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Wed. Nov. 21

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- last time we started talking about doping semiconductors, which typically is to increase conductivity

- recall an "intrinsic" semiconductor has a narrow enough bandgap so some electrons in the valence band (v.b.) are excited into the conduction band (c.b.)

$$n \propto e^{-E_g/2k_BT}$$

where n = # electrons in c.b.

- for intrinsic semiconductors, the # of holes in V.b. equals n: $n = p$

- with "doped" semiconductors (extrinsic), we alter the ratio of conduction electrons to holes (away from $\frac{n}{p} = 1$)

- <u>Example of doping</u>: Si doped with As

◉ As → pentavalent
○ Si → tetravalent

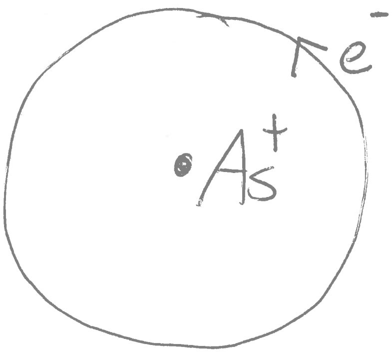
- one e^- does not take part in a bond & so is partially free to move through lattice
- As is an "n-type" donor because it donates a negatively charged electron
- Conversely, Al is a "p-type" donor, as it donates a hole (positive)

III	IV	V
Al	Si	P
Ga	Ge	As

p-type
column III

n-type
column V

- one additional note about the extra electron from n-type donors: they are not part of a molecular bond; however, they are bound by the positive nucleus of the donor



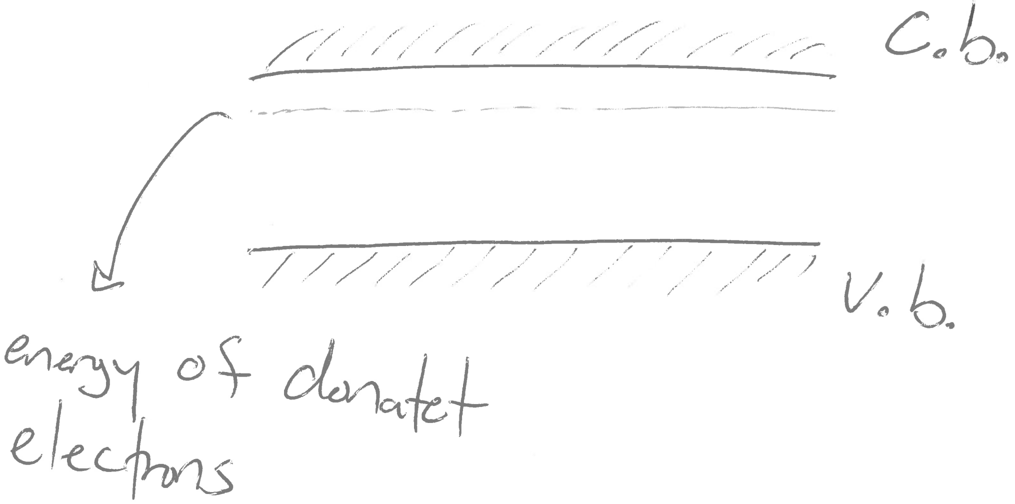
- behavior is not entirely dissimilar to the H-atom, with

$$V = \frac{e^2}{4\pi\epsilon r}$$

but note $\epsilon \neq \epsilon_0$, where ϵ is the permittivity of the materials arising from charges (other electrons + protons)

- binding much weaker than H atom, ~$\frac{1}{500}$th of binding energy in some cases

- because the binding energy is weak, these electrons (from the donors) have energies almost as high as those in the c.b.



- the gap from this level to the lower band edge of c.b. is narrow; thus, at room T, almost all of these electrons have been excited into the c.b., drastically changing the semiconductor's conductivity

- a similar phenomenology holds for p-type semiconductors

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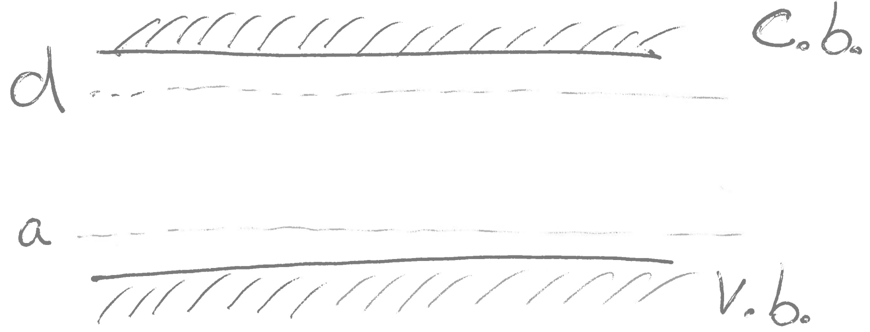
- a general band diagram has both donor (d) + acceptor (a) levels



- at room T, we expect a large portion of the acceptor level to be filled at the expense of the V.b.

- Critically, the current supplied by acceptors is actually in the V.b. due to the absense of electrons in that band that have been excited into the acceptor level (in forbidden energy gap)

- note that electrons in acceptor level do not contribute to current, but holes in V.b. do

- We may also "engineer" the band gap by alloying
  - Ex: aluminium - gallium - arsenide
    $\overset{}{\underset{III}{\text{aluminium}}} - \underset{III}{\text{gallium}} - \underset{V}{\text{arsenide}}$
    - alloy: $Al_xGa_{1-x}As$; $x \equiv$ fraction of Al
    - GaAs : $E_g = 1.4\,eV$
    - AlAs : $E_g = 2.7\,eV$
    - for $Al_xGa_{1-x}As$: $E_g = (1-x)1.4\,eV + x\,2.7\,eV$
    - thus we may alter the band gap arbitrarily between 1.4eV + 2.7eV by changing ratio of elements in alloy