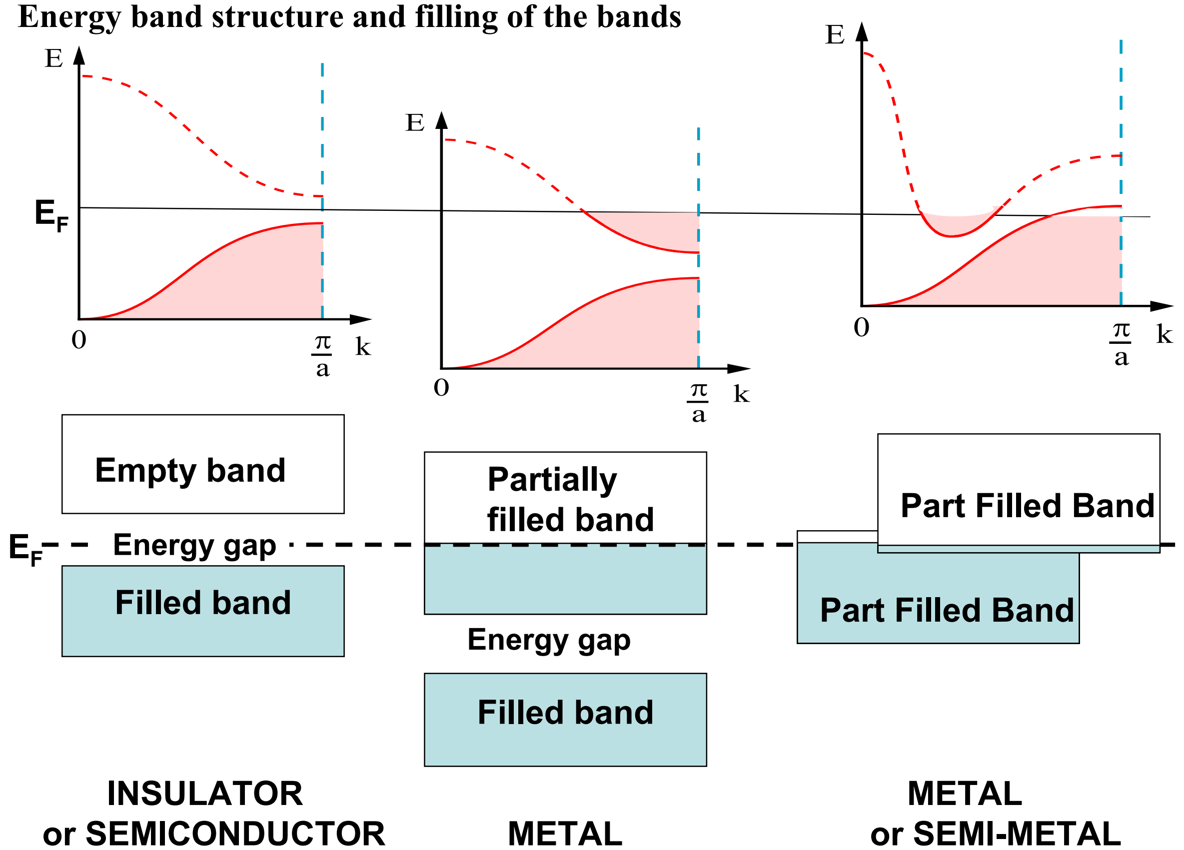
$$\cos(ka) = \cos(Ka) + \frac{2mV_0}{\hbar^2} \cdot \frac{\sin(Ka)}{Ka}$$



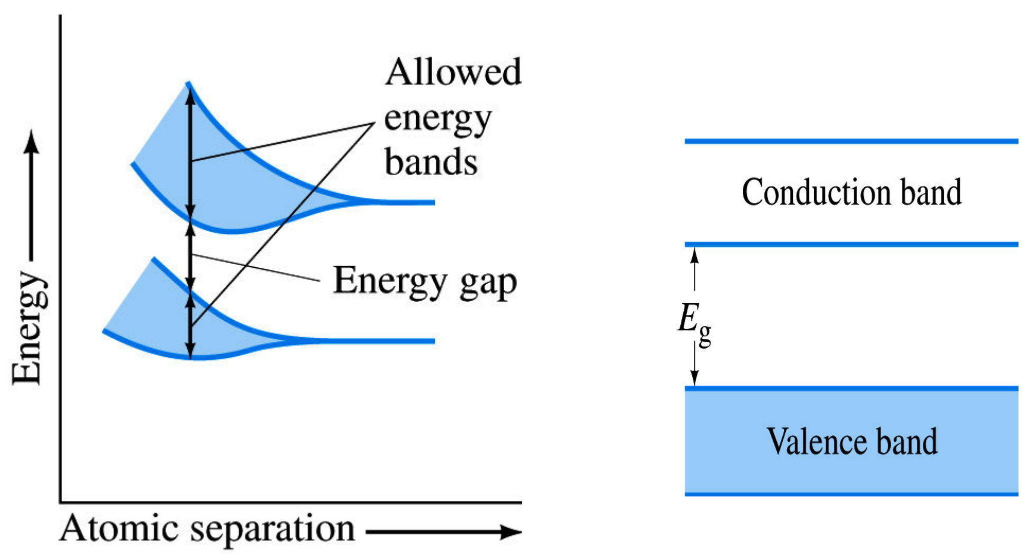
The allowed and forbidden bands are plotted in the E vs. k relation.



Energy band structure and filling of the bands



Energy band structure and filling of the bands: semiconductors



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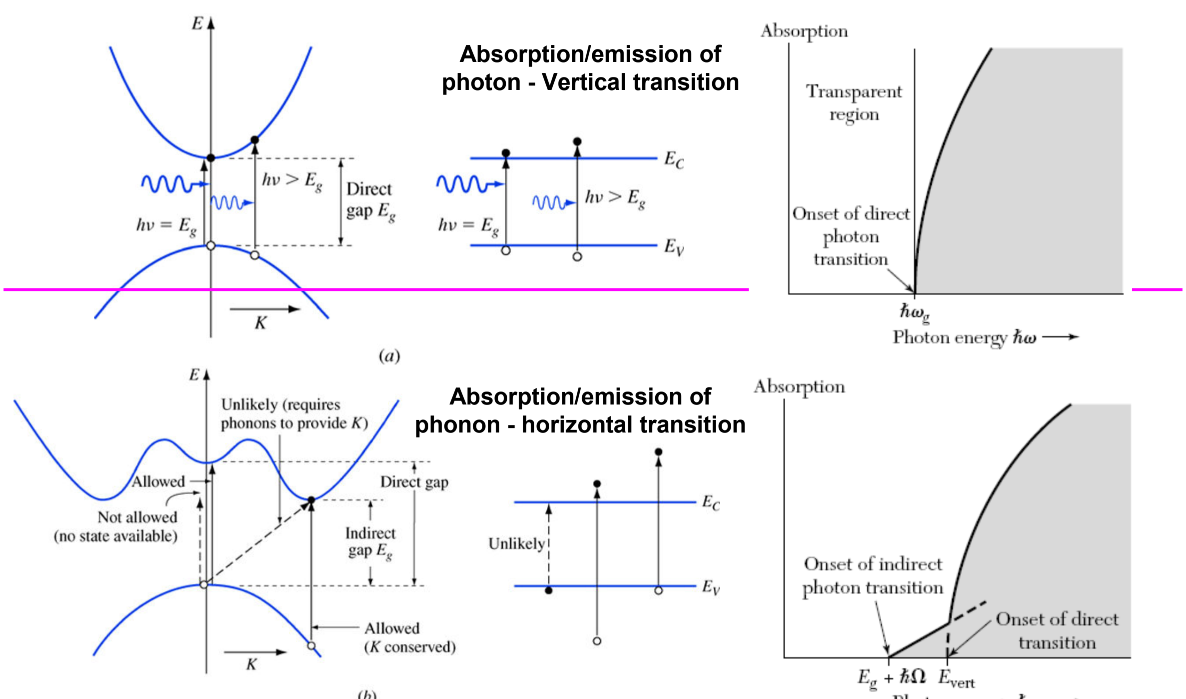
Interesting of semiconductors: light absorbtion

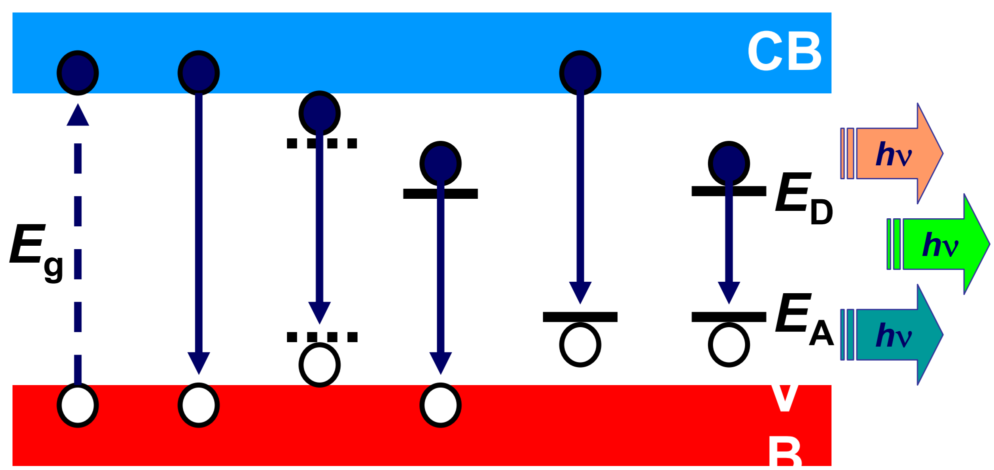


In any transition, *K* must be conserved as well as *E*.

(a) A direct gap semiconductor; on the left is the *E*-*K* diagram, and on the right the conventional energy band diagram.

(b) An indirect gap material (so called because conduction band minimum and the valence band maximum do not occur at the same value of *K*).

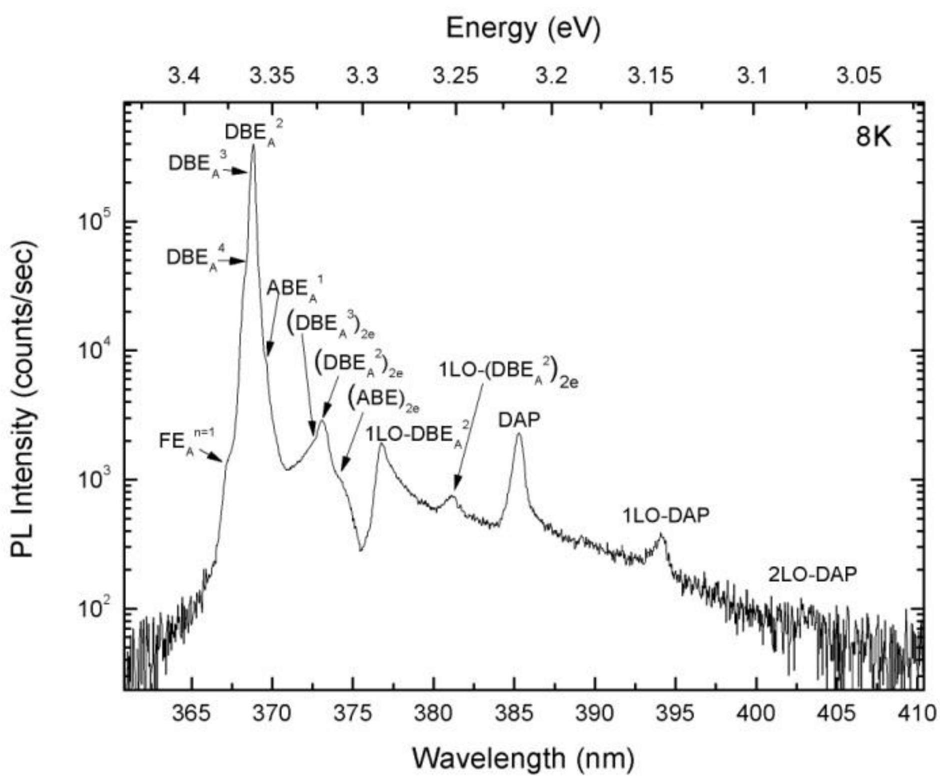
Interesting of semiconductors: photoluminescence



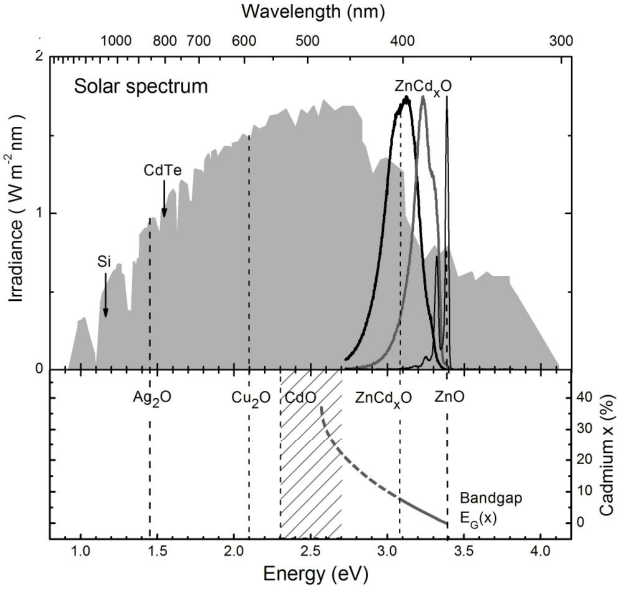
BAND-TO-BAND RECOMBINATION

$h\nu = E_g - nE_P$

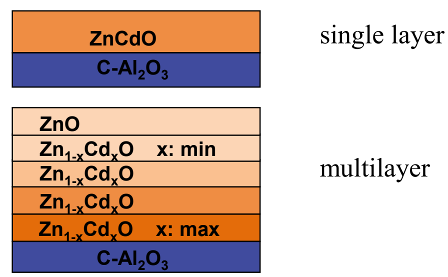
Interesting of semiconductors: photoluminescence



Interesting of semiconductors: band gap modulation for high efficiency solar cells



Schematic of the structures studied



Interesting of semiconductors: band gap modulation for high efficiency solar cells

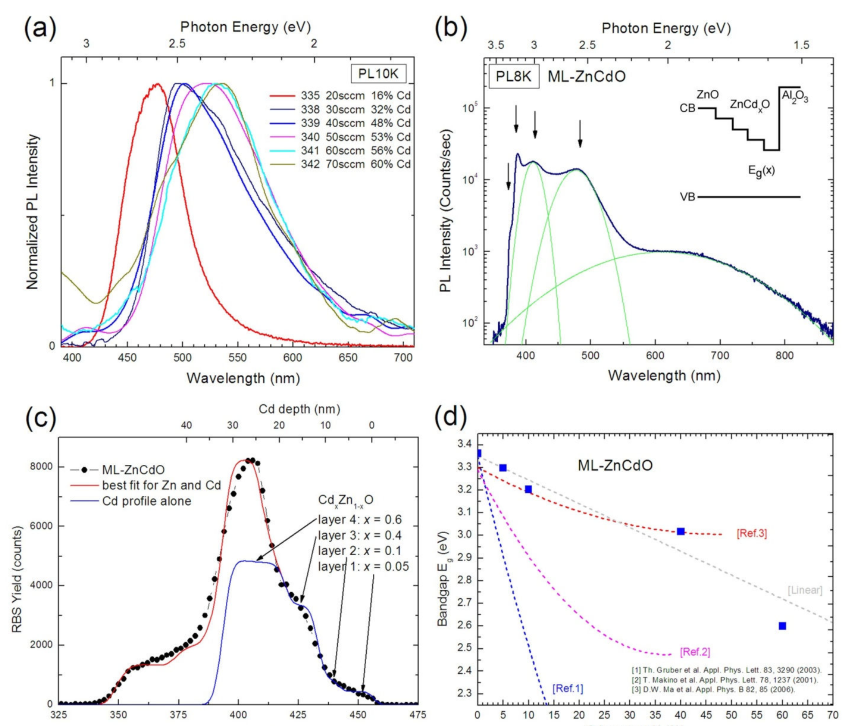


FIG.1. (a) Typical photoluminescence (PL) spectra from ZnCdO films as a function of Cd content; (b) PL spectrum of a ML-structure as recorded at 8K with a schematics of the band gap in the inset; (c) Cd profile through ML-structure as measured by RBS; (c) our results in the context of literature.

Lecture 22: Semiconductors, effective mass method, intrinsic carriers

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Effective mass method: nearly free electron in external electric field

$$< \mathbf{v_n(k)} >= \frac{< \mathbf{p} >}{\mathbf{m}} = \frac{\mathbf{1}}{\hbar} \nabla_{\mathbf{k}} \mathbf{E_n(k)}$$

$$\mathbf{F_{ext}} = \hbar \frac{\mathbf{dk}}{\mathbf{dt}}$$

Lets try to put these equations together....

$$a(t) = \frac{dv}{dt} = \frac{1}{\hbar}\frac{\partial}{\partial t}\frac{\partial E_N(k)}{\partial k} = \frac{1}{\hbar}\frac{\partial^2 E_N(k)}{\partial k^2}\frac{dk}{dt}$$

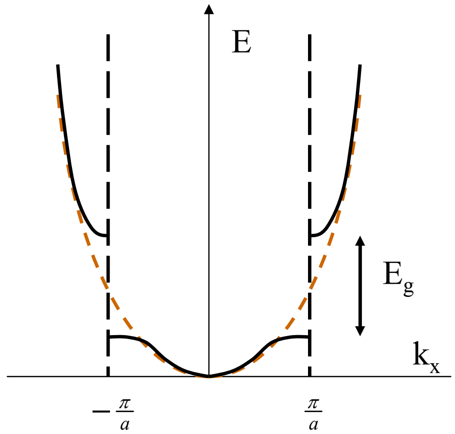
$$= \left[\frac{1}{\hbar^2}\frac{\partial^2 E_N(k)}{\partial k^2}\right] F_{\text{ext}}$$

Looks like Newton's Law if we define the mass as follows...

$$m^*(k) = \hbar^2 \left(\frac{\partial^2 E_N(k)}{\partial k^2}\right)^{-1}$$ effective mass

→ mass changes with k...so it changes with time according to k

Effective mass method: expanding E(k) in a band in Taylor series



$$f(a)+\frac{f'(a)}{1!}(x-a)+\frac{f''(a)}{2!}(x-a)^2+\frac{f^{(3)}(a)}{3!}(x-a)^3+\cdots$$

Effective mass method: solving Schrodinger equation without perodic potential for hydrogen-like behaiving impurities

Recall hydrogen model

1. (Bohr postulates)
Angular momentum is quantized. $L_n = m_0 v r_n = n\hbar \qquad n = 1, 2, 3, \ldots$

2. Centripetal force = columbic force $\frac{m_0 v^2}{r_n} = \frac{q^2}{4\pi\varepsilon_0 r_n^2}$

3. Solve for orbit radius $r_n = \frac{4\pi\varepsilon_0 (n\hbar)^2}{m_0 q^2}$

4. Write down the total energy

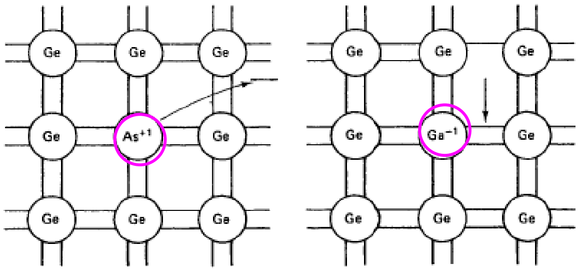
$$\text{K.E.} = \frac{1}{2}m_0 v^2 = \frac{1}{2}(q^2/4\pi\varepsilon_0 r_n)$$

$$\text{P.E.} = -q^2/4\pi\varepsilon_0 r_n \qquad (\text{P.E. set} = 0 \text{ at } r = \infty)$$

$$E_n = \text{K.E.} + \text{P.E.} = -\frac{1}{2}(q^2/4\pi\varepsilon_0 r_n)$$

$$\boxed{E_n = -\frac{m_0 q^4}{2(4\pi\varepsilon_0 n\hbar)^2} = -\frac{13.6}{n^2}\text{eV}}$$

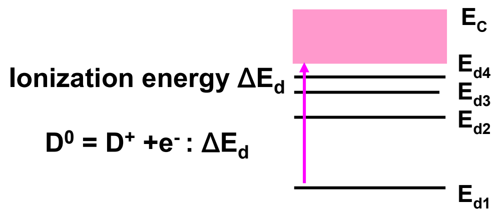
Effective mass method: solving Schrodinger equation without perodic potential for hydrogen-like behaiving impurities



Hydrogen model:

$$E_C - E_{im} = \frac{q^4 Z^2 m^*}{2n^2(4\pi\varepsilon\hbar)^2} = 13.6\left(\frac{Z}{n\varepsilon_r}\right)^2\left(\frac{m^*}{m}\right) eV$$

$$r_{.} = \frac{4\pi\varepsilon\hbar^2 n^2}{\ldots} = 0.53\frac{n^2\varepsilon_r}{\ldots}\left(\frac{m}{\ldots}\right) A$$



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Intrinsic carrier concentration in semiconductors

probability occupied by an electron:

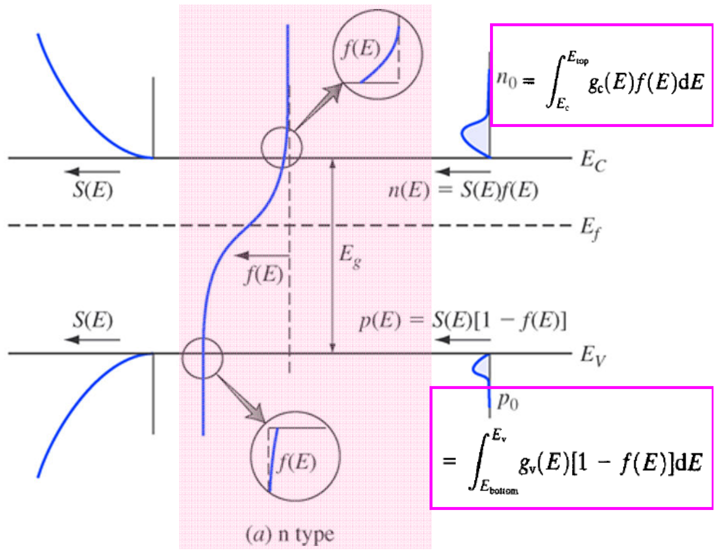
$$f(E) = \frac{1}{1+e^{(E-E_f)/kT}}$$

probability occupied by an hole (or not an electron):

$$1 - f(E) = \frac{1}{1+e^{-(E-E_f)/kT}}$$

E_f: *Fermi level*

Here *S(E)* is DOS or *g(E)*



$$n_0 = \int_{E_c}^{E_{top}} g_c(E) f(E) \mathrm{d}E$$

$$p_0 = \int_{E_{bottom}}^{E_v} g_v(E)[1 - f(E)] \mathrm{d}E$$

N_D^+ … Number of ionized donors per cm^3

N_D … Total donor concentration

N_A^- … Number of ionized acceptors per cm^3

N_A … Total acceptor concentration

***n_0* or** n … Electron concentration; total number of electrons per cm^3 in the conduction band.

***P_0* or** p … Hole concentration; total number of holes per cm^3 in the valence band.

n_i … Intrinsic carrier concentration; electron and hole concentration in intrinsic material.