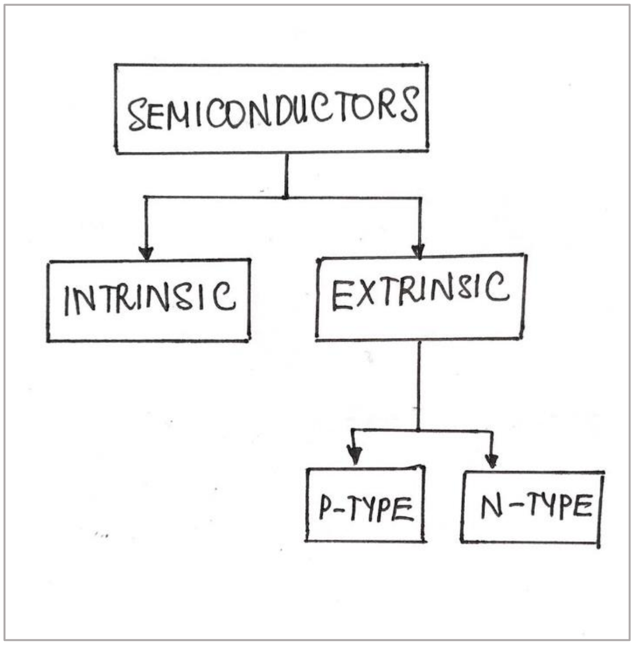
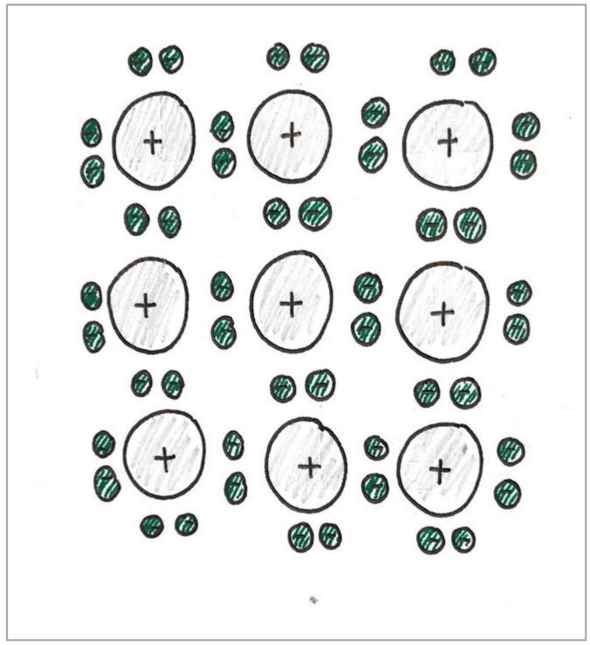
Doping

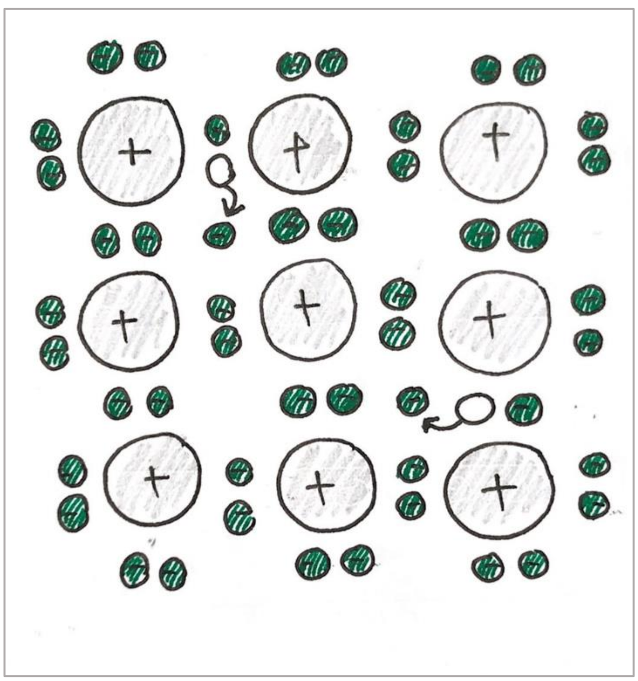
Lesson I – Intrinsic and Extrinsic Semiconductors (no band diagram)



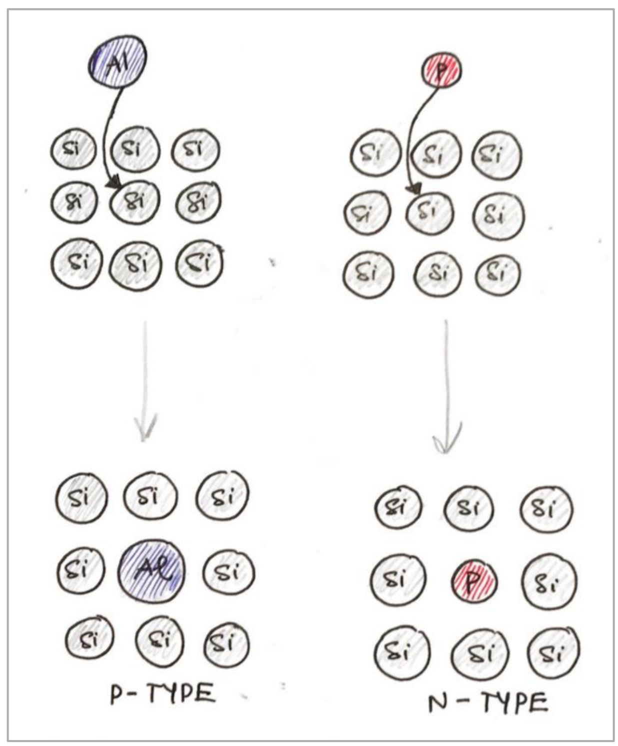
Apart from LED, semiconductors are extensively used in the field of electronics. Semiconductors are classified according to the materials that make them. Each type has different properties and is used in different applications.



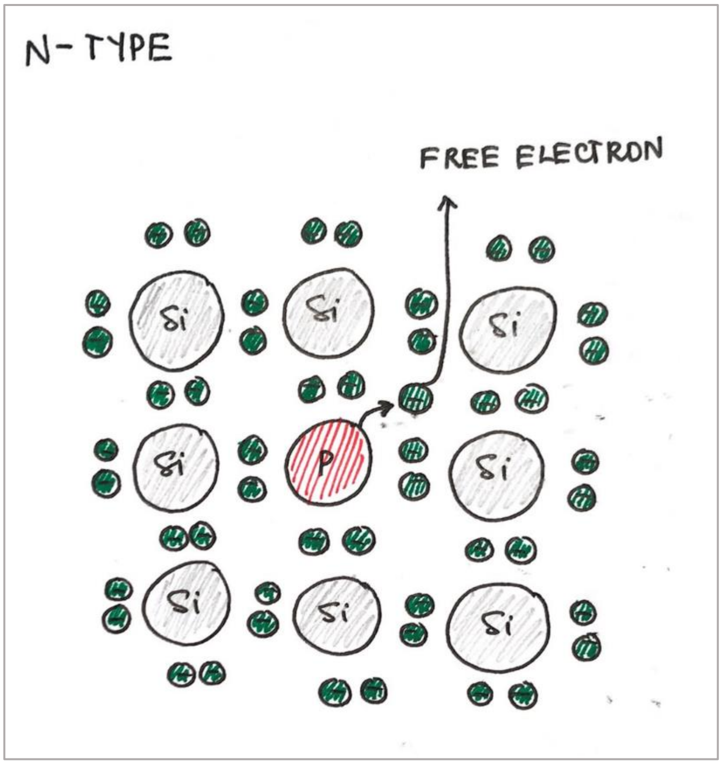
Intrinsic semiconductors are made from materials in their pure forms (undoped). Examples include pure Si, pure Ge, pure GaAs. A Si atom has 4 valence electrons and can bond with its 4 nearest neighbours.



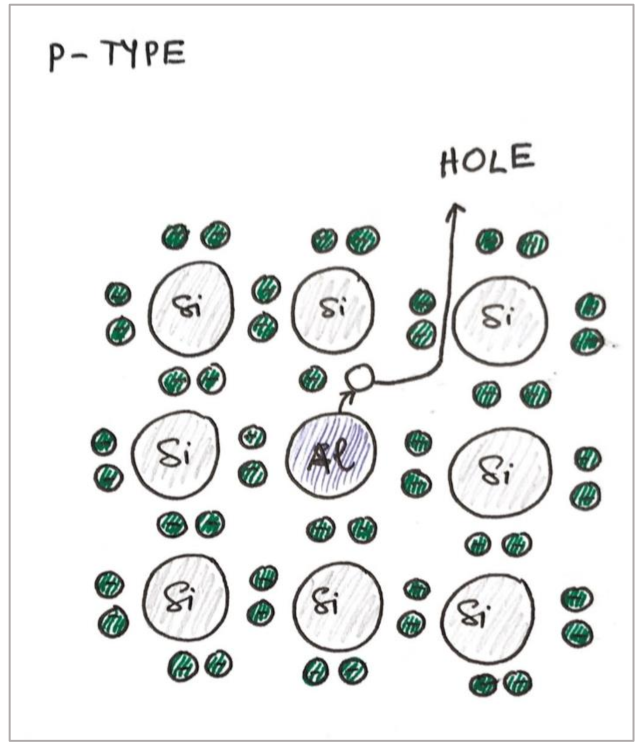
The valence electrons used in bonding cannot carry a current. Only when there is enough thermal energy, the valence electrons can escape the bond to travel around the lattice freely and carry an electric current.



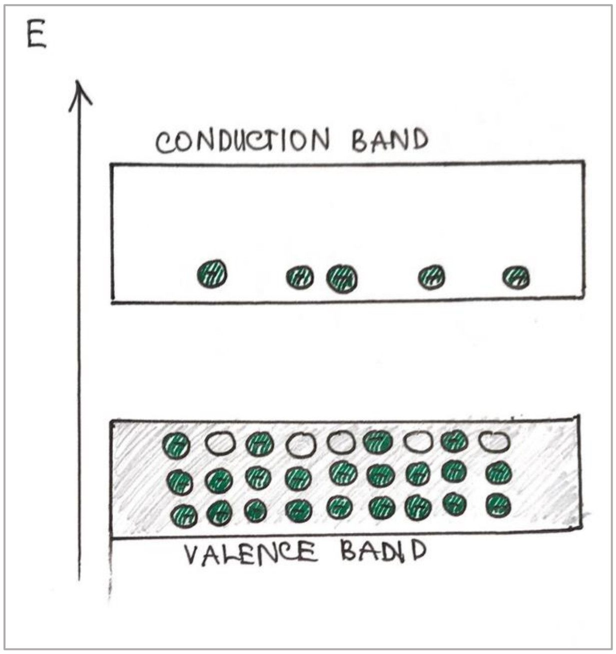
Extrinsic semiconductors are made by doping. By adding small fraction of impurity atoms with 1 extra or 1 fewer valence electron to a pure material (Si), we can increase the number of charge carriers.



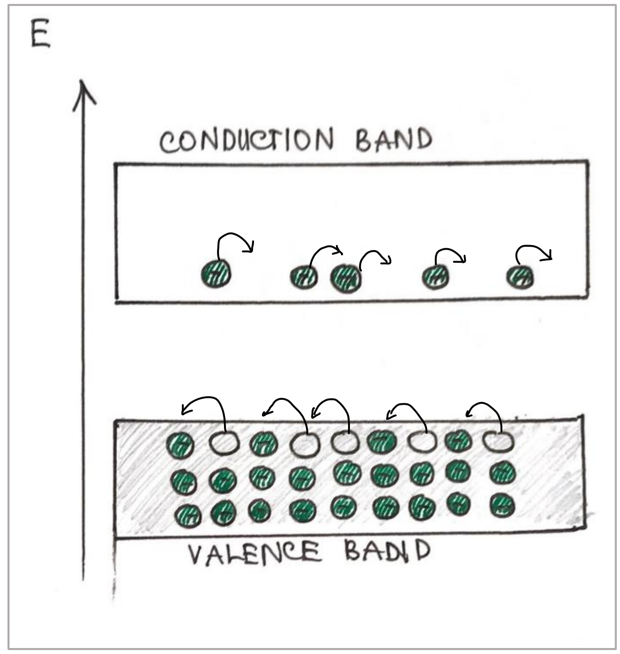
When an P atom (5 valence electrons) is added to Si, it brings with it 1 extra electron. The semiconductor has more mobile charges so it conducts better. We call this an N-type semiconductor.



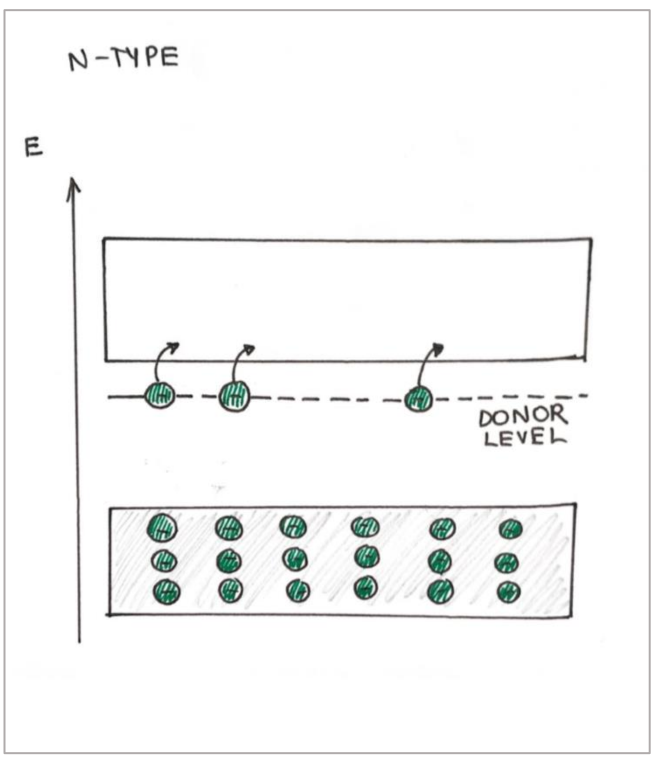
When an Al atom (3 valence eletrons) is added to Si, a hole is created due to the lack of electron. This still increases the number of charge carrier because an electron can move in to the hole. Equivalently, we can talk about the hole moving around, acting like a positive charge. Therefore, we call this an P-type semiconductor.



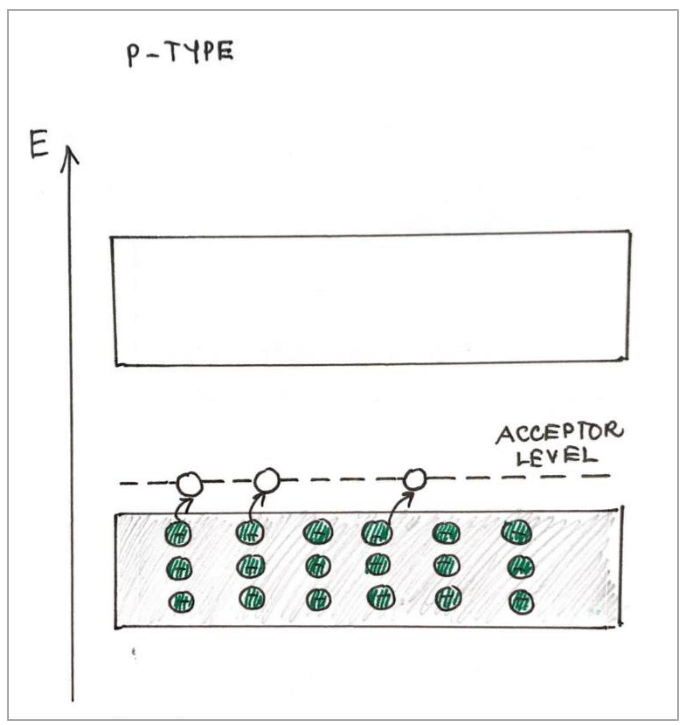
When electrons from valence band are excited to conduction band, they leave behind holes in the valence band. This means that the number of holes and free electrons woking as charge carriers in an intrinsic semiconductors are the same



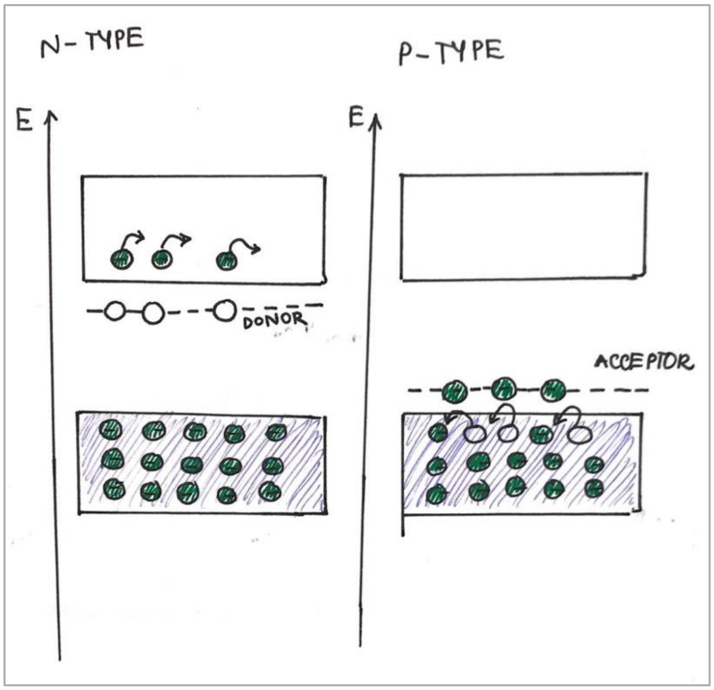
When an electric field is applied: electrons at the bottom of the conduction band moves in one direction. The electrons moves fill the holes, which is equivalent to the holes at the top of the valence band moving in the opposite direction.



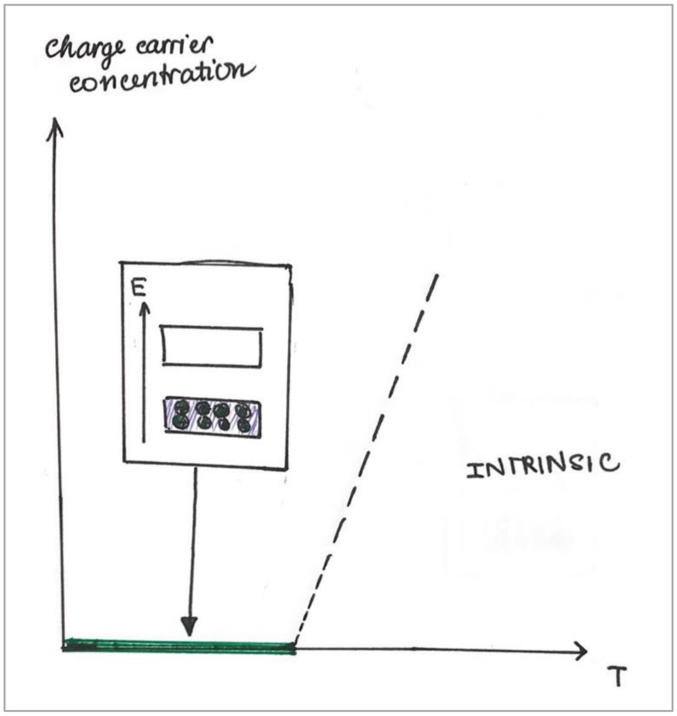
In a N-type semiconductor, the extra valence electrons from impurities fill the energy level just below the conduction band called the donor level. These donor electrons can be excited, i.e donated, to the conduction band with little thermal energy supplied.



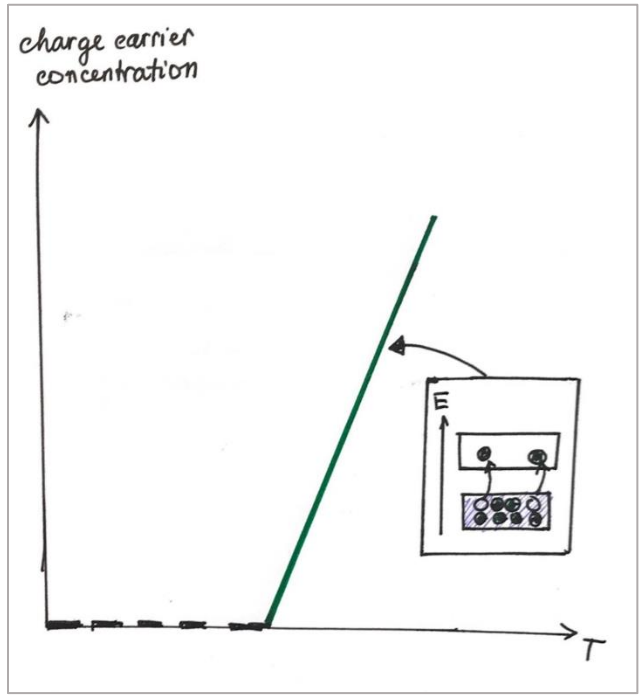
In a P-type semiconductor, the holes created from impurities fill the energy level just above the valence band called the acceptor level. These acceptor hole can be excited into the valence band, or in other words they can accept electron from the valence band, with little thermal energy supplied.



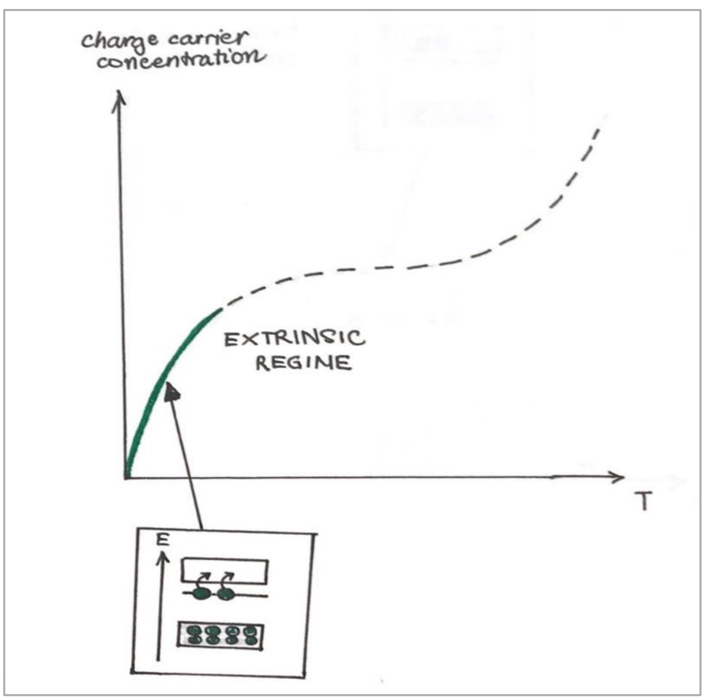
In an N-type semiconductor, electrons are the majority charge carriers. In a P-type semiconductor, holes are the majority charge carriers. When a donor state empties or an acceptor state fills, it is ionised.



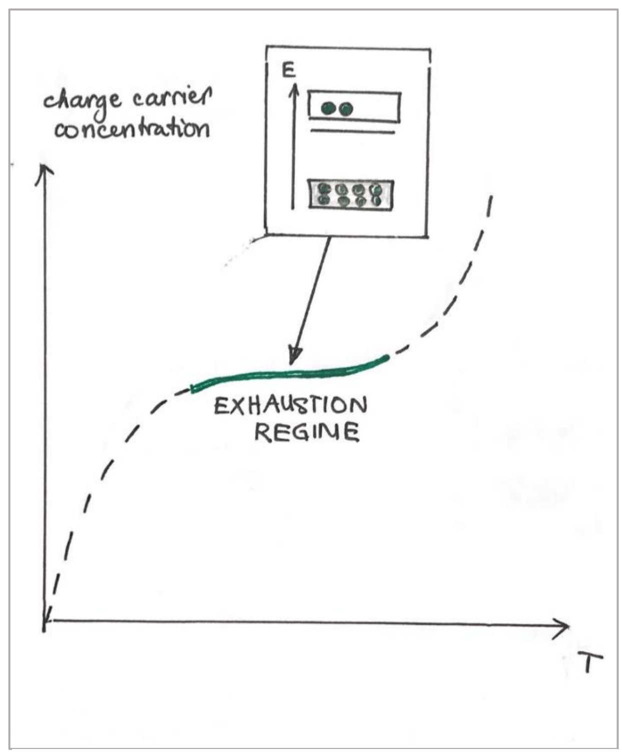
In this lesson, we are going to look at the temperature dependence of charge carrier concentration in a semiconductor. For an intrinsic semiconductor, below a certain temperature, there is not enough energy to excite across the band gap.



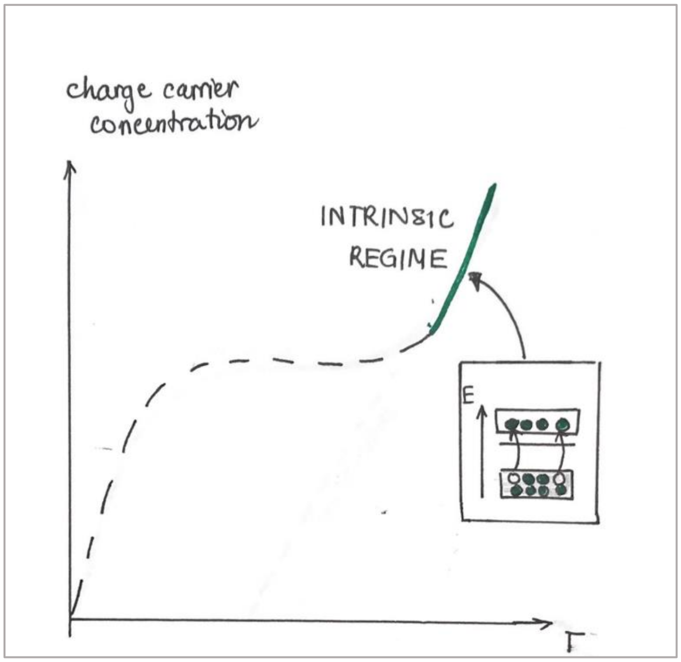
As temperature increases passing a certain point, the electrons in valence band overcome the energy barrier and moves up to the conduction band. The carrier concentration therefore increases.



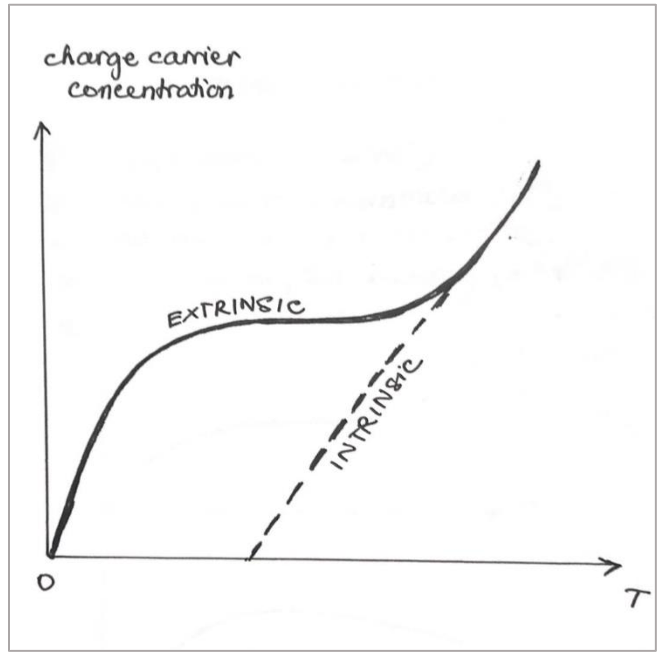
The behaviour of an extrinsic semiconductor is different. Take an N-type semiconductor for example. As temperature increases, the donor electrons overcome the small barrier and moves up to the conduction band, so the carrier concentration increases.



Once all the electrons have been excited from the donor levels, all dopants are ionised and therefore “exhausted”. Any furthur increase in temperature causes little change in number of electrons conducting in the conduction band.



At high temperature, there is enough energy to excite electrons from the valence band straight to the conduction band across the band gap. The extrinsic semiconductor now behaves like an intrinsic one.



The case is very similar with a P-type semiconductor, with the charge carriers being holes in this case.