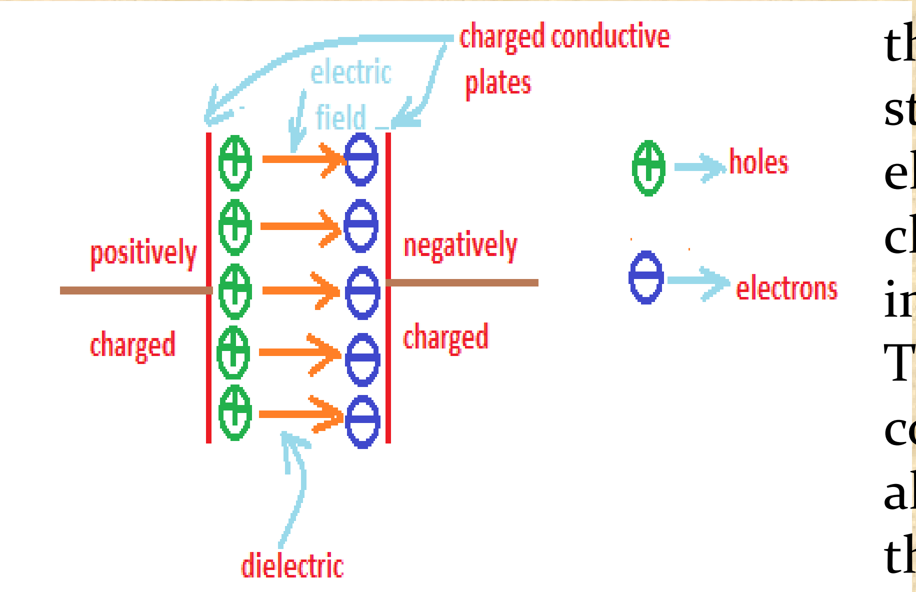
Capacitance in PN Junction

Dipanwita Das
Assistant Professor
Department of Physics
Dinabandhu Andrews College



The capacitor store electric charge in the form of electric field. This charge storage is done by using two electrically conducting plates (placed closed to each other) separated by a insulating material called dielectric. The plates or electrodes are good conductor of electricity. Thus they allow electric current to flow through them. On the other hand, dielectric material or medium is poor conductor of electricity. Therefore, it does not allow electric current to flow through it. However, it efficiently allows electric field to flow through it.

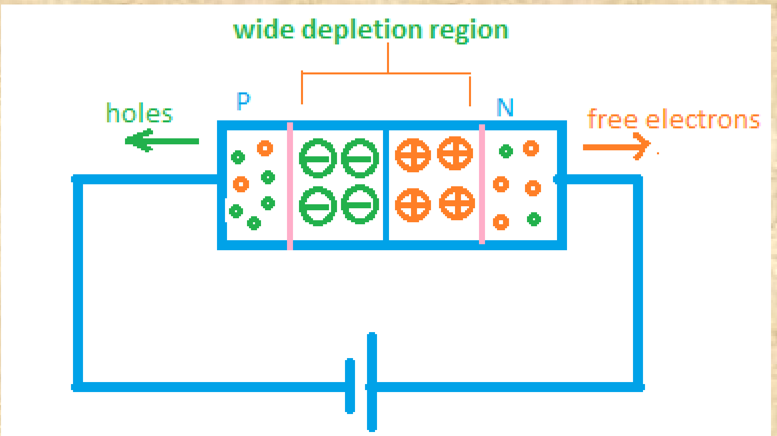
In basic capacitor, the capacitance is directly proportional to the size of the electrode
and inversely proportional to the distance between the electrodes.
In general, the capacitance of a parallel plate capacitor is expressed as

$$C = \frac{\varepsilon A}{d}$$

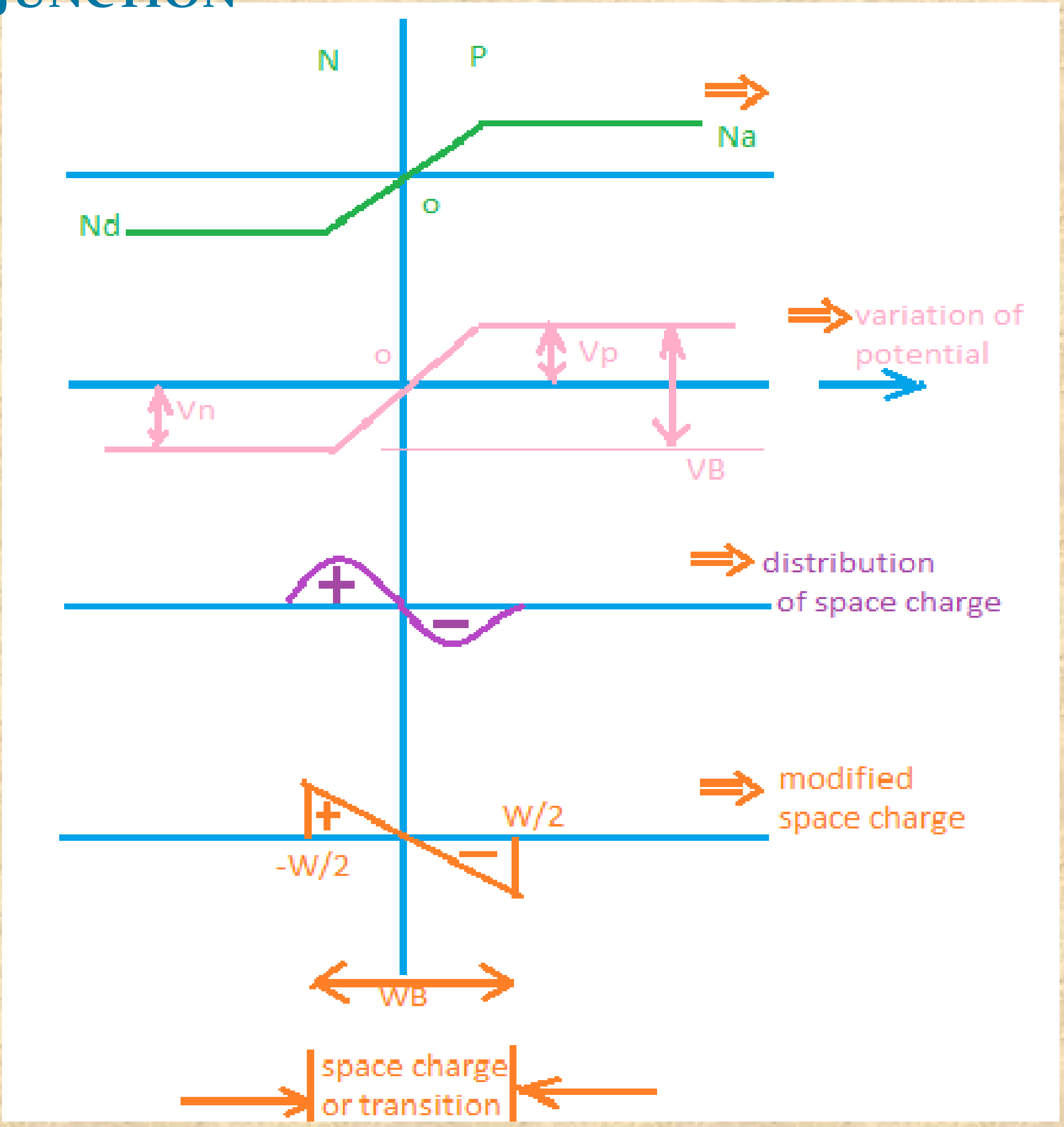
In PN junction, we consider two capacitive effects, i.e. TRANSITION CAPACITANCE C_T
and DIFFUSION CAPACITANCE C_D. Both type of capacitance are present in the forward and reverse regions but one so outweighs other in each region that we consider the effects of only one in each region.

TRANSITION CAPACITANCE

In REVERSE biased PN junction, the P type and N type regions have low resistance. Hence, P type and N type regions act like the electrodes. The depletion region of the PN junction diode has high resistance. Hence, the depletion region acts like the dielectric or insulating material. Thus, PN junction can be considered as a parallel plate capacitor.



GRADUAL JUNCTION



CALCULATION OF TRANSITION CAPACITANCE FOR GRADUAL JUNCTION

The space charge density is assumed to vary linearly with distance along X axis in space charge region and is given by

$\rho(x) = a x$ for $-W/2 < x < W/2$

Where a is grade constant = $\dfrac{e(N_d + N_a)}{W_B}$

$$= \frac{1}{W_B}\left(\frac{\sigma_n}{\mu_n} + \frac{\sigma_p}{\mu_p}\right)$$

Applying Poisson's Equation, we have

$$\frac{d^2V}{dx^2} = \frac{-\rho(x)}{\varepsilon} = -\frac{eax}{\varepsilon}$$

Integrating,

$$\frac{dV}{dx} = -\frac{ea}{2\in}x^2 + C_1$$

Boundary condition, $\dfrac{dV}{dx} = 0$ $\quad at\ x = \pm\dfrac{W}{2}$

We get $C_1 = \dfrac{ea}{8\in}W^2$ $\quad and\ \dfrac{dV}{dx} = \dfrac{ea}{2\in}\left(\dfrac{W^2}{4} - x^2\right)$

Integrating again from x = - W/2 to x = W/2, we get

$$V_T = \frac{ea\,W^3}{12\,\epsilon}$$

Q = average charge density × volume

$$= \frac{1}{2}\left(ea\,\frac{W}{2}\right) \times \left(\frac{W}{2}\,A\right) = \frac{AeaW^2}{8}$$

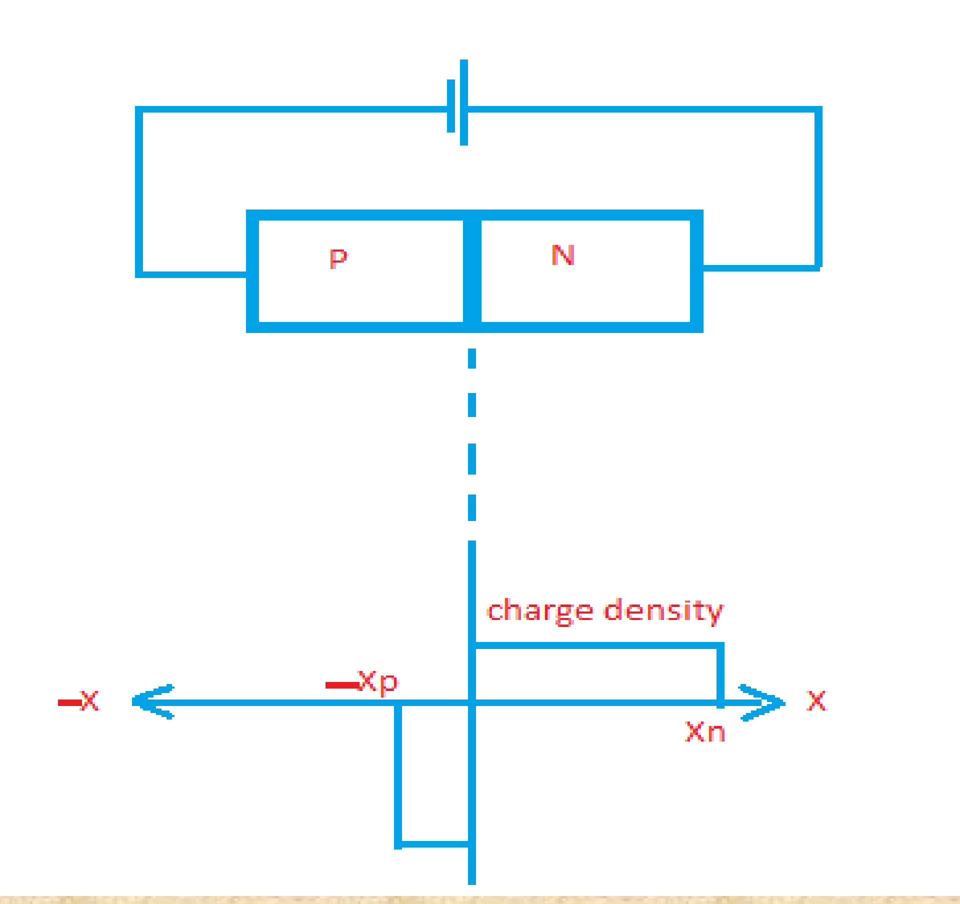
Transition capacitance, $C_T = \frac{dQ}{dV_T} = \frac{AeaW}{8} \cdot \frac{dW}{dV_T}$

$$= \epsilon\,A\left(\frac{ea}{12\,\epsilon\,V_T}\right)^{1/3}$$

Thus, in a linear graded PN junction $C_T \propto V_T^{-1/3}$

Practically C_T lies in the range 5 to 20 pF

CALCULATION OF TRANSITION CAPACITANCE FOR STEP GRADED JUNCTION OR ABRUPT JUNCTION



Step graded junction is one in which there is an abrupt change from p type impurity to n type impurity.
Let us take a junction in which the acceptor impurity concentration (Na) is assumed to be much larger than the donor impurity concentration(Nd)

From charge neutrality condition $$eN_a x_p = eN_d x_n$$

If Na >> Nd , Xp << Xn, to simplify we neglect Xp

The Poisson's equation $$\frac{d^2V}{dx^2} = -\frac{eN_d}{\epsilon}$$

Integrating, and applying boundary conditions, we get $$V_T = \frac{eN_d}{2\epsilon} W^2$$

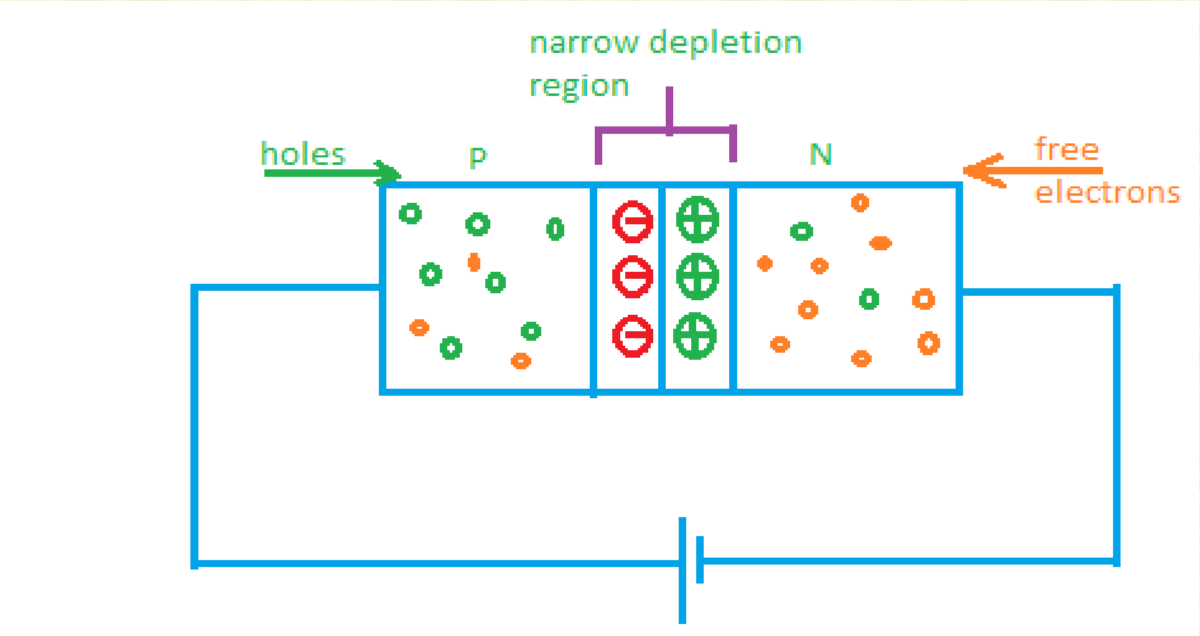
The charge in the junction $Q = (eN_d)(WA)$

Transition capacitance $C_T = \frac{dQ}{dV_T} = eN_d A \frac{dW}{dV_T} = \in A / (\frac{eN_d}{2 \in V_T})^{1/2}$

Thus $C_T \propto V_T^{-1/2}$

Thus, unlike ordinary capacitors the transition capacitance is voltage sensitive and may be used as variable capacitance or varactors.

DIFFUSION CAPACITANCE



Diffusion capacitance occurs in the forward biased PN junction. Here the diffusion capacitance has larger value than transition capacitance.

Diffusion capacitance occurs due to stored charge of minority carriers near depletion region.

The electrons(majority carriers) which cross the depletion region and enter into the p region will become the minority carriers of the p region. Similarly the holes which cross the depletion region and enter into the n region will become minority carriers of the n region.

This large no of charge carriers accumulated near depletion region before they recombine.

The accumulated charge on both side of the depletion region behaves like electrodes and the thin depletion region acts like dielectric.