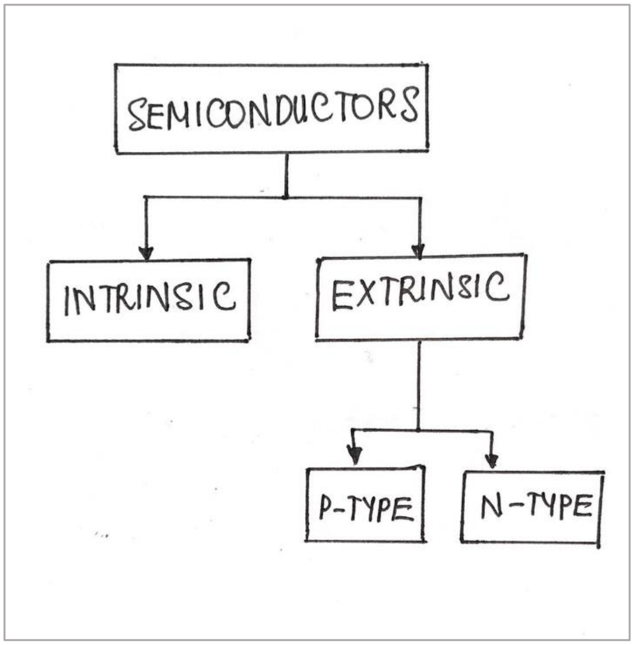
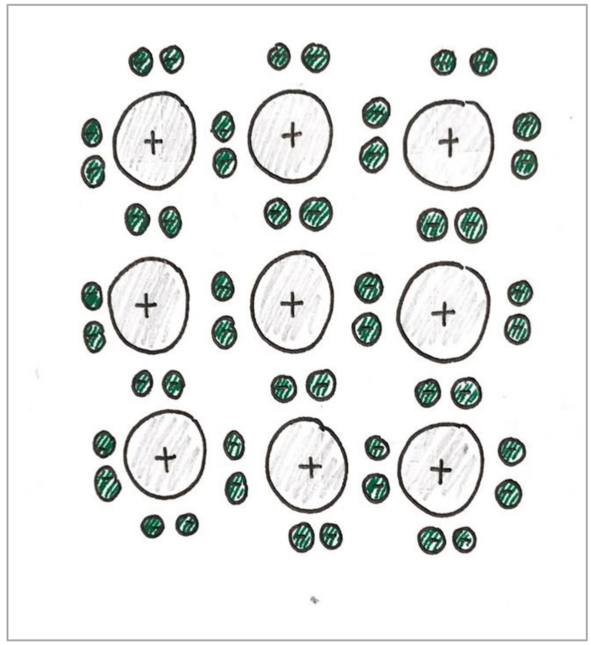
Doping

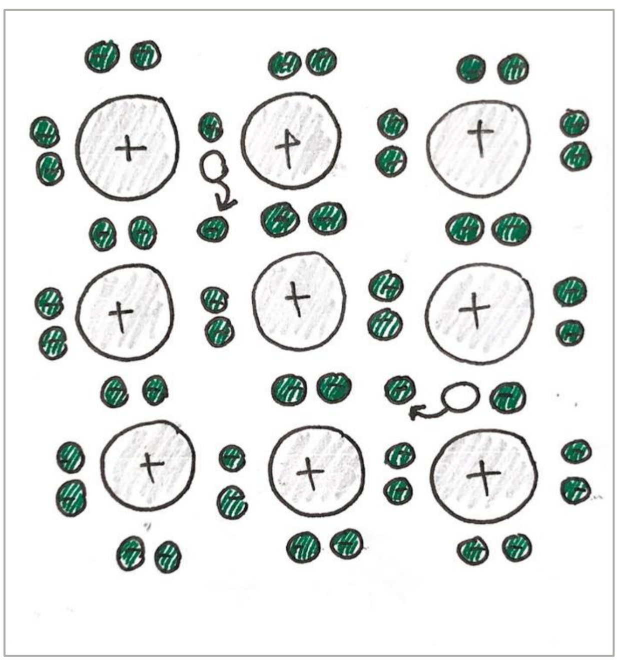
Lesson I – Intrinsic Semiconductors



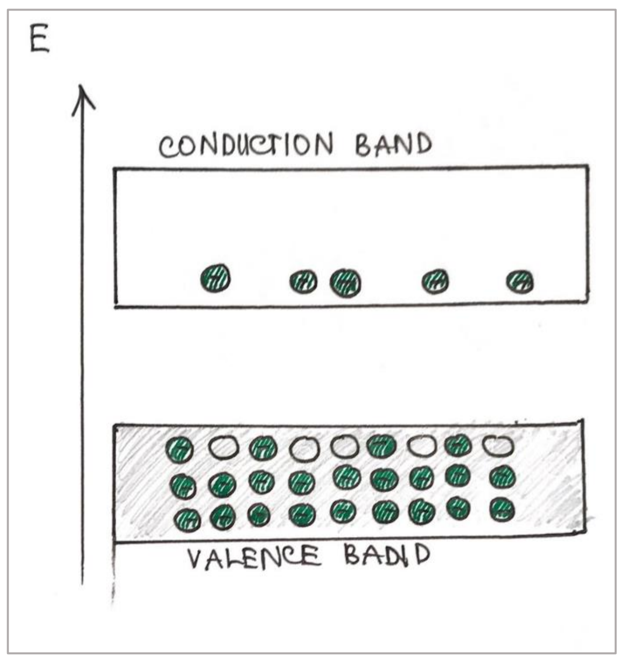
Apart from LED, semiconductors are extensively used in the field of electronics. Semiconductors are classified according to the materials that make them. Each type has different properties and is used in different applications.



Intrinsic semiconductors are made from materials in their pure forms (undoped). Examples include pure Si, pure Ge, pure GaAS.

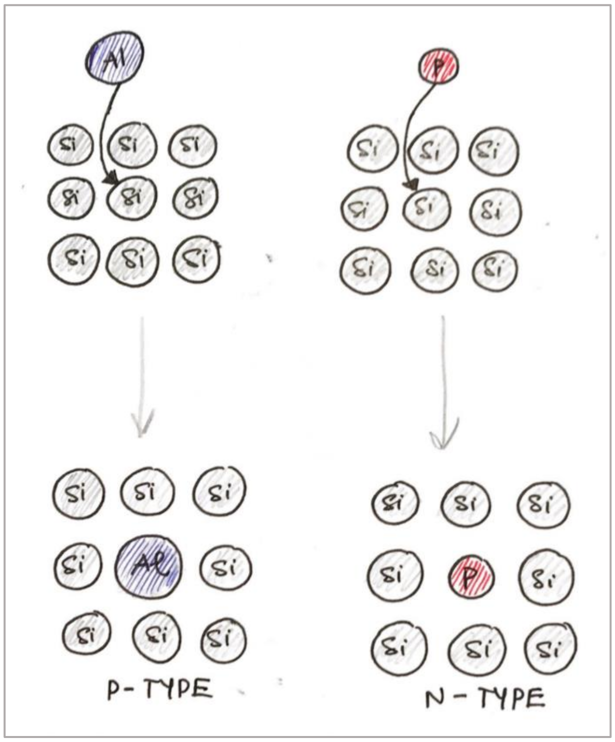


When there is enough thermal energy, the valence electrons are excited to the conduction band. This results in free electrons in the conduction band and leaves holes in the valence band. The numbers of free electron and holes are therefore equal.

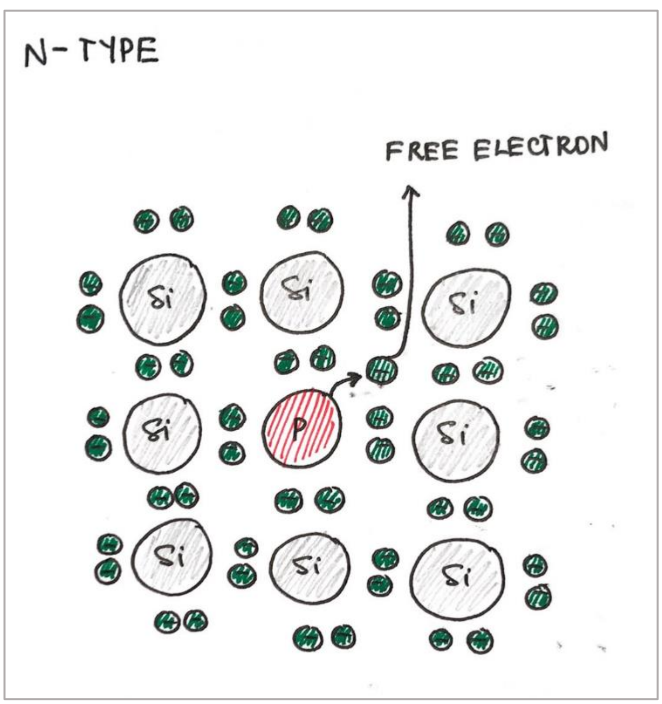


When an electric field is applied: electrons at the bottom of the conduction band moves in one direction. The electrons moves fill the holes, which is equivalent to the holes at the top of the valence band moving in the opposite direction. The movement of both holes and electrons contribute the to conductivity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

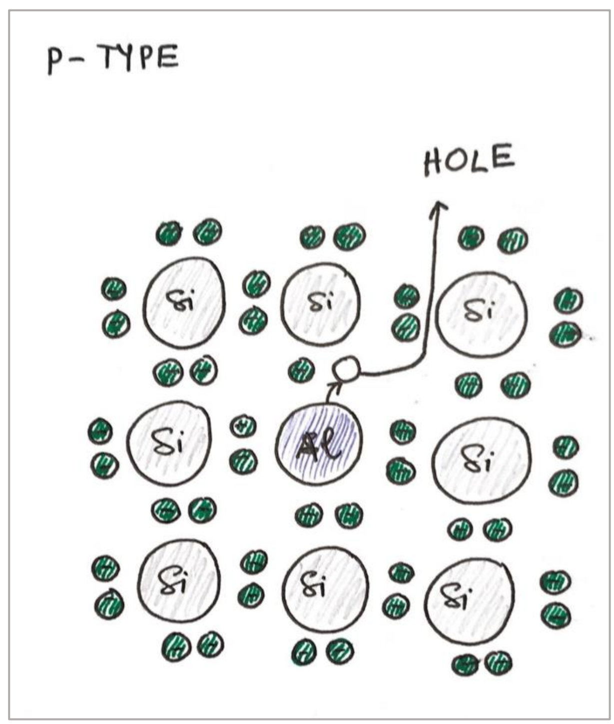
Lesson II – Extrinsic Semiconductors



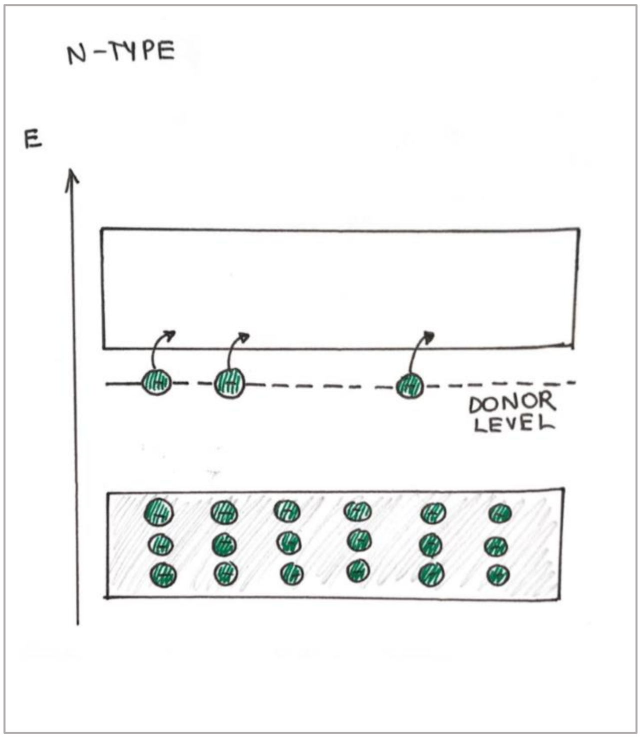
Extrinsic semiconductors are made by adding small fraction of impurities to pure materials, a process called doping. With Si (4 valence electrons), this can be done with either a group III element (3 valence electrons) or a group V element (5 valence eletrons.)



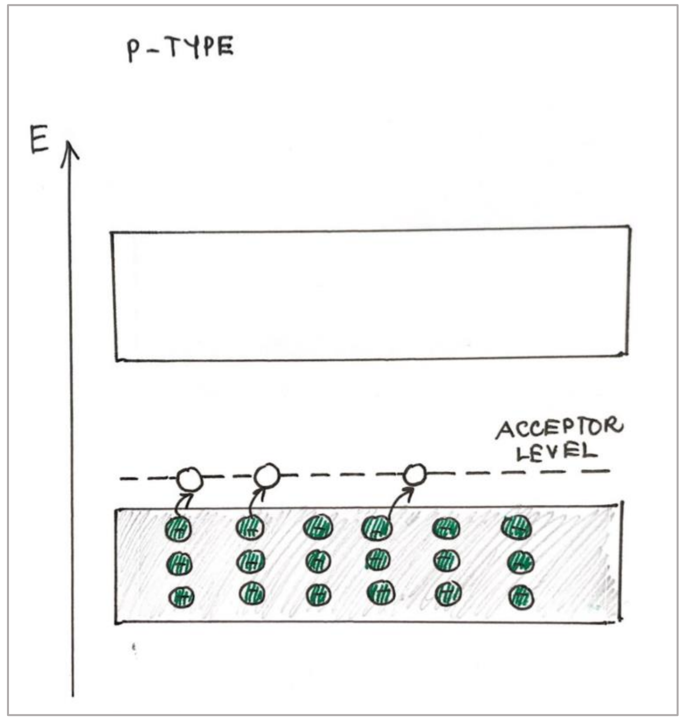
When an P atom is added to Si, 4 of the valence electrons are used in bonding with Si while 1 electron remains free. When an electron field is applied, the free electron behaves like a negative charge moving towards the positive electrode. Therefore, we call this an N-type semiconductor.



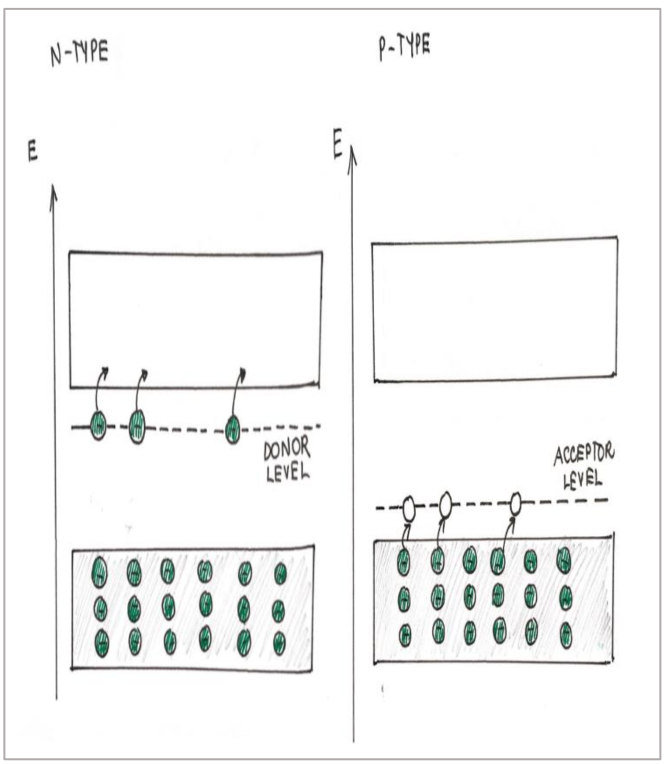
When an Al atom is added to Si, all 3 of the valence electrons are used in bonding, leaving 1 electron in Si unable to form bond. This leaves a hole in the lattice. When an electron field is applied, the hole behaves like a positive charge moving towards the negative electrode. Therefore, we call this an P-type semiconductor.



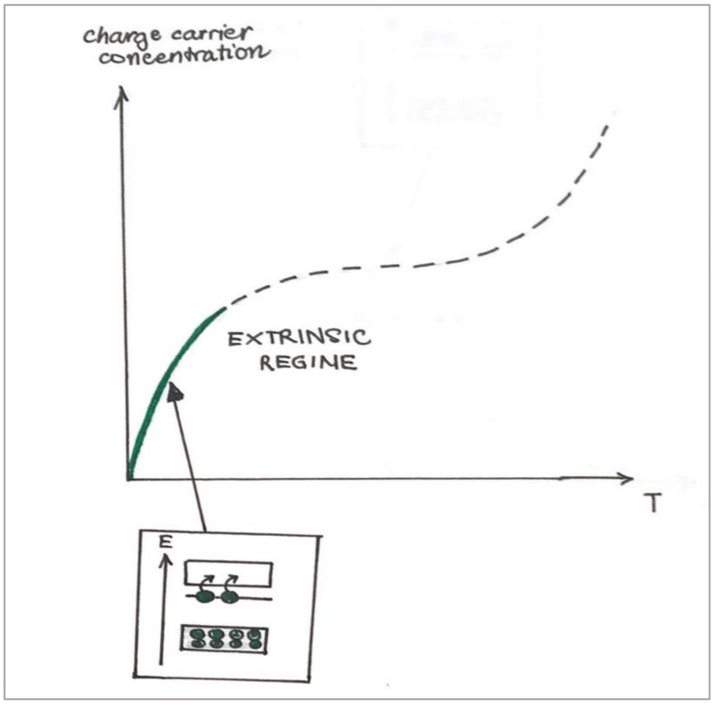
In a N-type semiconductor, the extra valence electrons from impurities fill the energy level just below the conduction band called the donor level. These donor electrons can be excited, i.e donated, to the conduction band with little thermal energy supplied.



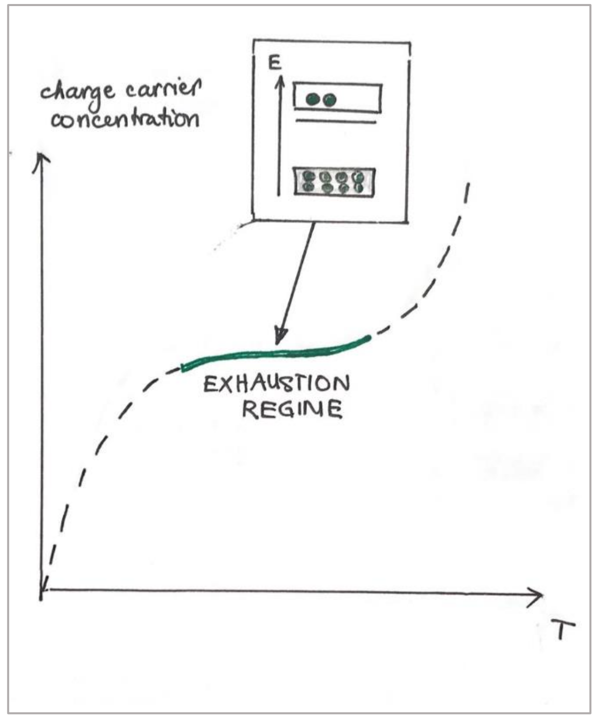
In a P-type semiconductor, the holes created from impurities fill the energy level just above the valence band called the acceptor level. These acceptor hole can be excited into the valence band, or in other words they can accept electron from the valence band, with little thermal energy supplied.



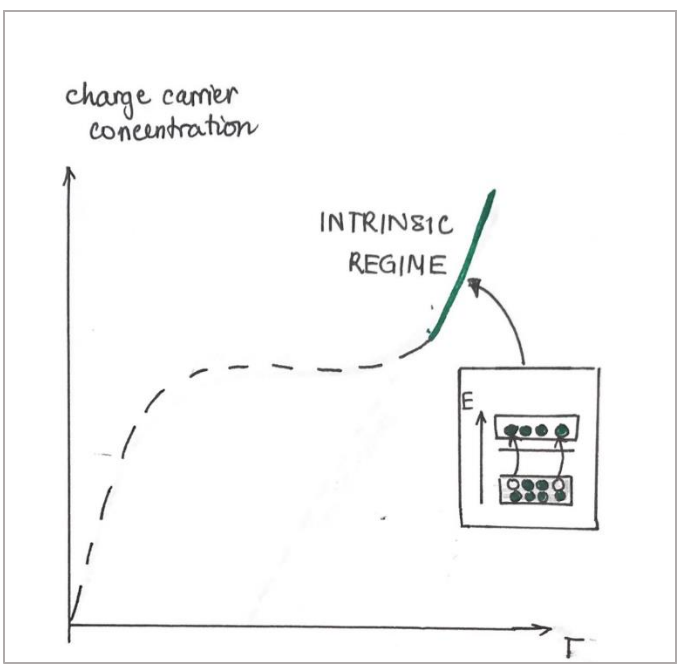
In an N-type semiconductor, electrons are the majority charge carriers. In a P-type semiconductor, holes are the majority charge carriers. Doping levels are typically of the order of one impurity atom per million host atoms. When a donor state empties or an acceptor state fills, it is ionised.



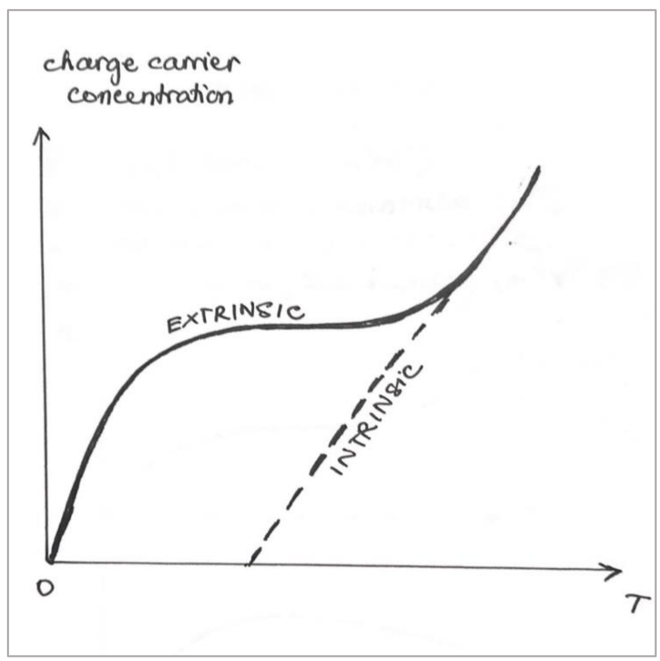
In this lesson, we are going to look at the temperature dependence of charge carrier concentration in a semiconductor. Take an N-type semiconductor for example. At 0K, there is no energy to excite donor electrons. As temperature increases, the donor electrons overcome the small barrier and moves up to 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 "axhausted". Any furthur increase in temperature causes little change in number of electrons conducting in the conduction band.



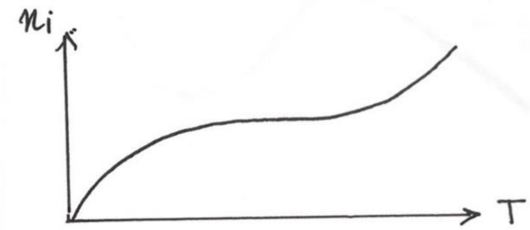
At high temperature, there is enough energy to excite electrons from the valence band straight to the conduction band across the band gap. The extrinsic semiconductor now behaves like an intrinsic one.

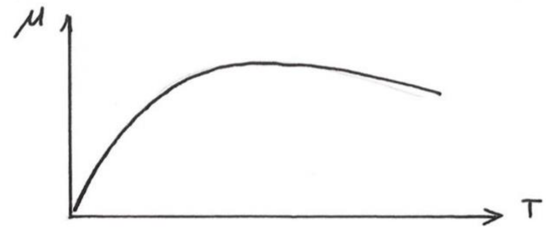


The case is very similar with a P-type semiconductor, with the charge carriers being holes in this case.

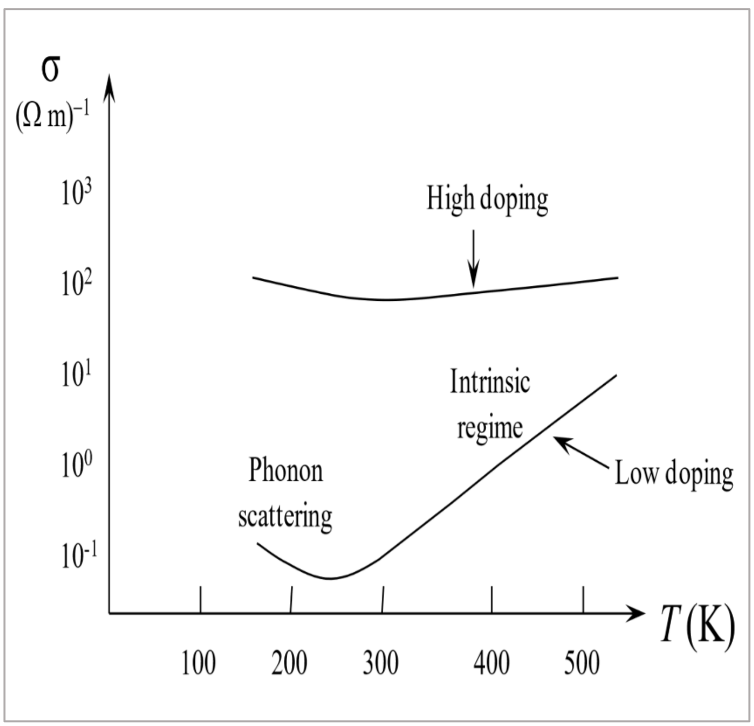
$$\boxed{\sigma = n_i e (\mu_e + \mu_h)}$$

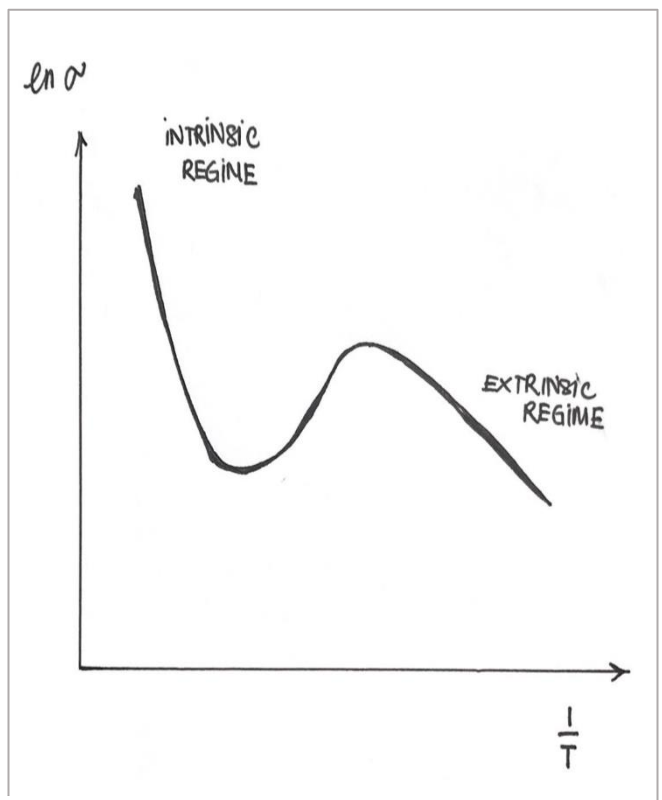
σ = conductivity ($\Omega^{-1} m^{-1}$)
n_i = charge carrier concentration (m^{-3})
e = electronic charge = 1.60×10^{-19} C
μ_e, μ_h = electron, hole mobility ($m^2 V^{-1} s^{-1}$)





Conductivity doesn't just depend on the charge carrier – it also depends on the carrier mobility, As temperature increases, the mobility of electrons and holes increases at first due to gain in kinetic energy. Then it decreases when lattice vibration takes over and impede their motion





For low doping levels, the conductivity first decreases although carrier concentration increases because lattice vibrations dominates. As temperature increases more, electrons can cross the band gap so effect of increasing carriers outweights effect of decreasing mobility. For high doping levels, conductivity is higher overall because there are more charge carriers. This also means that the effect of temperature is less pronounced since the rate of increase in carrier concentration balances the decrease in mobility.