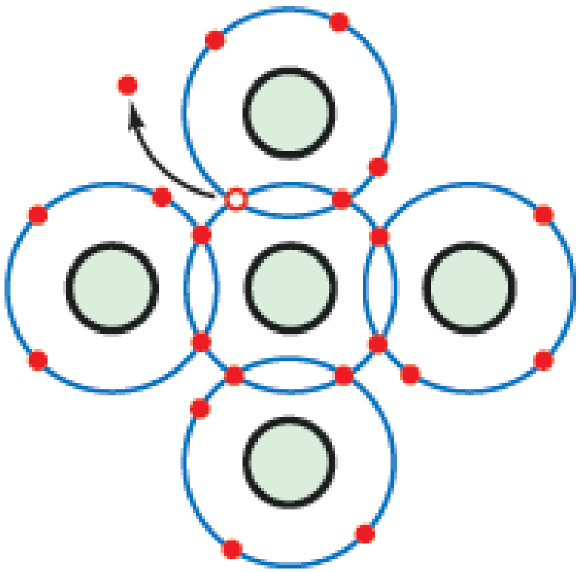
Semiconductors
&
Diode

Few Important terms

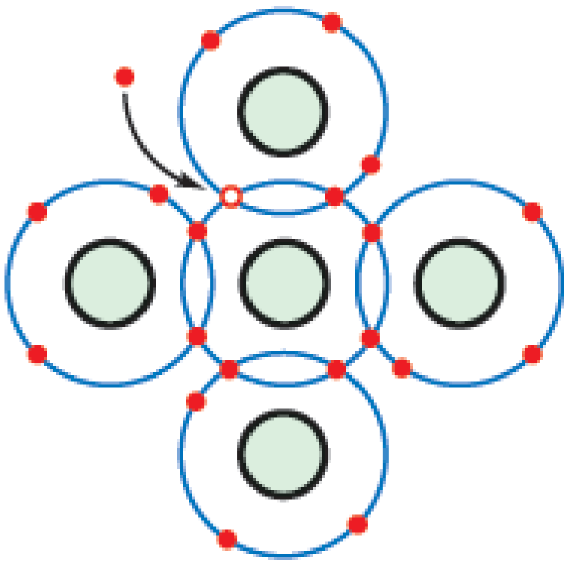
The Hole : If and electron departed from the valence orbit, it creates a vacancy in the called a **hole.** This hole behaves like a positive charge because the loss of the electron produces a positive ion. The hole will attract and capture any electron in the immediate vicinity. The existence of holes is the critical difference between conductors and semiconductors. ***Holes enable semiconductors to do all kinds of things that are impossible with conductors.***



Recombination and Lifetime

In a pure silicon crystal, **thermal** (heat) **energy** creates an equal number of free electrons and holes. The free electrons move randomly throughout the crystal. Occasionally, a free electron will approach a hole, feel its attraction, and fall into it. ***Recombination*** is the merging of a free electron and a hole.

The amount of time between the creation and disappearance of a free electron is called the ***lifetime***. It varies from a few nanoseconds to several microseconds, depending on how perfect the crystal is and other factors.



Main Ideas:

At any instant, the following is taking place inside a silicon crystal:

1. Some free electrons and holes are being created by thermal energy.
2. Other free electrons and holes are recombining.
3. Some free electrons and holes exist temporarily, awaiting recombination.

Exciton:

An **exciton** is a bound state of an electron and a hole which are attracted to each other by the electrostatic Coulomb force. It is an electrically neutral quasiparticle. This plays an important role in conducting polymer.

What is a Drift Current?

Drift current can be defined as the charge carrier's moves in a semiconductor because of the electric field. Once the voltage is applied to a semiconductor, then electrons move toward the +Ve terminal of a battery whereas the holes travel toward the –Ve terminal of a battery.

What is Diffusion Current?

The diffusion current can be defined as the flow of charge carriers within a semiconductor travels from a higher concentration region to a lower concentration region. The process of diffusion mainly occurs when a semiconductor is doped non-uniformly.

Mobility (μ) and Conductivity (σ):

The **mobility** characterizes how quickly an electron/hole can move through a metal or semiconductor, when pulled by an electric field. The term **carrier mobility** refers in general to both electron and hole mobility.

Drift velocity (v_d) = μ x E

Consider a sample with cross-sectional area A, length l and an electron concentration of n. The current carried by each electron must be ev_d.

Electron current density (J_n) = $I_n/A = env_d = en\mu_e E$

Similarly, hole current density (J_h) = $ep\mu_h E$

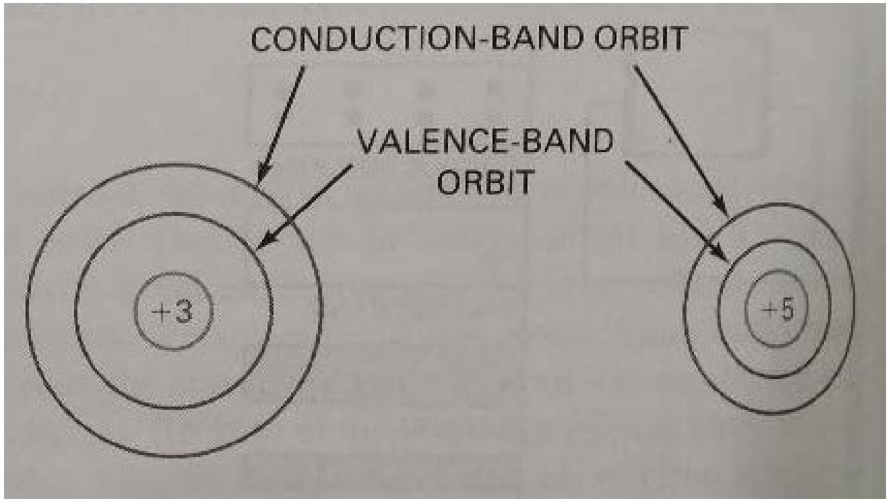
So total current density = $(en\mu_e + ep\mu_h)\ E$

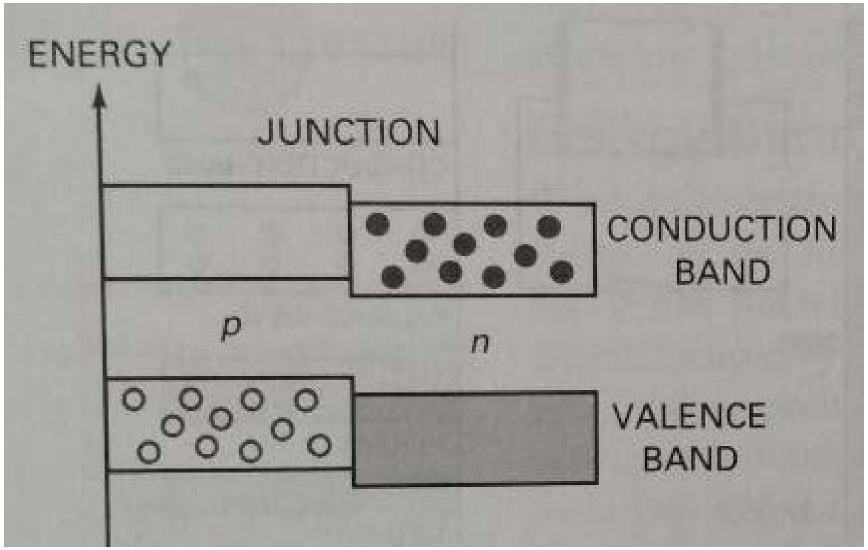
Conductivity (σ):

As $J = \sigma E$, so $\sigma = en\mu_e + ep\mu_h$

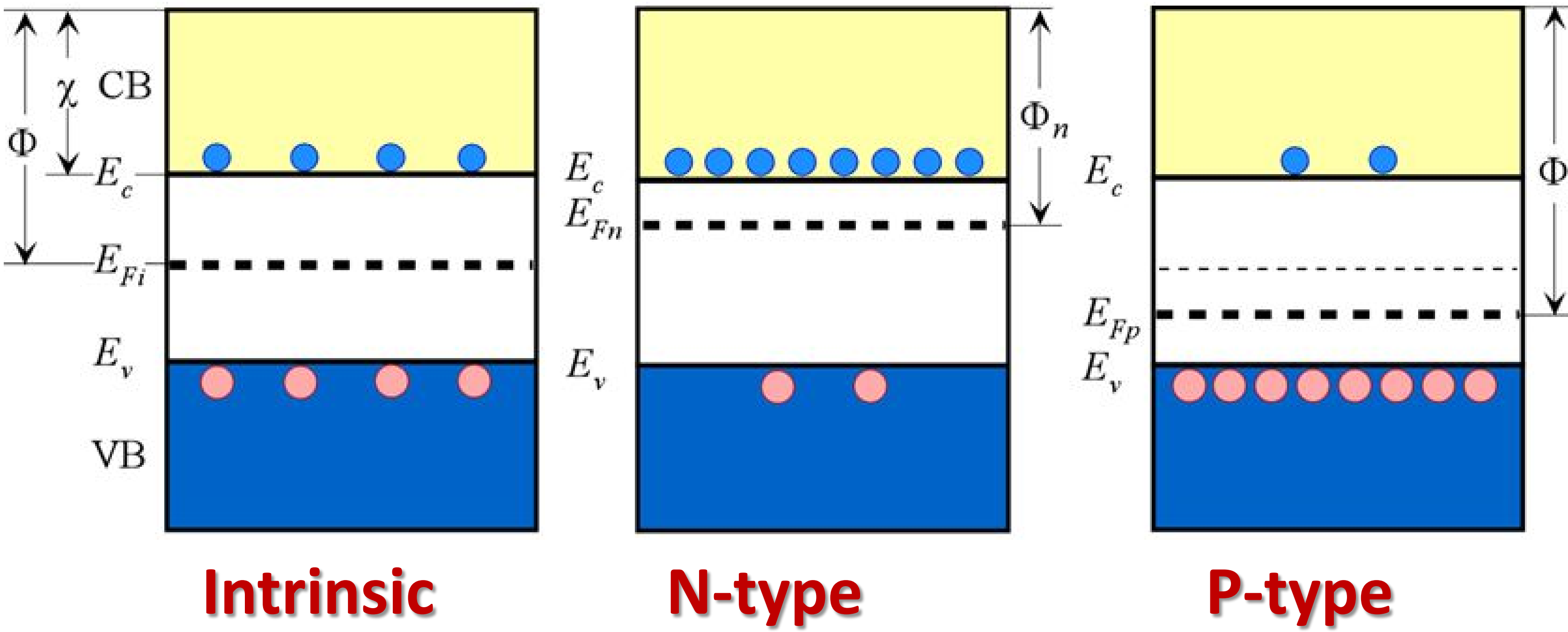
Energy Levels – Energy Hill:

We can identify the total energy of an electron with the size of its orbit to a good approximation. Electrons in the smallest orbit are on the first energy level; electrons in the second orbit are on the second energy level; and so on. So, *Higher Energy in Larger Orbit*. P-type atom has larger orbits, equivalent to higher energy level, N-type atom has smaller orbit and lower energy level.

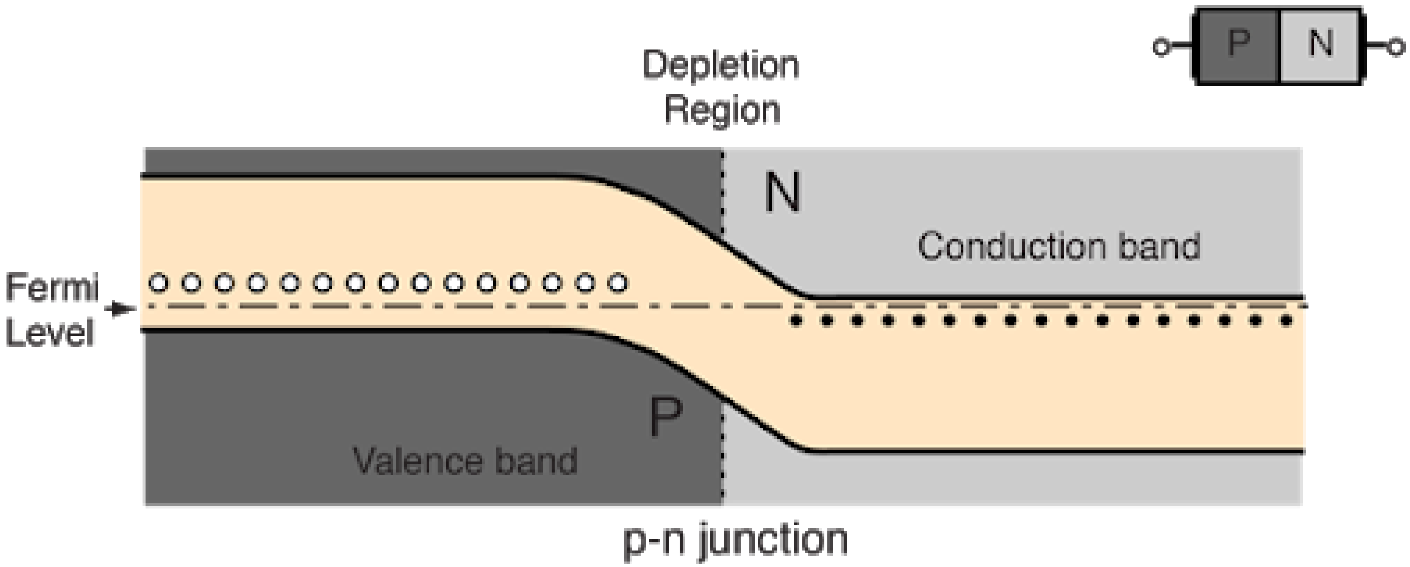


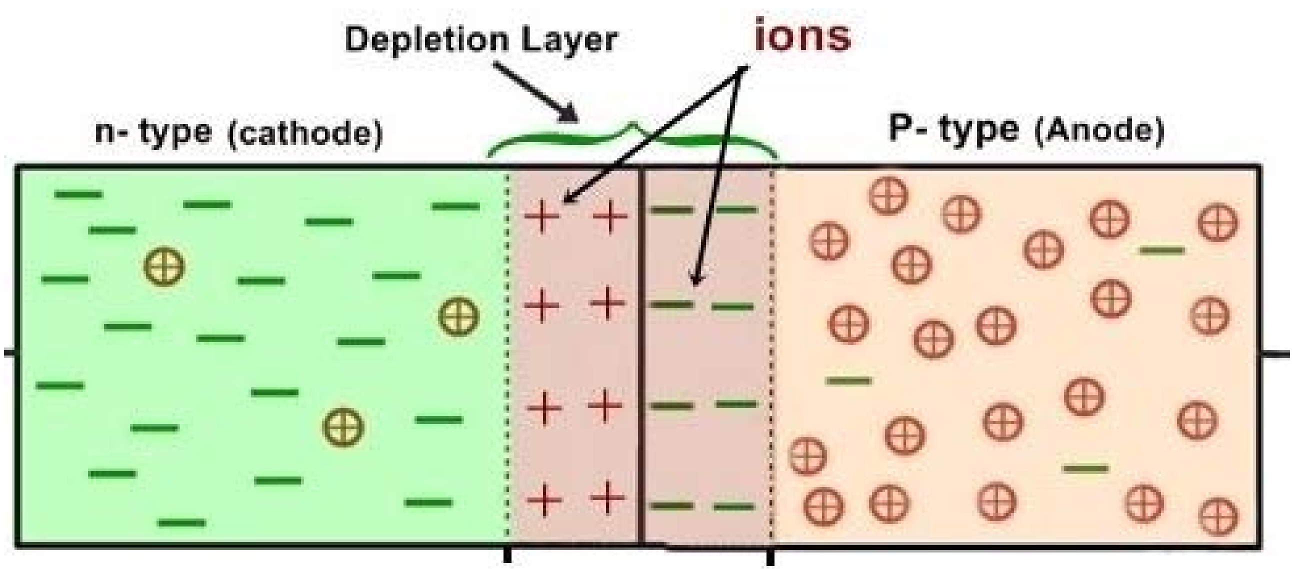


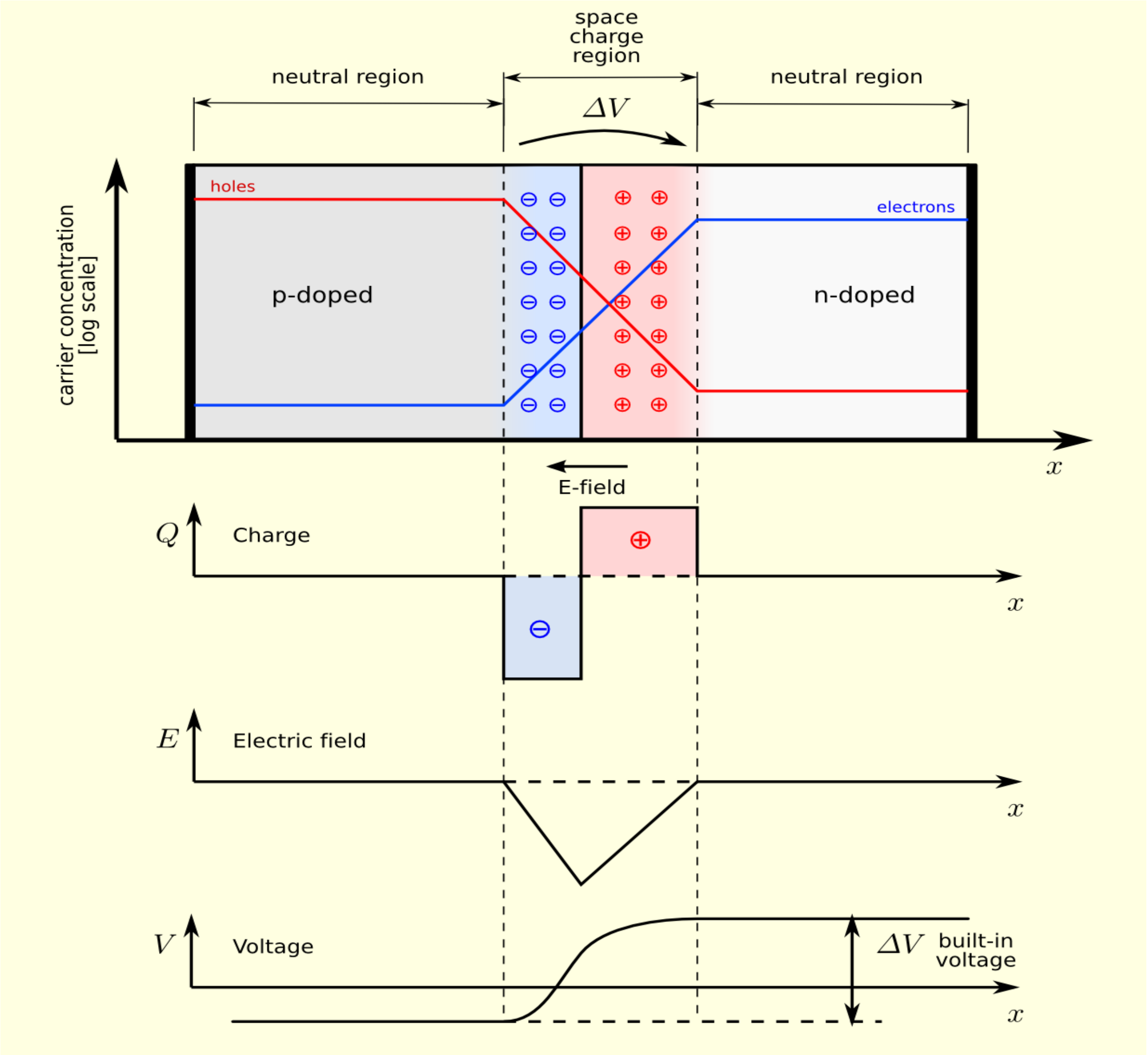
Energy band diagram of Intrinsic, N and P type semiconductor



Unbiased P-N junction







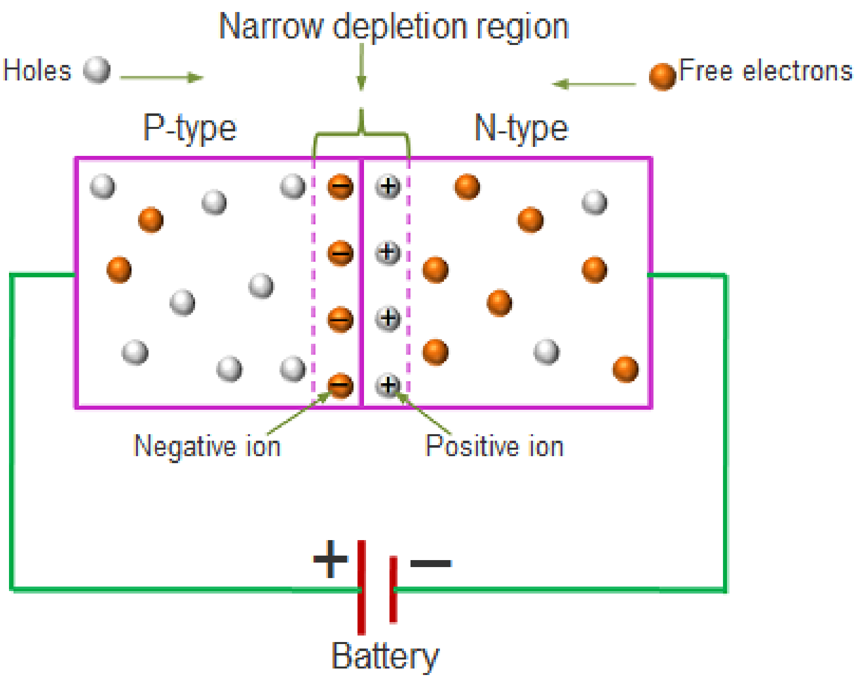
space
charge
region
neutral region
neutral region
ΔV
holes
electrons
carrier concentration
[log scale]
p-doped
n-doped
x
E-field
Q
Charge
x
E
Electric field
x
V
Voltage
ΔV built-in
voltage
x

The barrier potential of germanium is approximately 0.3 V, and of silicon is 0.7 V.

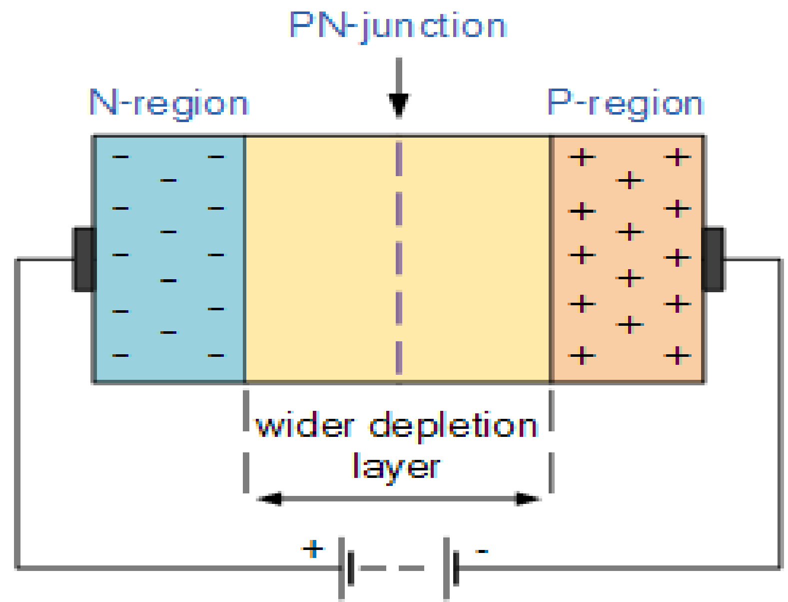
Questions:

1. Are the P and N type semiconductors are charged?
2. Can the barrier potential be measured with a voltmeter?

Biased P-N junction diode



Forward biased



Reverse biased

1. ***What is the effect of temperature on the width of depletion layer?***
2. ***What is the effect of doping concentration on the width of depletion layer?***

Junction Capacitance in P-N junction

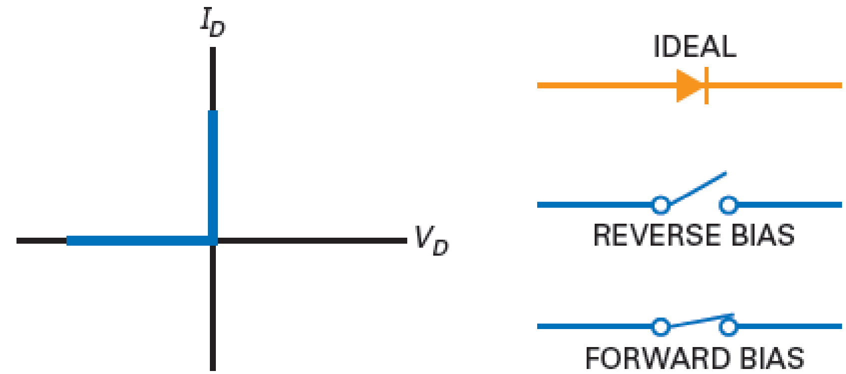
In a reverse biased p-n junction diode, the p-type and n-type regions have low resistance. Hence, p-type and n-type regions act like the electrodes or conducting plates of the capacitor. The depletion region of the p-n junction diode has high resistance. Hence, the depletion region acts like the dielectric or insulating material. Thus, p-n junction diode can be considered as a parallel plate capacitor. In depletion region, the electric charges (positive and negative ions) do not move from one place to another place. However, they exert electric field or electric force. Therefore, charge is stored at the depletion region in the form of electric field. The ability of a material to store electric charge is called capacitance. Thus, there exists a capacitance at the depletion region.

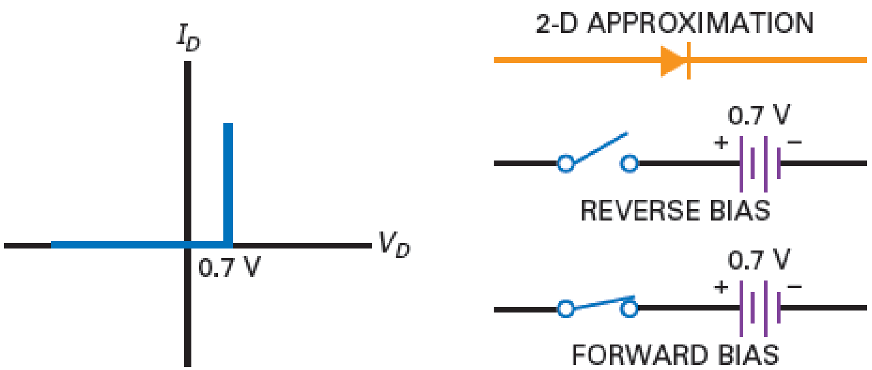
Barrier Potential and Junction Temperature

The barrier potential in the PN-junction diode is the barrier in which the charge requires additional force for crossing the region. In other words, the barrier in which the charge carrier stopped by the obstructive force is known as the potential barrier.

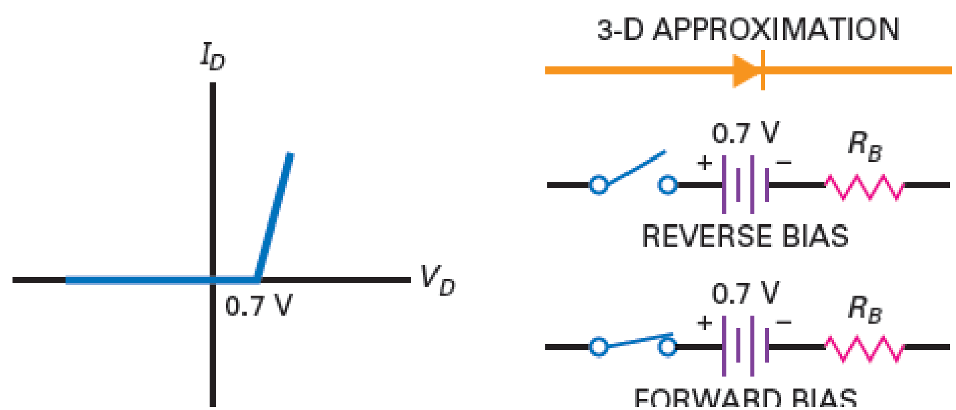
The **junction temperature** is the temperature inside a diode, right at the *P-N* junction. The barrier potential depends on the junction temperature. An increase in junction temperature creates more free electrons and holes in the doped regions. As these charges diffuse into the depletion layer, it becomes narrower. This means that there is *less barrier potential at higher junction temperatures.*

Ideal diode curve and approximations

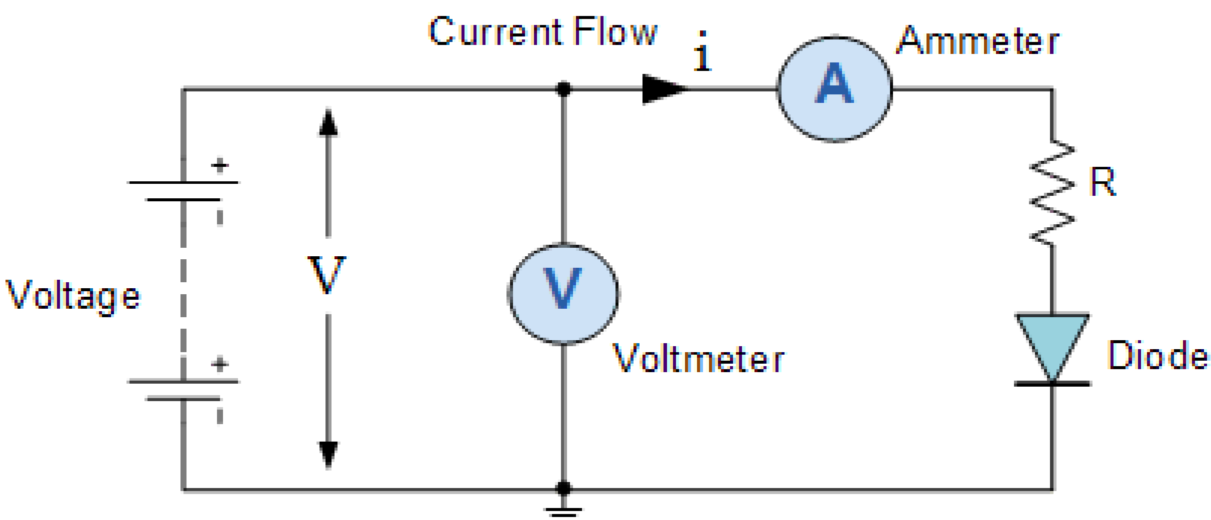


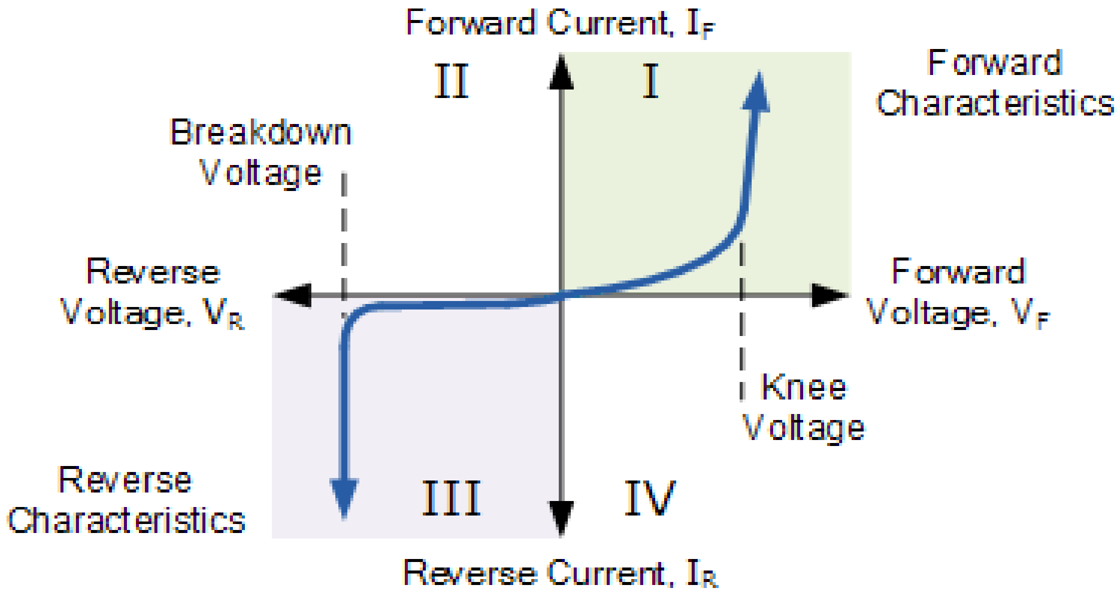


Bulk Resistance of a diode = Resistance of P layer + Resistance of N layer



Current-Voltage characteristics of a diode





Ideal diode equation

The current-voltage function of and ideal diode is:

$$I_D = I_S\left(e^{\frac{kV_D}{T}} - 1\right)$$

Where, $\boldsymbol{I_s}$ is the reverse saturation current, $\boldsymbol{V_D}$ is the applied voltage and ***k***=11600/η, η=1 for Ge and 2 for Si

What is the origin of reverse saturation current?

Avalanche breakdown:

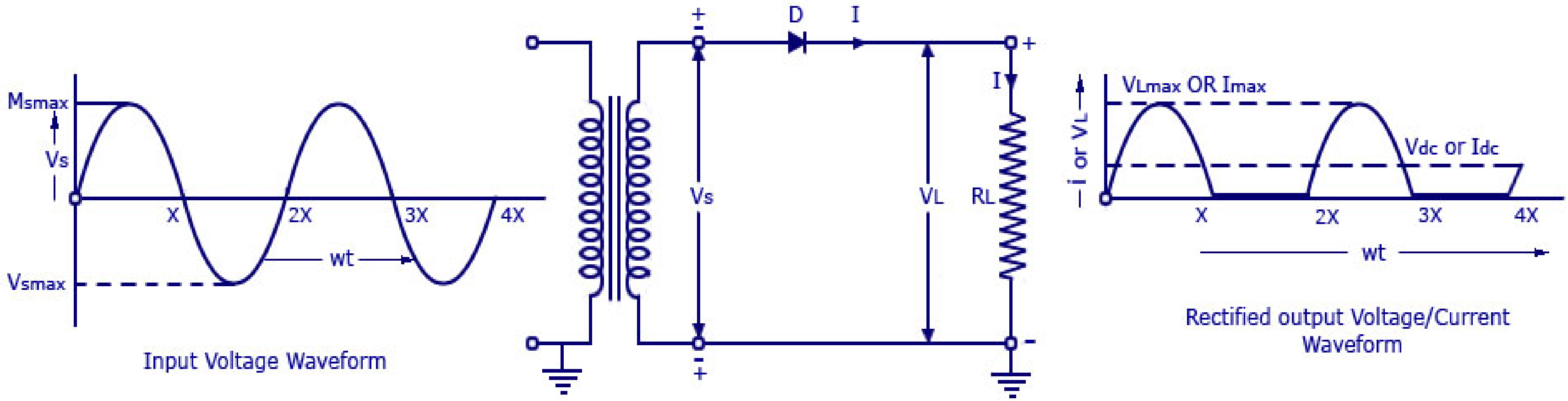
The minority carriers, under reverse biased conditions, flowing through the junction acquire a kinetic energy which increases with the increase in reverse voltage. At a sufficiently high reverse voltage, the kinetic energy of minority carriers becomes so large that they knock out electrons from the covalent bonds of the semiconductor material.

Zener breakdown:

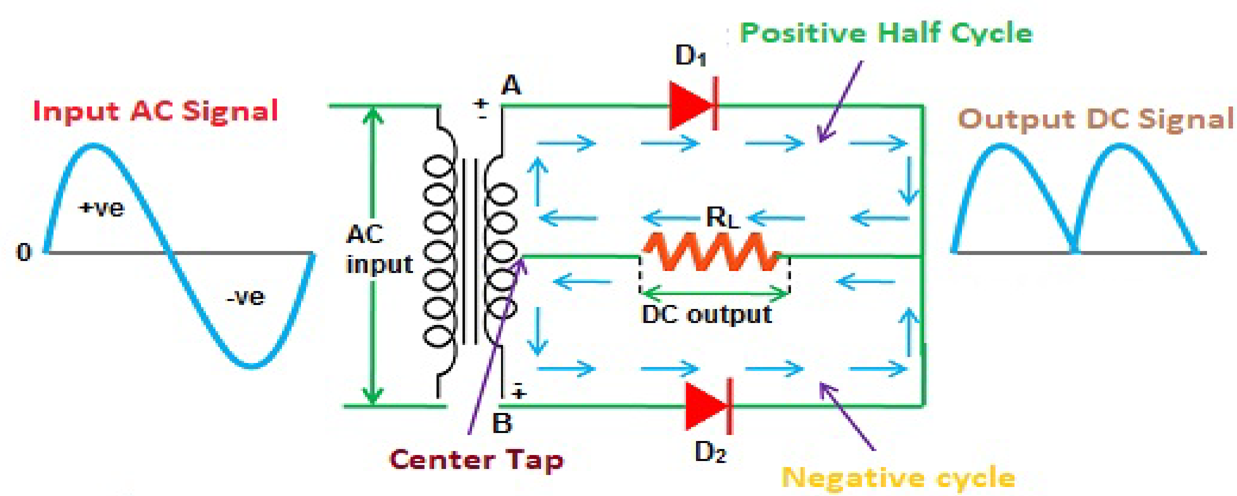
Under a very high reverse voltage, the depletion region expands and the potential barrier increases leading to a very high electric field across the junction. The electric field will break some of the covalent bonds of the semiconductor atoms leading to a large number of free minority carriers, which suddenly increase the reverse current.

Diode as Rectifier

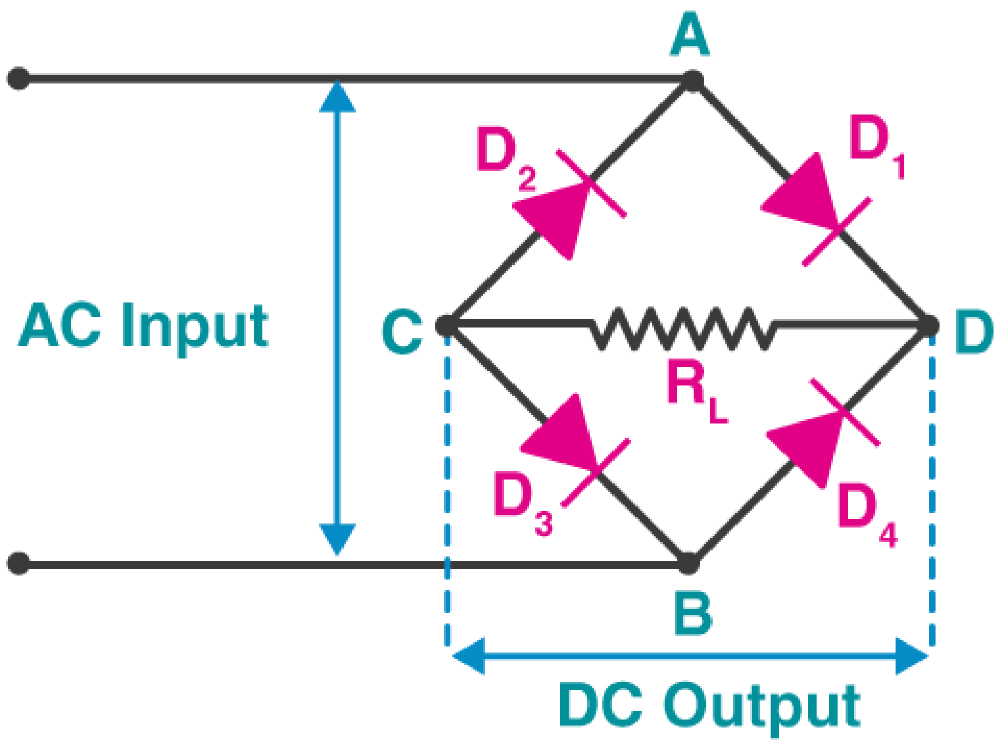
Half wave Rectifier



Full wave Rectifier



Bridge Rectifier



What are the advantages of Bridge Rectifier?

What is Ripple Factor (R.F.)?

When the fluctuation occurs within the output of the rectifier then it is known as ripple. The rectifier output mainly includes the AC component as well as the DC component. The ripple can be defined as the AC component within the resolved output. The definition of the R.F. (γ) is the ratio of the AC component's RMS value and the DC component's RMS value within the output of the rectifier.

According to the definition of R.F, the whole load current RMS value can be given by, $I_{RMS}^2 = I_{DC}^2 + I_{AC}^2$

R.F. = $\frac{I_{AC}}{I_{DC}} = \sqrt{\frac{(I_{RMS})^2}{(I_{DC})^2} - 1}$

Calculate the Ripple Factor for Full Wave and Half Wave Rectifier.

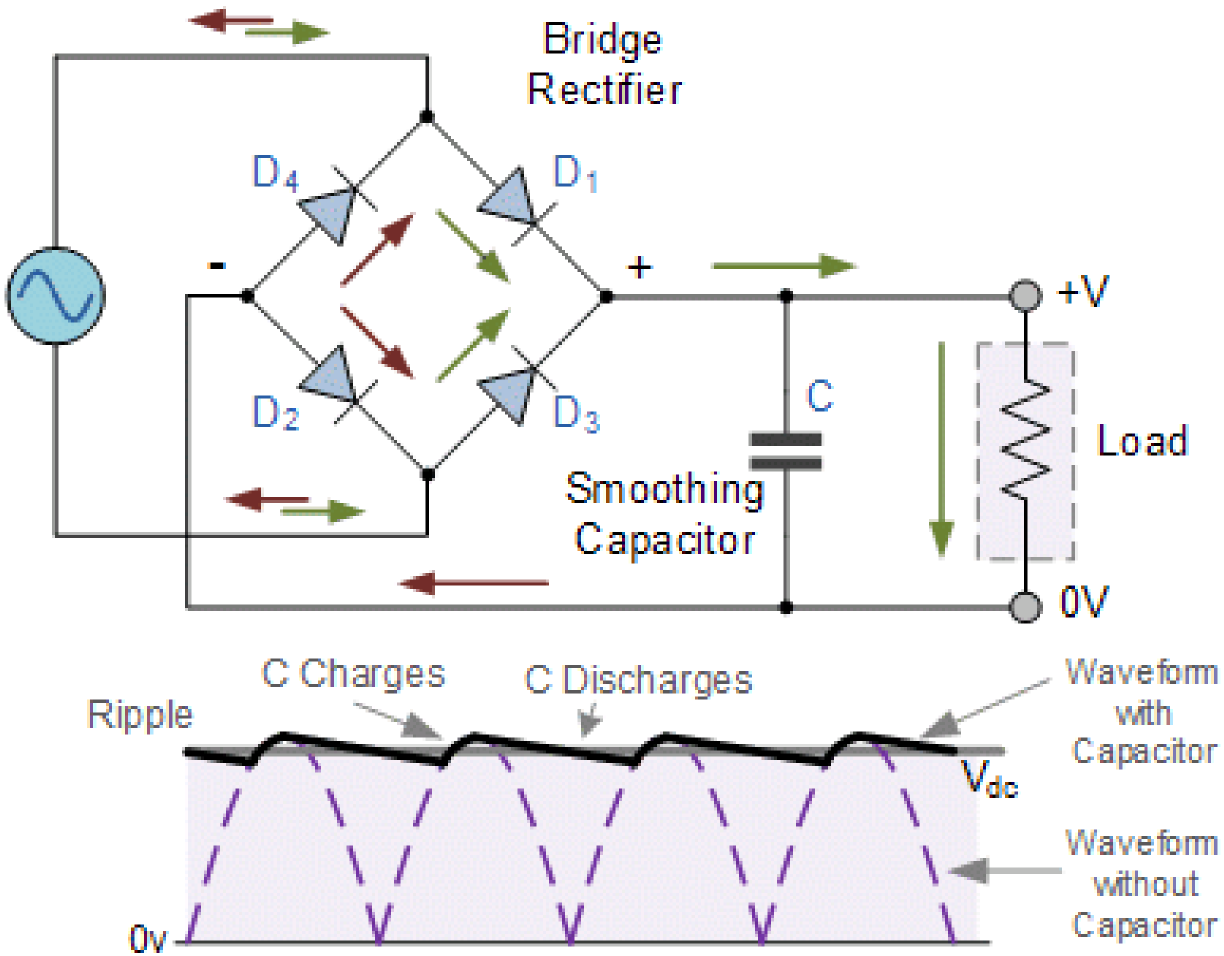
Filter

The filter is a device that allows passing the dc component of the load and blocks the ac component of the rectifier output. Thus the output of the filter circuit will be a steady dc voltage.

Inductive Reactance (X_L) = ωL and Capacitive Reactance (X_C) = $1/\omega C$

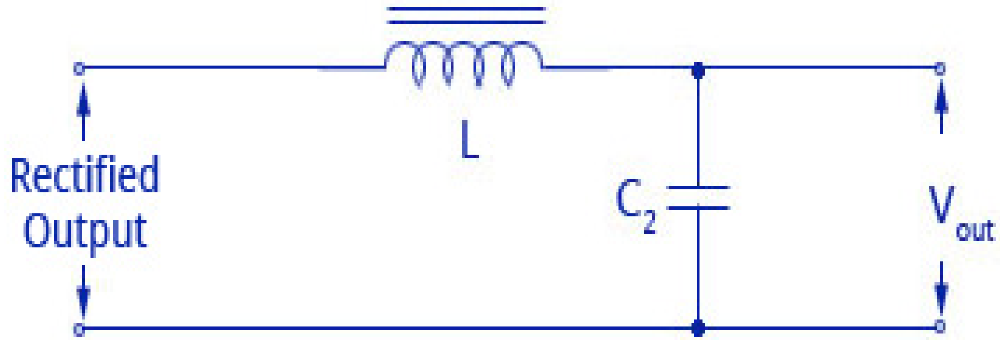
The filter circuit can be constructed by the combination of components like capacitors, resistors, and inductors. Inductor is used for its property that it allows only dc components to pass and blocks ac signals. Capacitor is used so as to block the dc and allows ac to pass.

Full wave rectifier with C filter

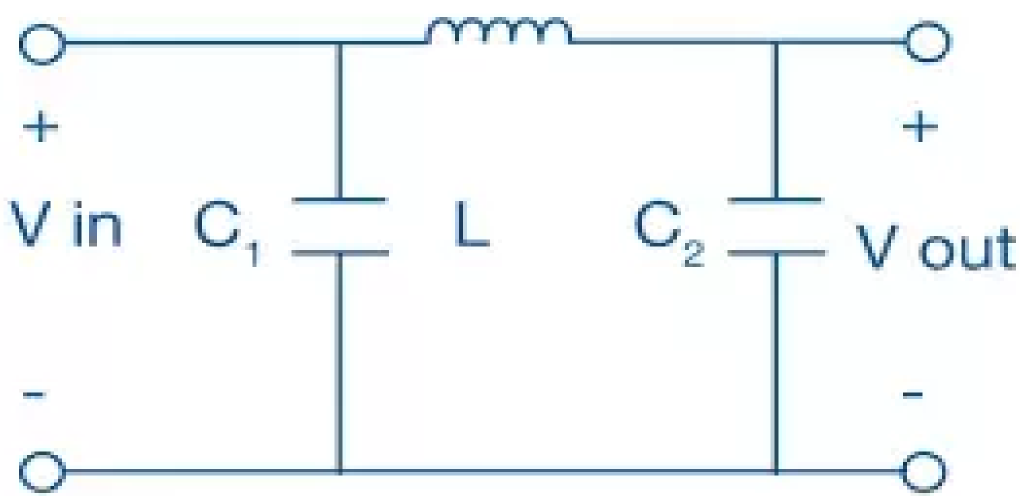


Resultant Output Waveform

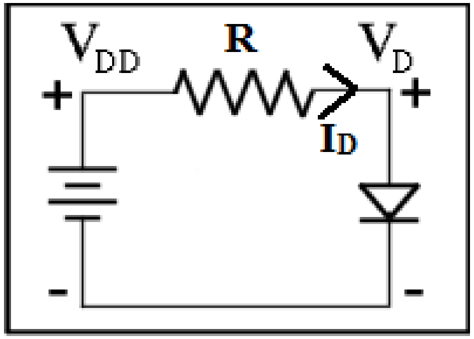
L-C Filter - Inductor input L Section Filter



Basic Pi-Filter



DC Load Line and Operating (Q) point of a Diode



$$V_{DD} = V_D + I_D R$$