The total number or maximum number (***Ne***) of electrons that can occupy any principal quantum number ***n*** is

$$N_e = 2n^2$$

Quantum Sub-shells

The principal quantum shells, apart from the first, are split into sub-shells. Each principle quantum shell contains a different number of sub-shells. The first energy level contains one sub-shell, the second energy level contains two and so on. The sub-shells are distinguished by letters s, p, d, f, and so on. The energy of electrons in the sub-shells increases in the order **s** < **p** < **d** < **f.**

The contents the subshells in each shell are shown in the table below.

Principal Quantum Shell	*Max Number of Electrons*	*Sub-shell*	*Capacity*	*Name of sub-shell*
K (n = 1)	2	s	2	1s
L (n = 2)	8	s	2	2s
		p	6	2p
M (n = 3)	18	s	2	3s
		p	6	3p
		d	10	3d
N (n = 4)	32	s	2	4s
		p	6	4p
		d	10	4d
		f	14	4f

Not every electron is constrained to forever occupy a certain shell or subshell of an atomic nucleus. Although electrons tend to remain in their shells because of their force of attraction to the positively charge nucleus, some of them acquire enough energy (e.g. from heating) to break away from their

ρ = resistivity of the material, $\Omega\,.\,\mathrm{m}$

l = length, m

A = cross-sectional area, m^2

The *conductance*, G, of the material, which is defined as the reciprocal of resistance, units Siemens (S). This implies that *conductivity, σ*, is the reciprocal of resistivity:

$$\sigma = \frac{1}{\rho}$$

Thus the units of conductivity are $1/(\Omega\,.\,\mathrm{m})$ or siemens/meter (S/m).

Recall that,

$$\begin{aligned} \mathrm{J} = J_n + J_p &= nq_n\mu_n\bar{E} + pq_p\mu_p\bar{E} \\ &= \left(nq_n\mu_n + pq_p\mu_p\right)\bar{E} \\ &= \sigma\bar{E} \end{aligned}$$

the expression $\left(\mathrm{nq_n\mu_n + pq_p\mu_p}\right)$is equal to the conductivity, σ, of the material. It is evident from the above equation that current density within a semiconductor is directly proportional to the applied electric field.

For an intrinsic semiconductor, $n = p = n_i$, therefore,

$$J = n_i\left(q_n + q_p\right)q\bar{E}$$

and conductivity of an intrinsic semiconductor is

$$\sigma_i = n_i q\left(q_n + q_p\right)$$

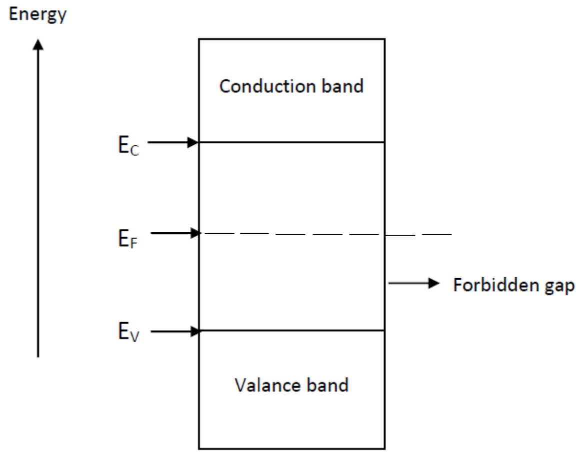
NB: In general the *conductivity any semiconductor* is computed as shown:

$$\sigma = nq_n\mu_n + pq_p\mu_p$$

Example 2

a) Compute the conductance and resistivity of the intrinsic silicon bar in ***Example 1.***

b) Use the results of (a) to find the current in the bar when the 18 V potential difference is applied to it.

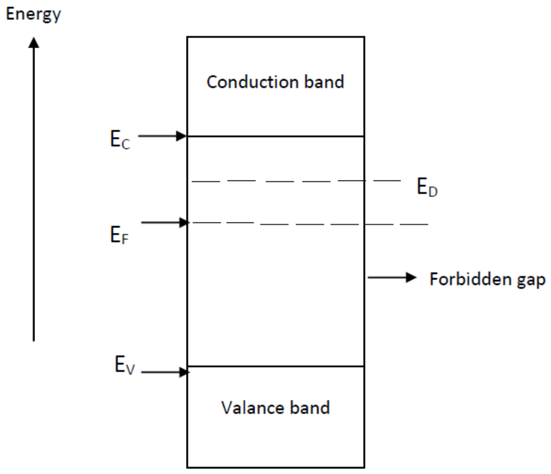


Energy band diagram showing the Fermi level E_F

of an intrinsic semiconductor

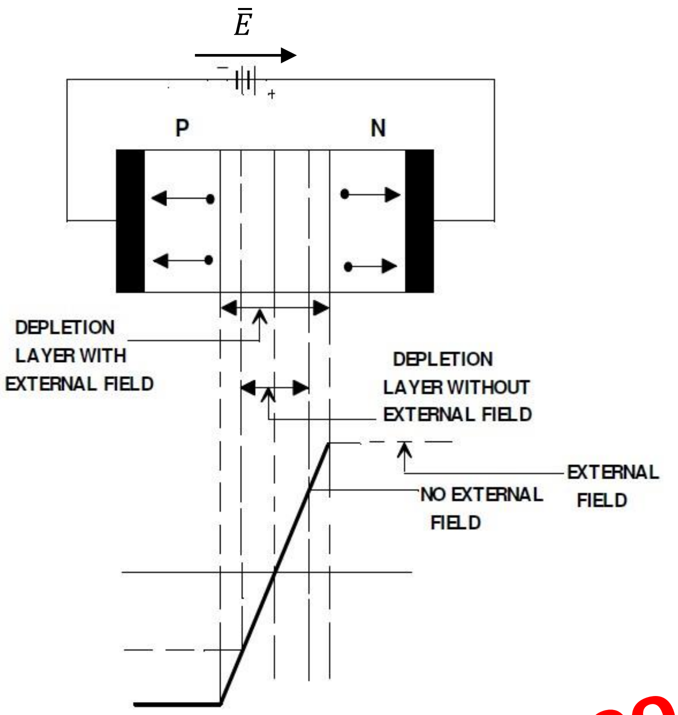
Fermi-level of a N-type semiconductor

For a *N*-type semiconductor, when donor atoms are added, they provide a *Donor energy level*, E_D which is just below the *conduction band* E_C. The donor electron can easily be excited to the conduction band, thus becoming one of the conduction electrons moving freely through the semiconductor. When a potential difference is applied, these electrons will move in the conduction band in a direction opposite to that of the electric field to produce current flow.



Energy band diagram showing the Fermi level E_F

of a N-type semiconductor



I-V Characteristics of the *P-N* junction

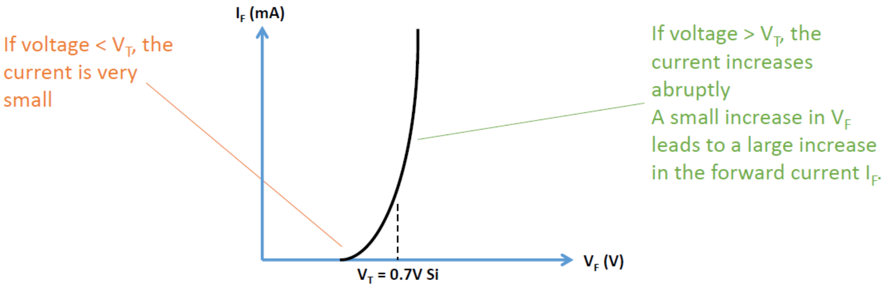
A graph between current and voltage applied across the *P-N* junction is called characteristics of the *P-N* junction

If the forward current is to be treated as positive (upwards), then the reverse current should be below the horizontal axis, i.e. downwards or negative. Similarly, forward voltage is plotted to the right of 0 and reverse voltage to the left of 0 i.e. in negative direction.

Forward Characteristics:

When the external voltage is zero, i.e., when the circuit is open, the potential barrier at the junction does not allow the flow of current and, therefore, the circuit current is zero.

- Forward biased V-I characteristics



long should the bar be in order for the current in it to be 1.2 mA when 9V is applied to its ends?

15. A silicon PN junction is from N material doped with $2.5 \times 10^{21}\ \mathrm{donors/m^3}$ and P material doped to have the same impurity density. Find the thermal voltage and barrier voltage at 40^{o}C.
16. A silicon p-n junction has a saturation current of $1.8\ \times 10^{-14}$A at 27℃ . Assuming $\eta = 1$ find its current when it is forward bias voltage is 0.6V and 0.65V

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