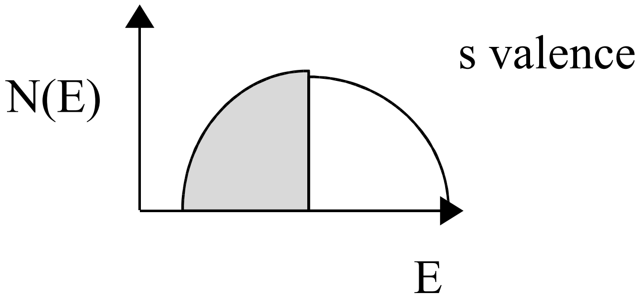
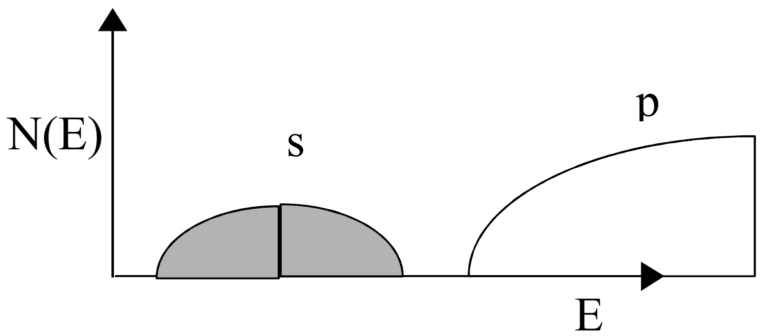
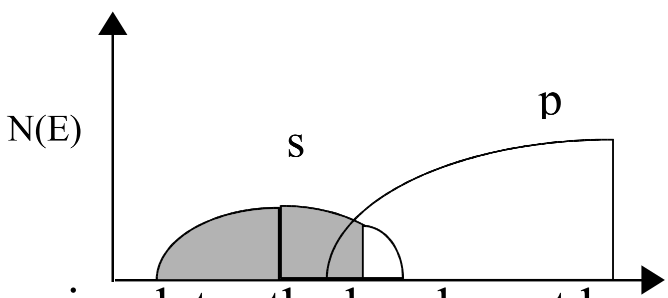
Electrical conductivity

Conductor, has a partially filled band.
alkali metal
Na, K we have an ns band, which can contain 2 electrons per atom. Since we only have one electron per atom we have a half-filled band.



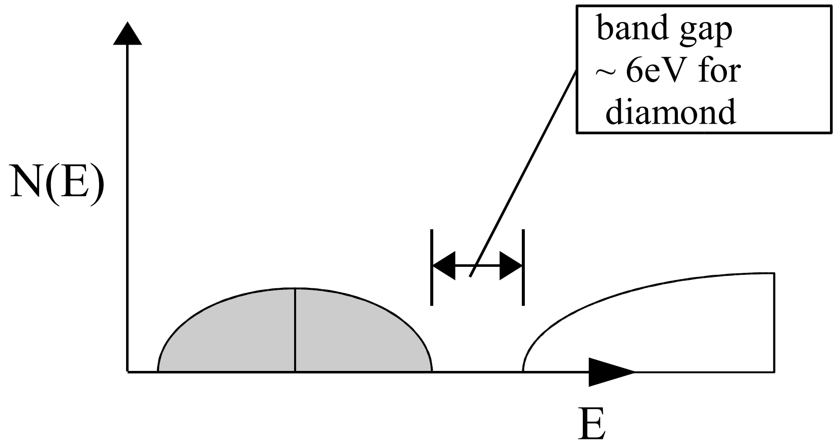
Alkaline earth. Not so straightforward.
Simplistically we have an ns band and 2 electrons per atom hence a completely filled s band - no conductivity - an insulator. However, this ignores the overlap between the s and p. With this overlap we can now get conductivity.





For an insulator the band must be completely full or empty.

For an insulator the band structure would be:



Between an insulator and a conductor is a semiconductor: Here the band diagram is similar to an insulator except the band gap is smaller, typically 0.5 to 3.0 eV. Electrons can now be promoted into the empty band by an outside stimulus such as light, hν, or simply thermal energy.

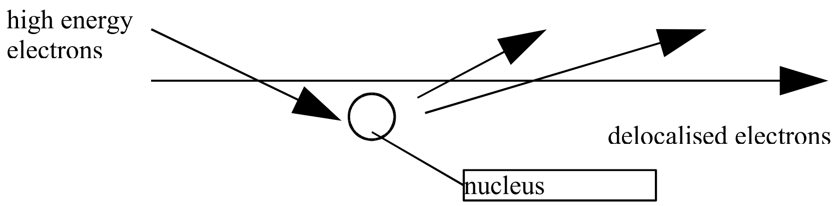
Two types of conduction mechanism in a semiconductor: electrons and positive holes.

- electrons in the conduction band

- positive holes, vacant electron levels that are left behind in the valence band.

Evidence for bands

x-ray emission and absorption:



High energy electrons displace inner core electrons, when outer shell electrons fall back to occupy this level characteristic x-ray frequencies are emitted.

Transitions between inner or core levels are sharp showing the electrons come from discrete orbitals, e.g. 2p-1s in Cu.

On the otherhand consider the n=3 to n=2 transitions in Al. This spans a range of 13eV. Cut-off at ~73 eV represents electrons that are in the 3p and close to the Fermi energy. Emission shape is similar to the shape of the theoretical band. Shows the valence electron can drop from an orbital spanning broad range in energies as would be expected for a band.

Types of semiconductor

Intrinsic

Semiconductivity is found in the pure material with the number of electrons, n, in the conduction band governed only by:
I) Magnitude of the band gap
II) Temperature [Boltzmann distribution]

Examples are Group IV elements ;
diamond (6.0 eV) insulator
{silicon (1.1 eV), germanium (0.7 eV),
grey tin (0.1 eV); semiconductors}
white tin (0 eV), metal Pb (0 eV) metal

Question - why is silicon not metallic?
Why do the 3s and 3p bands not overlap as they do for Na and Mg?

No simple answer -
- detailed quantum mechanical description
- different crystal structure to Na and Mg.

Extrinsic

Conductivity controlled by the addition of dopants.

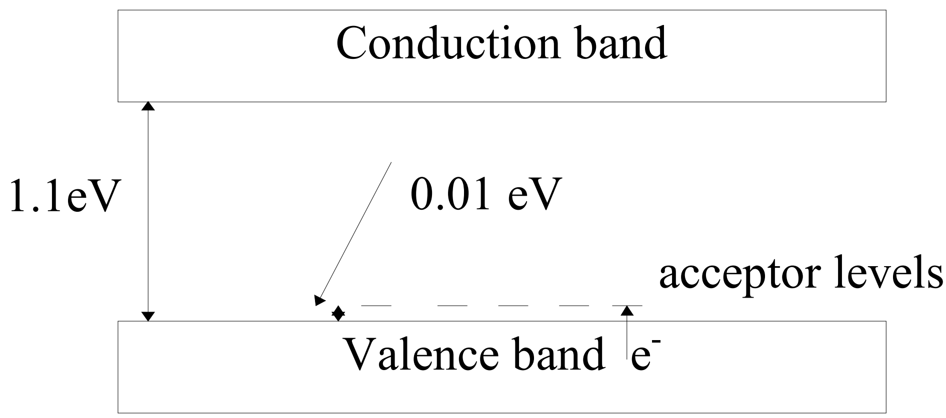
- n-type , electron rich atom such as P
- p-type , electron deficient atom such as B
- add small amounts 10^{-2} atom %.

Do not add/remove electrons from existing bands

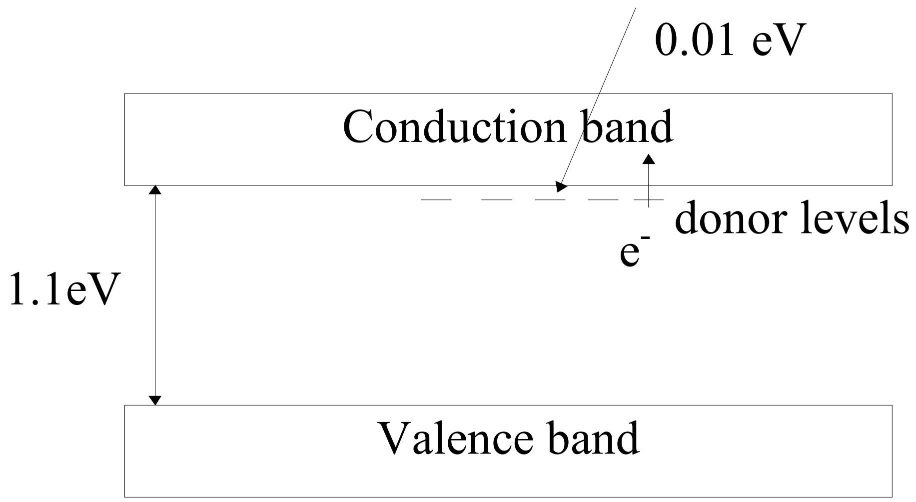
Create donor or acceptor levels close to original bands ~ 0.1 eV away

No conduction with donor/acceptor levels

p-type (B,Ga)
Acceptor level



n-type (P,As)
Donor level

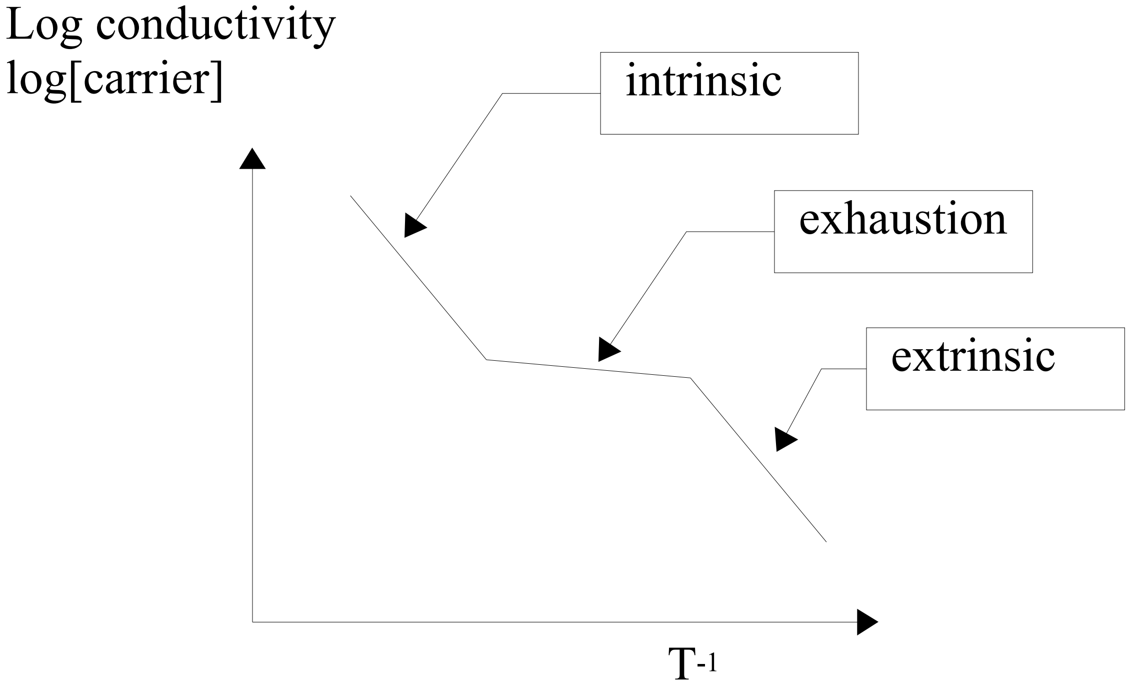


Note:

1.Extrinsic semiconductors have much higher conductivities than intrinsic ones are room temperature. At 25^{o}C pure silicon instrinsic ~10^{-2} Scm^{-1} extrinsic several orders of magnitude higher.

2.Can accurately control the conductivity of extrinsic semiconductors by controlling the concentration of dopant

Temperature dependence



Extrinsic

- carrier concentration at low temperatures variable because the band gap of ~0.1 eV is large compared to thermal energies.
- determined by the dopant concentration.

Exhaustion region

- concentration of extrinsic carriers is at a maximum
- conductivity and concentration of carriers now independent of temperature.
- desirable to have materials in the exhaustion region Relatively insensitive to temperature changes

Intrinsic

- At still higher temperatures the intrinsic carrier concentration exceeds the extrinsic and so both carrier and conducitivity increase again.