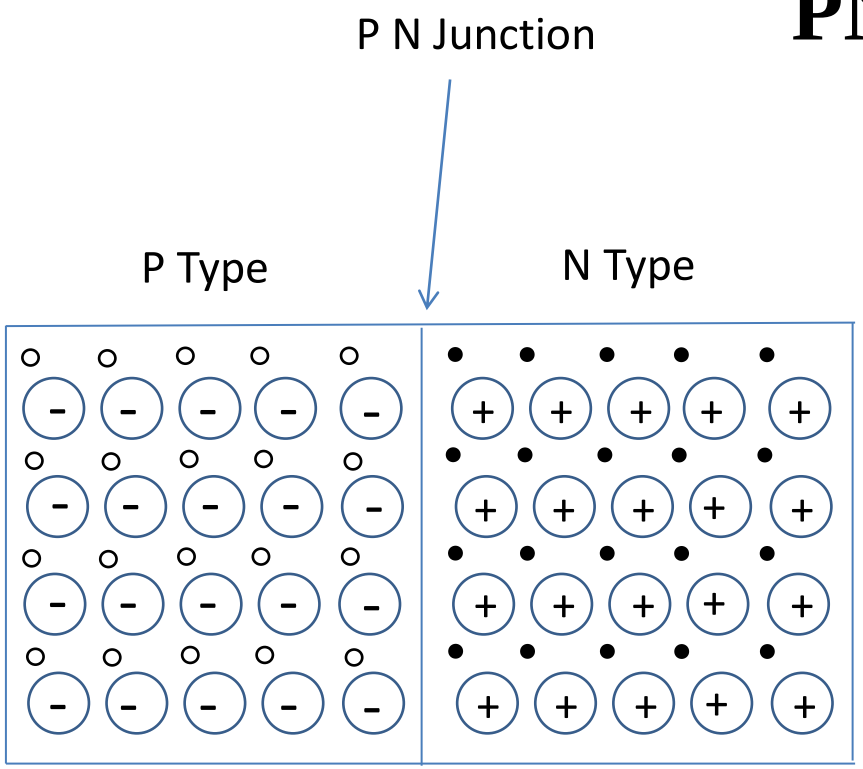
Module 1

Lecture 4

PN JUNCTION DIODE

PN Junction Diode



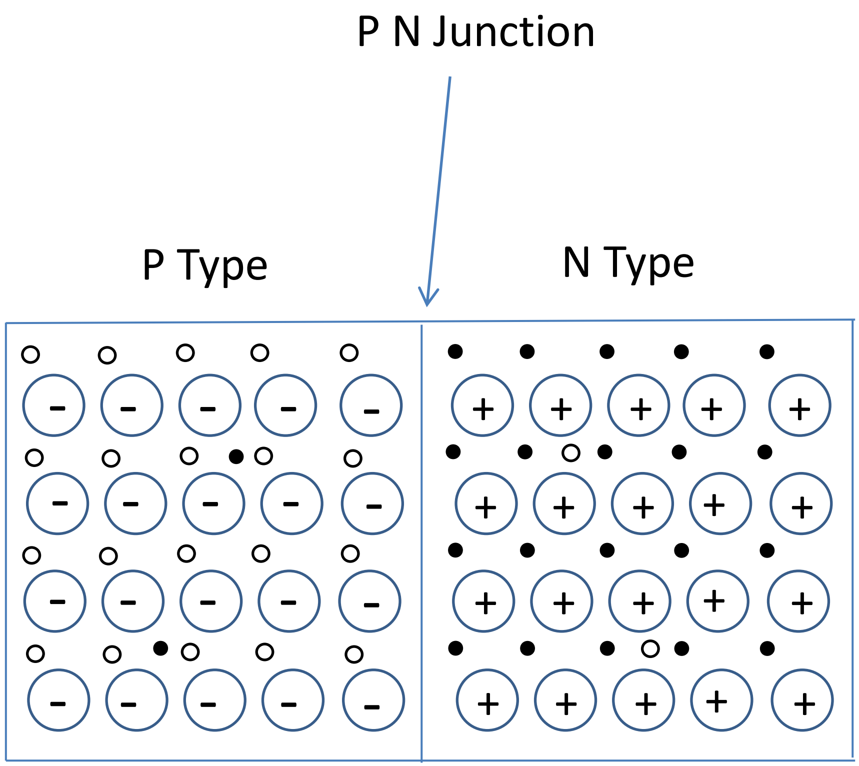
P N Junction Diode

If in a single piece of a semiconductor material half portion is doped by p type impurity and another half portion is doped by n type impurity.

Then the plane which divides the two regions is called as junction and we get a **p n junction**.

This pn junction makes a useful device called as **p-n junction diode** or **semiconductor diode**.

Junction theory



P N Junction Diode

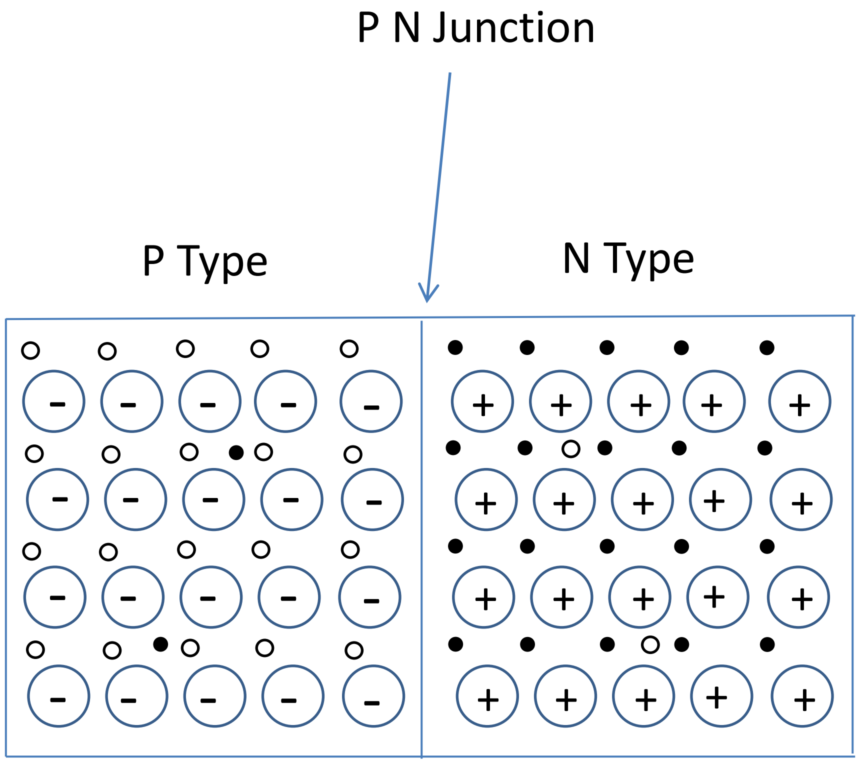
The most important characteristics of PN junction is its ability to conduct current in one direction only. That is its support **unidirectional current**.
In the other (Reverse) direction its offers very high resistance.

Now we need to study the working principle of p-n junction diode.

To understand the behaviour of PN junction diode there is a need of dividing working in three parts

- PN junction with no external bias
- PN junction with Forward bias
- PN junction with Reverse bias

PN Junction with No External Bias



P N Junction Diode

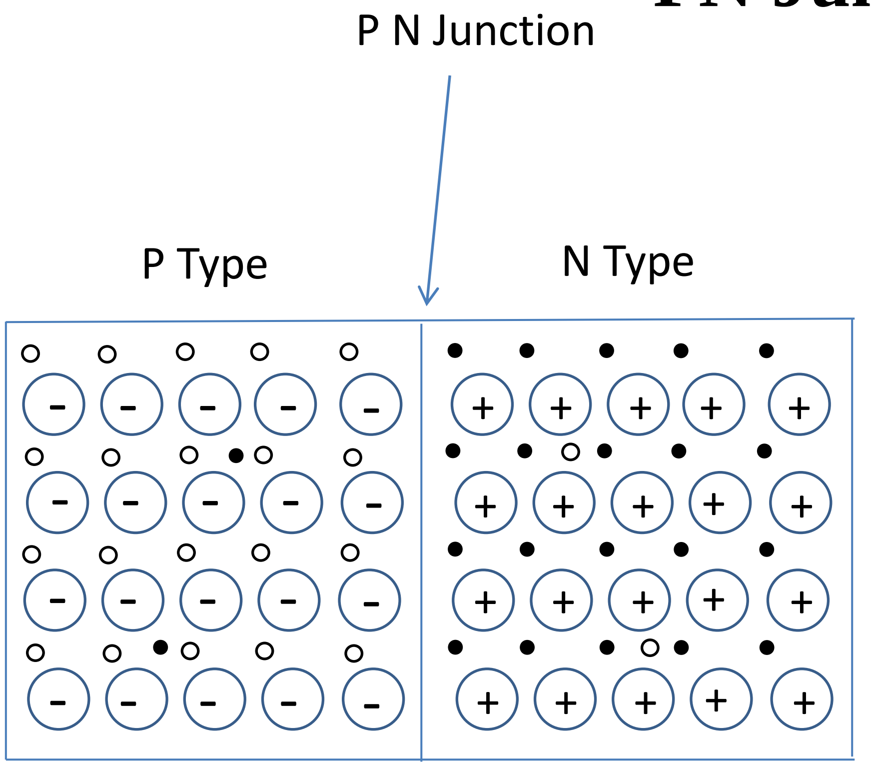
The figure shows the situation where junction has just been formed.
At that instant the holes are still there in P region and electrons are in N region.
Now we observer that

Concentration of holes in P region is far greater than the concentration of holes in N region.
Concentration of electrons in N region is far greater than the concentration of electrons in N region.

It means there is concentration gradient across the junction.

Due to this concentration gradient charge carriers(Electrons and holes) start to diffuse.

PN Junction with No External Bias



P N Junction Diode

Holes from P reigion diffuse into N region.
Electrons from N region diffuse into P region.

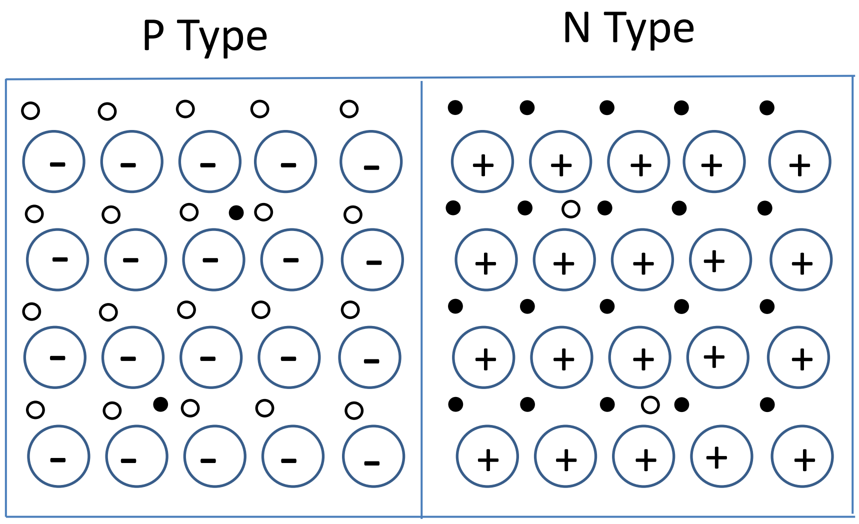
In this process these electrons and holes recombine with each other and get eliminated.

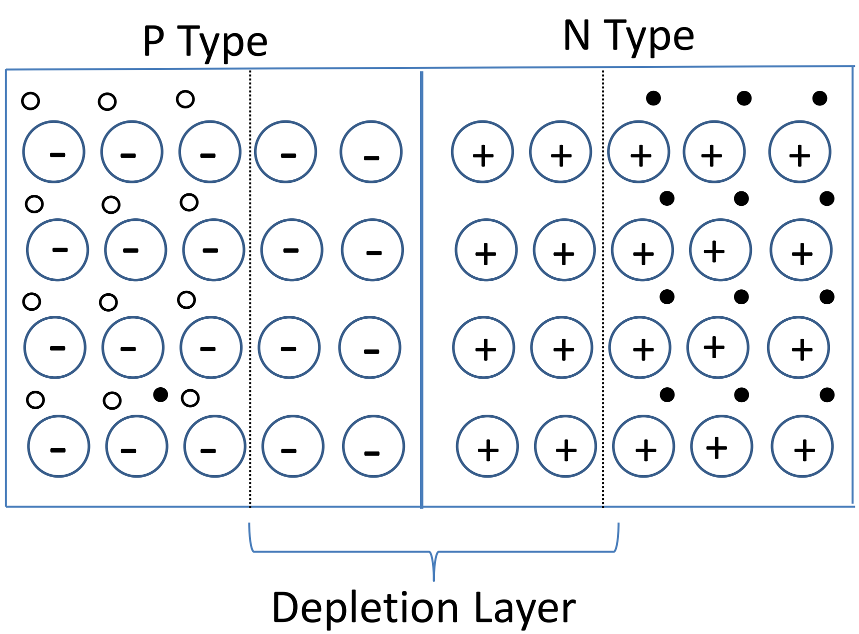
It appears that all the holes from P type and all the electrons from N type will be recombined.

And thus all the holes and electrons will disappear and we will be left with intrinsic (pure) semiconductor again.

But this does not happen.

PN Junction with No External Bias





Formation of depletion layer

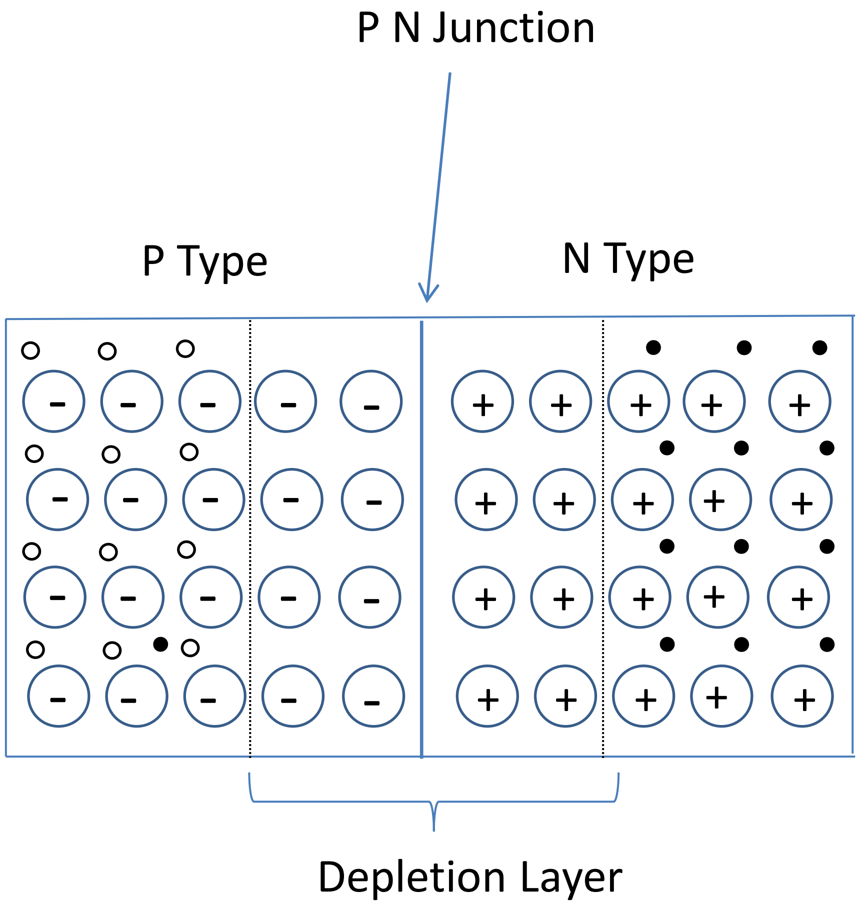
The diffusion of holes and free electrons across the junction occurs for a very short time.

After a few recombination of holes and electrons in the immediate neighbourhood of the junction

We get parallel layers of opposite charges facing each other.

That is the **depletion layer** which is formed across the junction.

• PN Junction with No External Bias



This depletion layer stops further recombination of electrons and holes.

Let us understand this

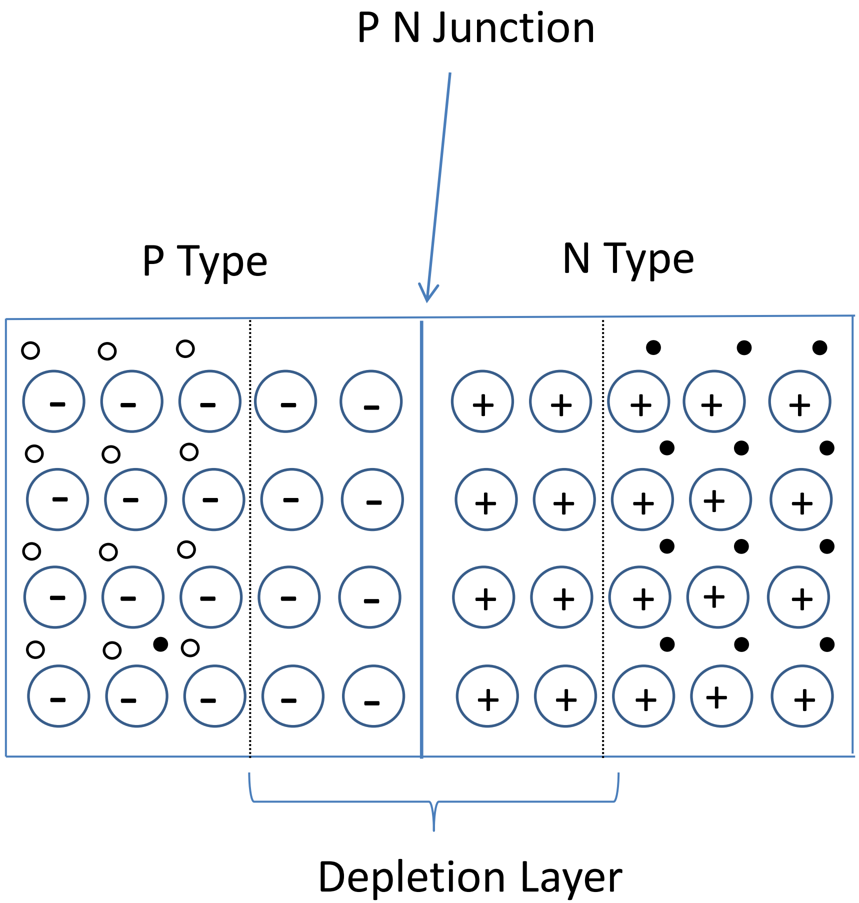
Suppose a hole from P region is succeeded to enter the depletion region and tries to cross the junction.

Then the layer of positive charges(Ions) in the N type region will repel this hole back to P region.

And if an electron from N region is succeeded to enter the depletion region and tries to cross the junction.

Then the layer of Negative charges(Ions) in the P type region will repel this electron back to N region.

• PN Junction with No External Bias



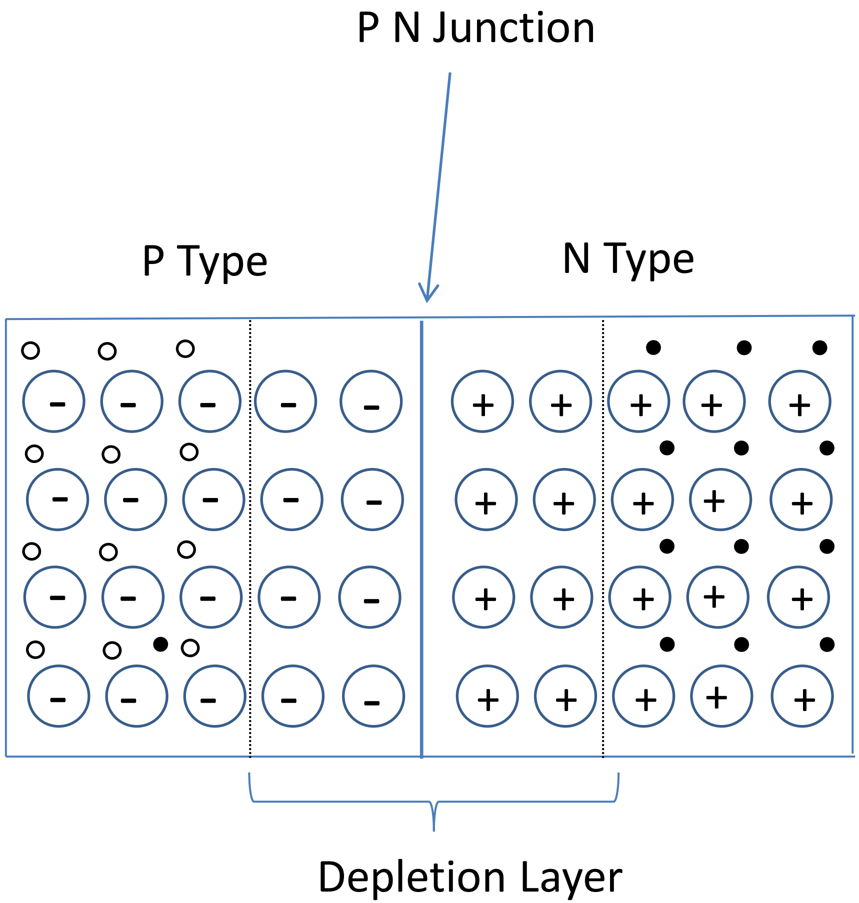
Suppose a hole from P region is succeeded to enter the depletion region in order to cross the junction.

Then there are chances that this hole will be captured by the layer of fixed impurity ions (negatively charged fixed ions in this case) hence this hole is neutralized by the layer of fixed ions.

Similarly suppose a free electron from N region is succeeded to enter the depletion region in order to cross the junction.

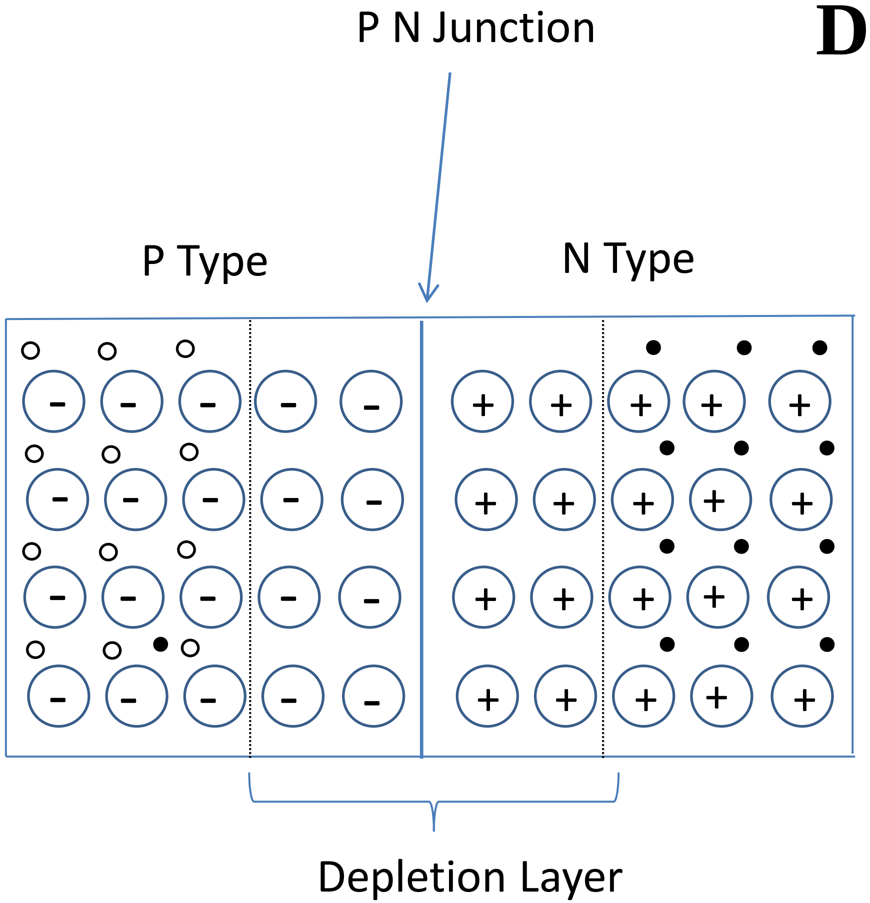
Then there are chances that this free electron will be captured by the layer of fixed impurity ions (positively charged fixed ions in this case) hence this free electrons neutralized by the layer of fixed ions

- **PN Junction with No External Bias**



So we can summarise that under no bias condition ,free electrons and holes are not allowed to cross the junction.

DEPLETION REGION



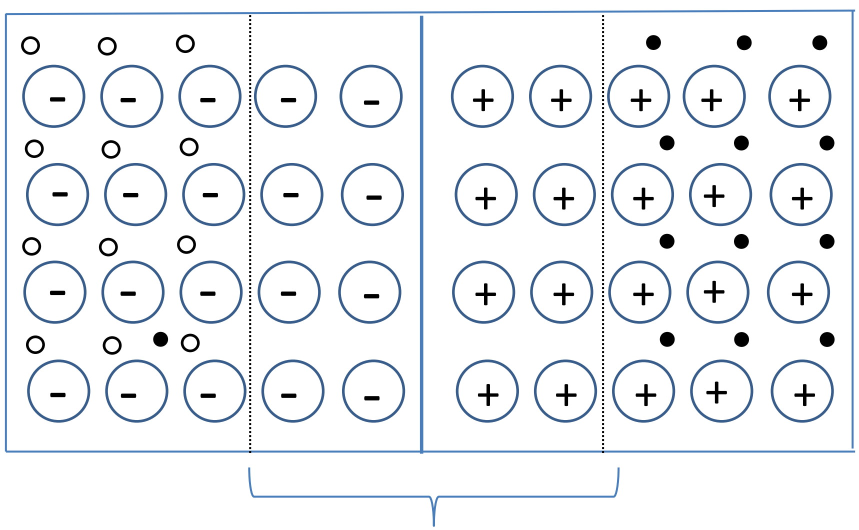
The region containing the uncompensated acceptor and donor ions is known as depletion region.

Why depletion ?

Because there is a depletion of mobile charges (Holes and electrons) in this region.

This region is also called as **space charge region**

Junction Potential or Barrier Potential



From the figure it is clear that depletion region has oppositely charged layer of fixed ions on its two sides.

Because of this charge separation an electric potential difference(V_B) is established across the junction.
This is known as **Junction potential** or **barrier potential.**

At room temperature (300 K) Barrier potential is

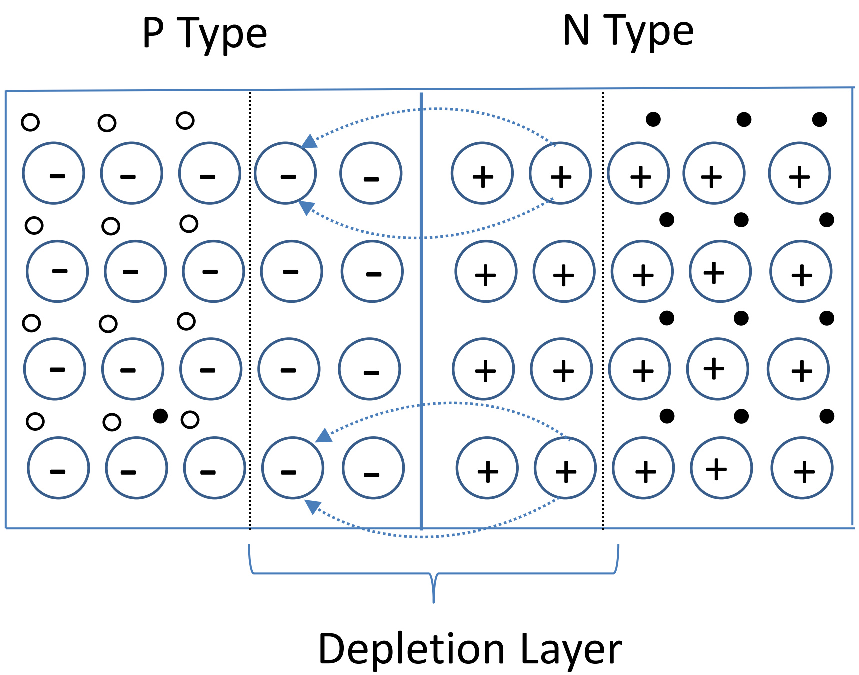
For Si

$$\mathbf{V_B = 0.7\ V}$$

For Ge

$$\mathbf{V_B = 0.3\ V}$$

Barrier

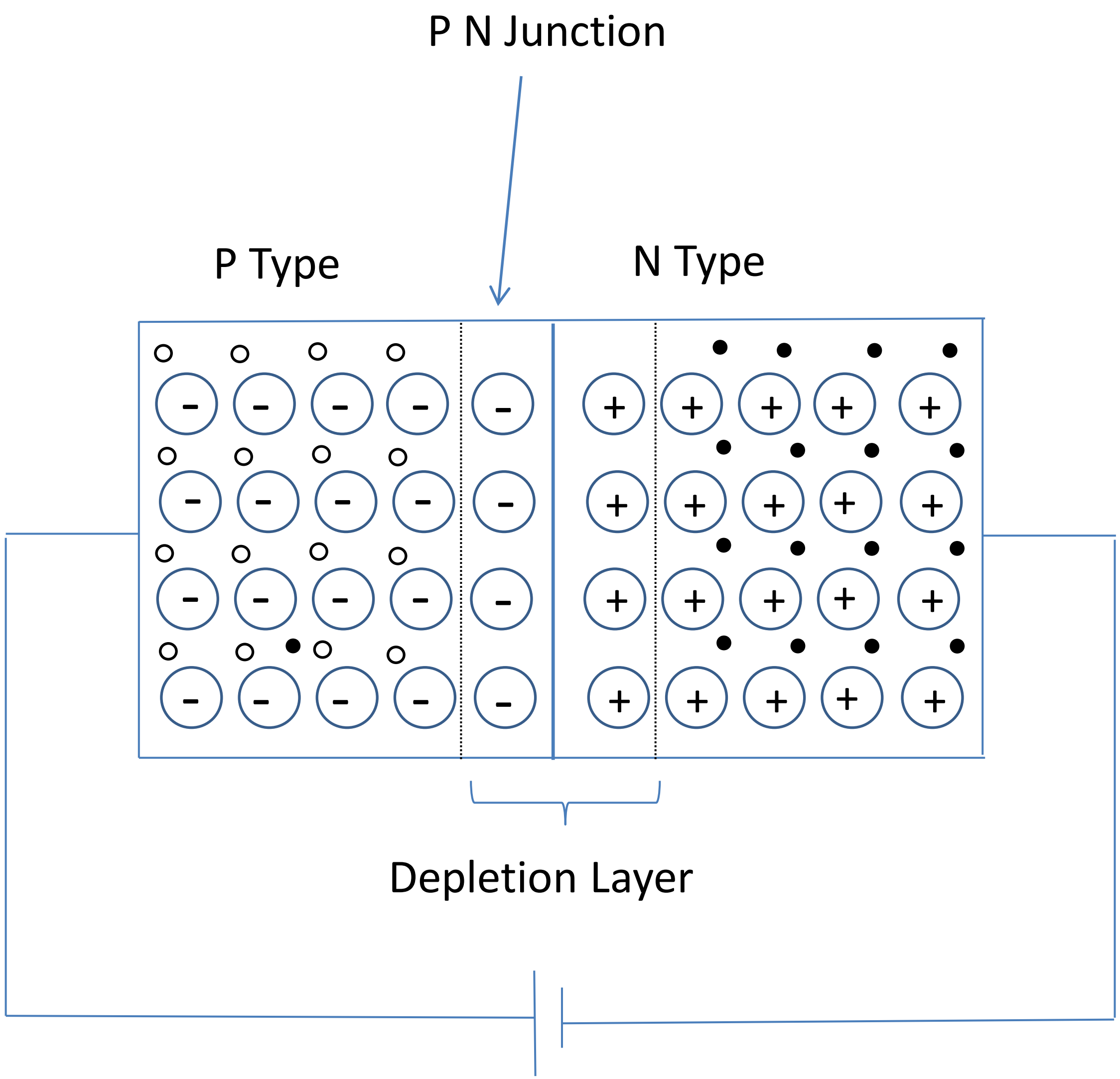


Electric field between acceptor ions and donor ions is called a barrier.

Note:- Junction potential is also known as **height of the barrier.**

Note:- The thickness of depletion region is about $\mathbf{10^{-6}}$ **m**.

PN Junction with Forward Bias



Now we will connect the battery.

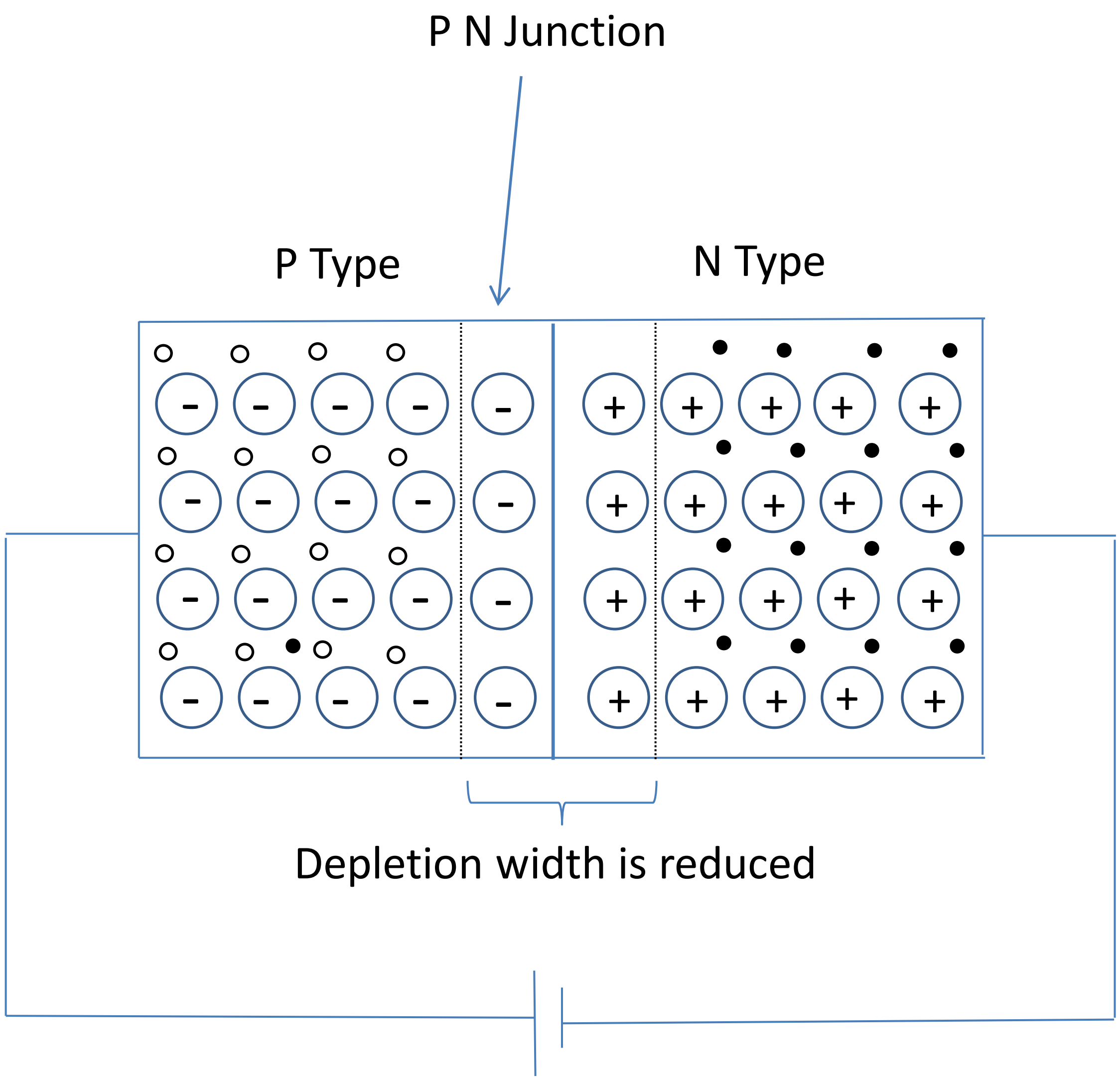
If battery is connected in PN junction such that

i) Positive terminal of battery is connected to P type.

ii) Negative terminal of battery is connected to N type.

Then PN junction is in forward bias.

PN Junction with Forward Bias



In forward biasing

Holes in the P type are repelled by the positive terminal of the battery and moves towards the junction.

Free electrons in the N type are repelled by the negative terminal of the battery and therefore moves towards the junction.

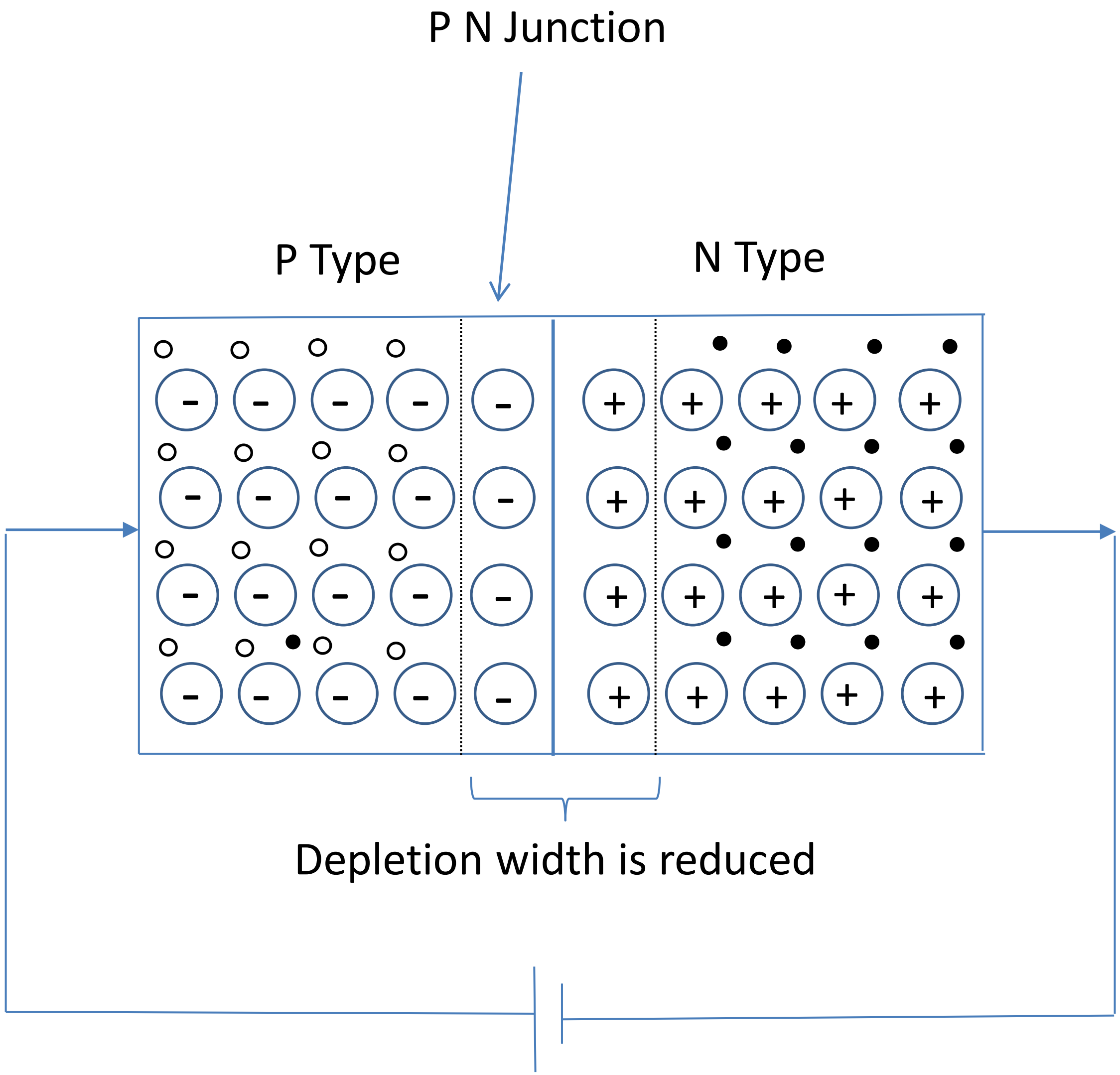
There are chances

that holes from P type recombine with the negatively charged acceptor ions.

that free electrons from N type recombine with the positively charged donor ions.

And hence depletion width is reduced as shown in the figure.

PN Junction with Forward Bias



Because depletion width is reduced .
So potential barrier is reduced.
Therefore a continuous flow of electrons and holes start across the junction.

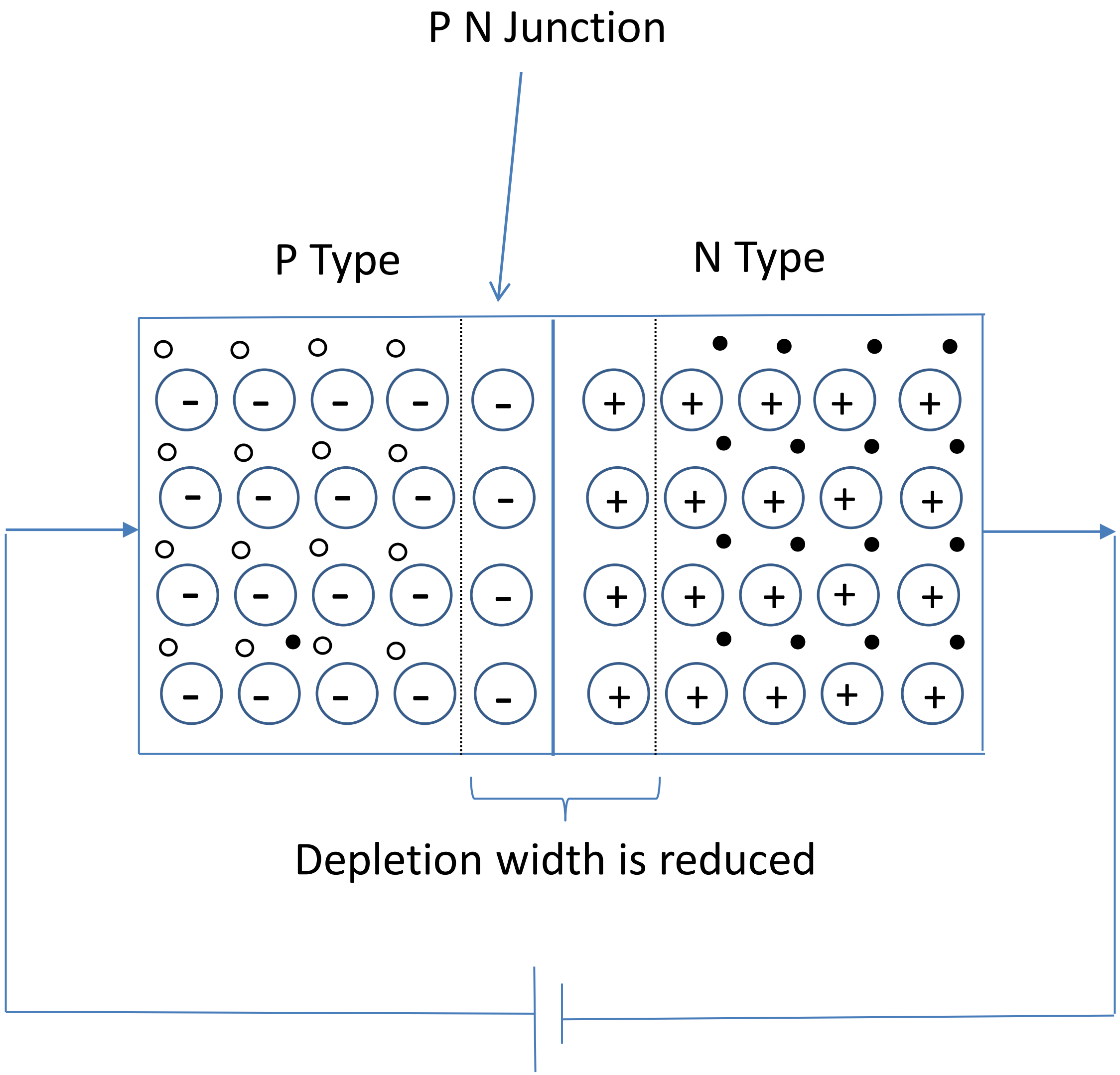
And we say a continuous current starts to flow acros sthe junction.

This current is also called as **forward current**.

Note:-

i)This current is due to majoity Carriers (Holes in P type region and free electrons in N type region).
ii) Direction of the forward current is form P region to N region.

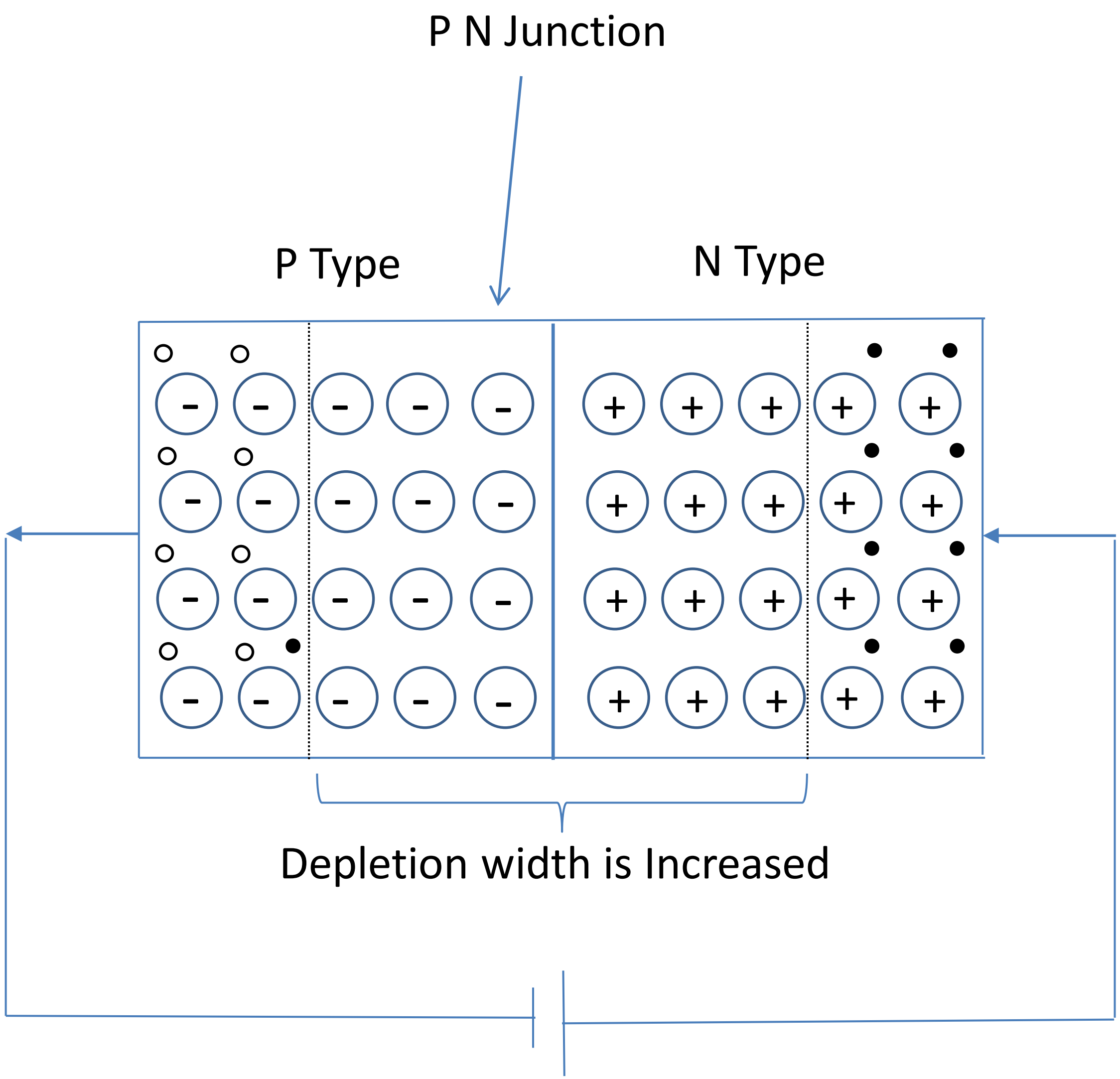
PN Junction with Forward Bias



To summarize we can say whenever forward biasing is applied across the PN junction.

Due to lowering of potential barriers a forward current is set up across the junction which flows from P type region to n type region.

PN Junction with Reverse Bias



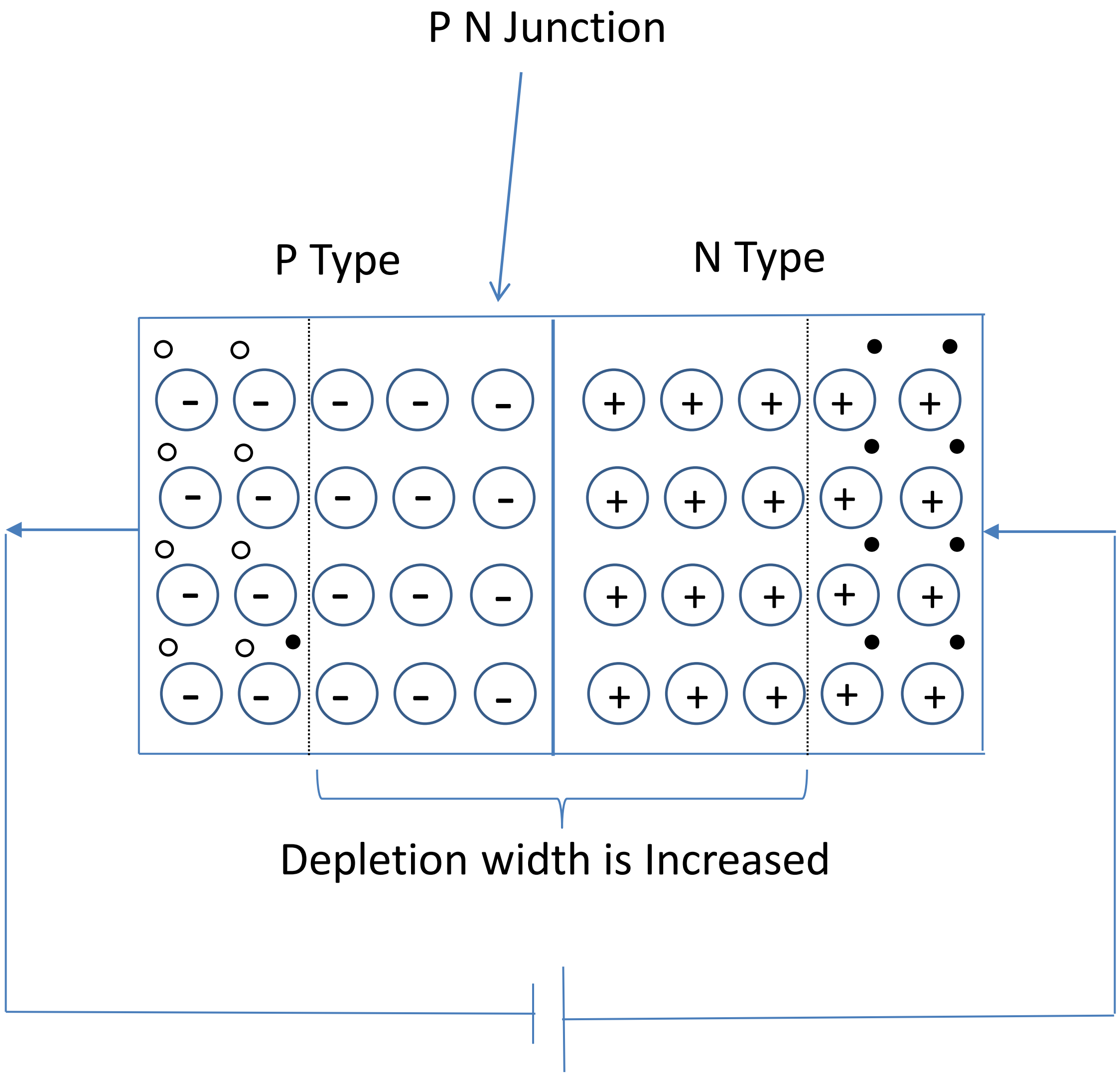
If battery is connected in PN junction such that

i) Negative terminal of battery is connected to P type.

ii) Positive terminal of battery is connected to N type.

Then PN junction is in reverse bias.

PN Junction with Reverse Bias



Now in reverse bias we observe following things

If battery is connected in PN junction such that

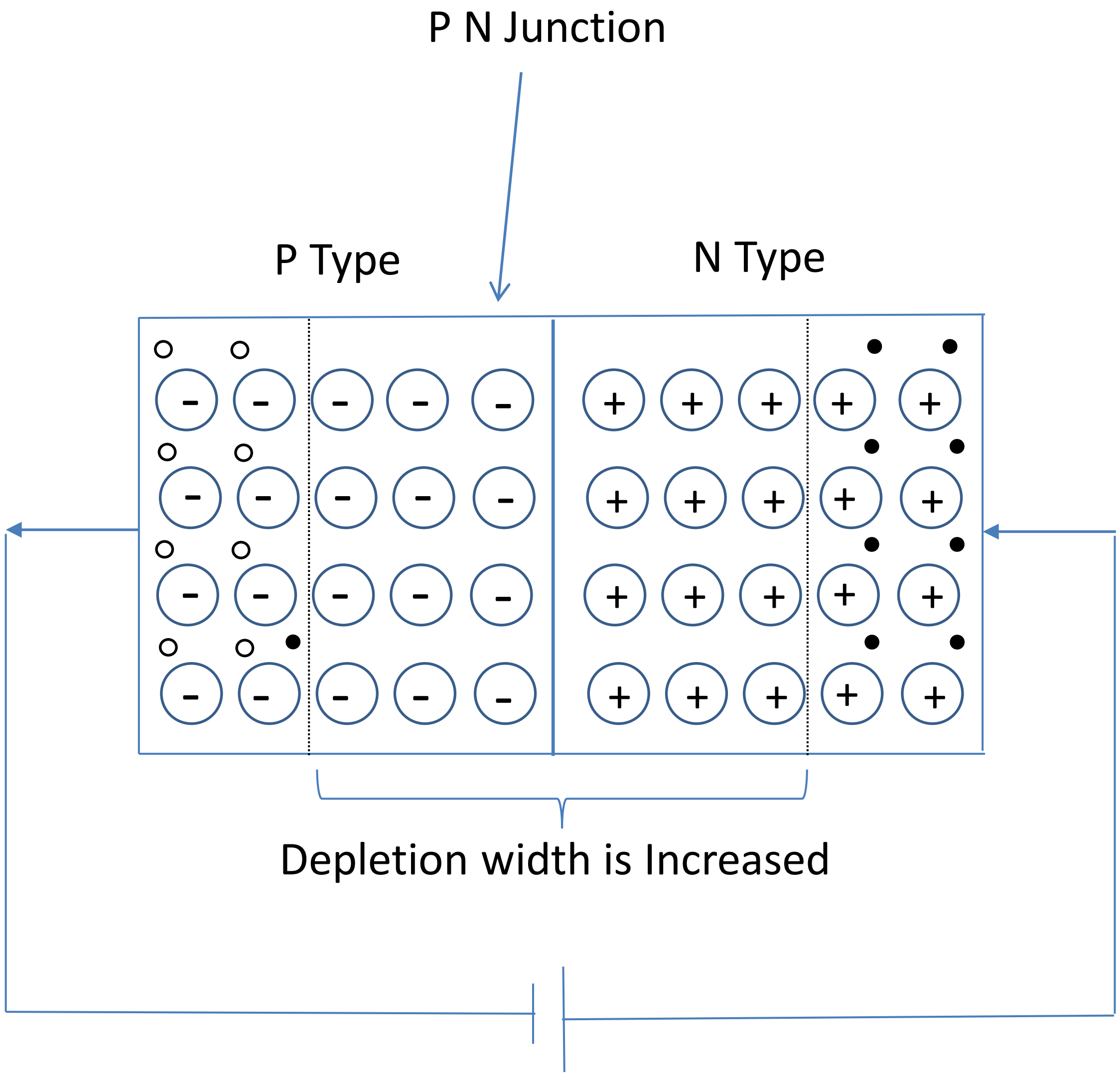
i) Holes in the P region are attracted towards the negative terminal of the battery.

ii) Free electrons in the N region are attracted towards the positive terminal of the battery.

This action widens the depletion region.

Hence potential barrier is increased.

PN Junction with Reverse Bias



To summarize we say that

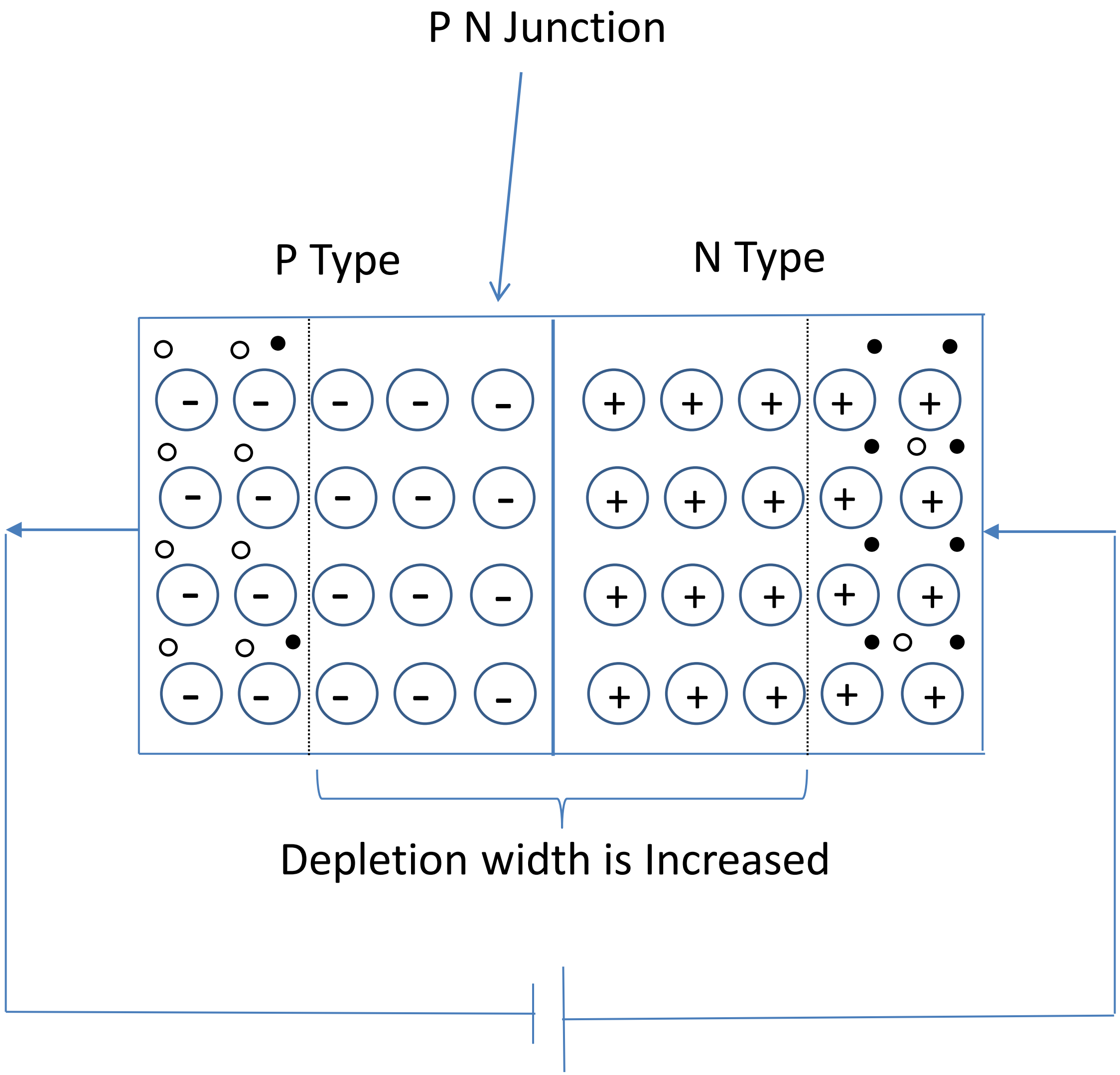
Whenever a PN junction is reverse biased the depletion width is increased which in turn increases the barrier potential.

This increased barrier potential makes it more difficult for the majority carries to cross the junction.

And we say there is no forward current.

It means junction offers high resistance to the forward current

PN Junction with Reverse Bias



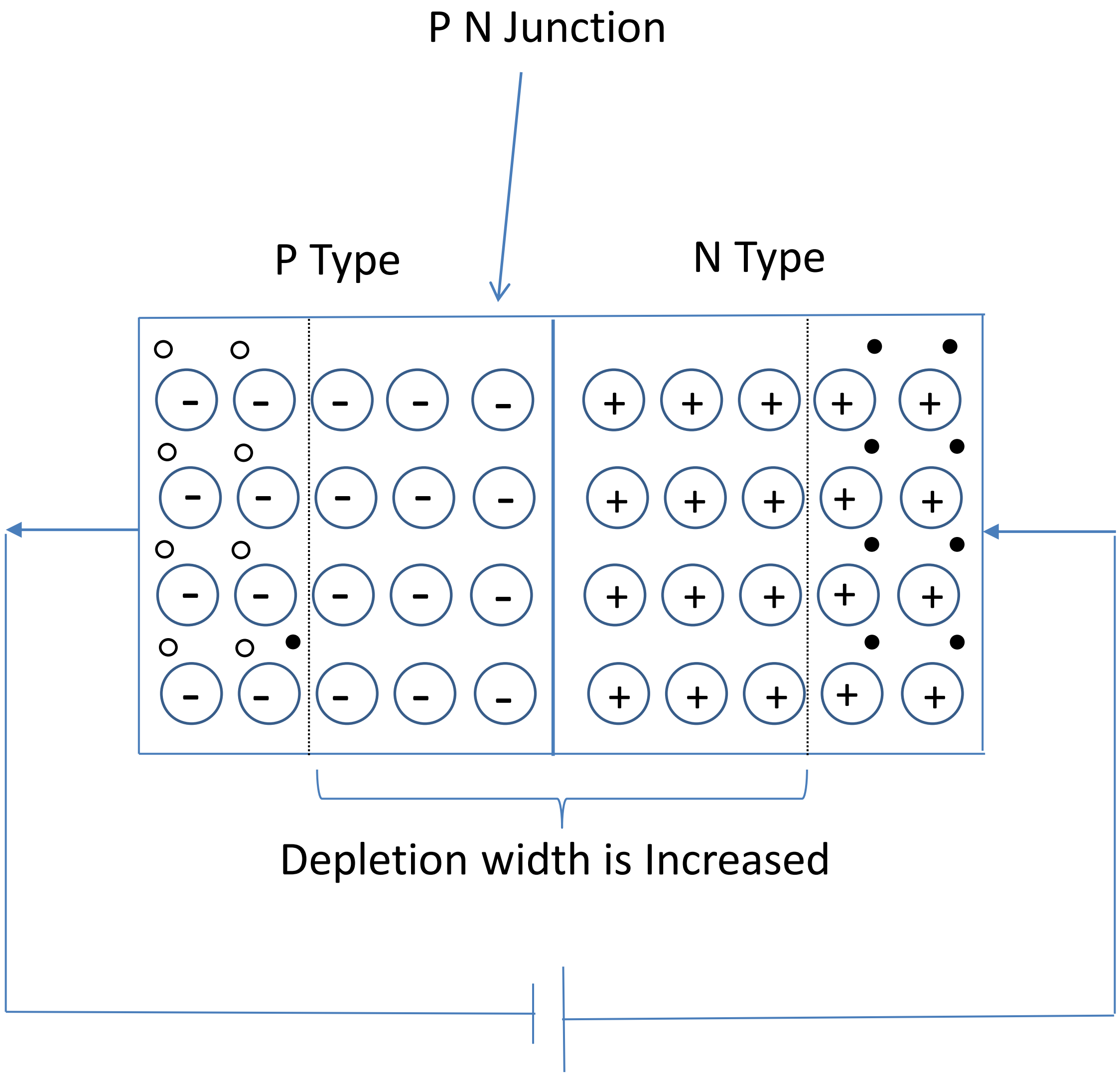
This increased barrier potential stops the majority carriers to flow across the junction but it helps the minority carriers(Free electrons in P type region and holes in N type region)to cross the junction.

The rate of generation of minority carriers depends on the breaking of covalent bonds. And breaking of covalent bonds depends on temperature.

If the temprature is fixed the rate of generation of minority carriers is alos remains constant.

It means this current which is due to the flow of minority carriers is fixed at a given temperature.

PN Junction with Reverse Bias



Direction of this current is from N type region to p type region.

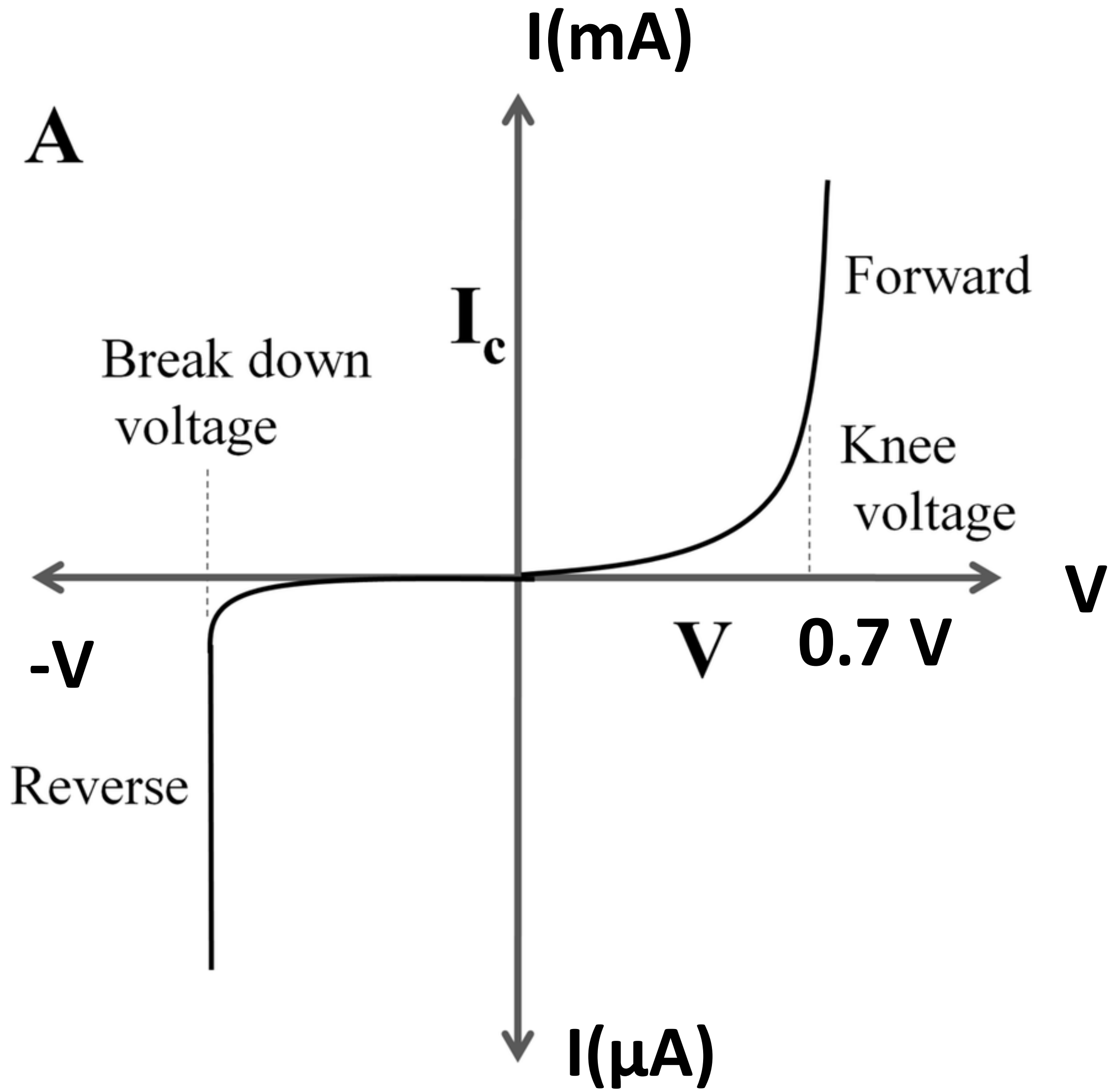
That is why this current is called as reverse current.

Because this current depends on temperature and remains constant for a given temperature that is why this current is called as **reverse saturation current(I_0 or I_S).**

This is very small as the number of minority carriers is very small.

It is of the order of
i)nanoamperes for silicon diode
ii)Microamperes for germanium diode.

V-I CHARACTERISTICS OF DIODE



Thank you