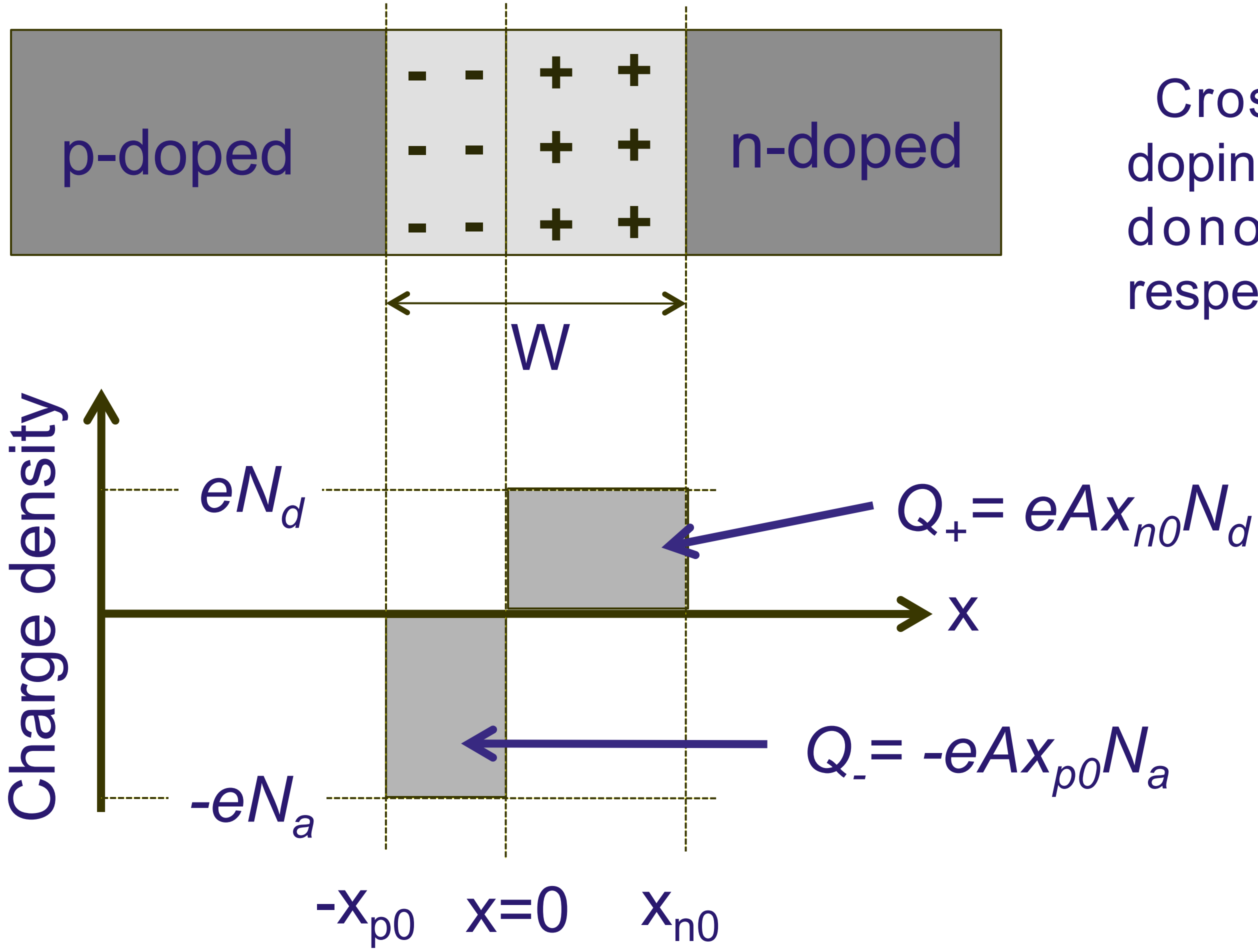
Lecture 11

- Poisson's Equation
- Space charge at the Junction
  - Depletion width
- Disturbing the equilibrium - qualitative
  - p-n junction under zero, forward, reverse bias

Space Charge at a Junction



Cross-sectional area A, doping densities of N_d, N_a for donors and acceptors, respectively.

Space Charge at a Junction

- Assume neutrality outside depletion region, W
- Neglect carriers within the depletion region
- Charge density in depletion region is governed by ionized dopants (assume all ionized at room temp)
- Total net charge in depletion region is zero to maintain overall charge neutrality

That is $eAx_{p0}N_a = eAx_{n0}N_d$ and $W = x_{p0} + x_{n0}$

Extent of depletion in each doped region depends on relative doping levels in that region (small doping large depletion and visa versa)

hence $x_{p0}N_a = x_{n0}N_d$ - we will use this a lot.....

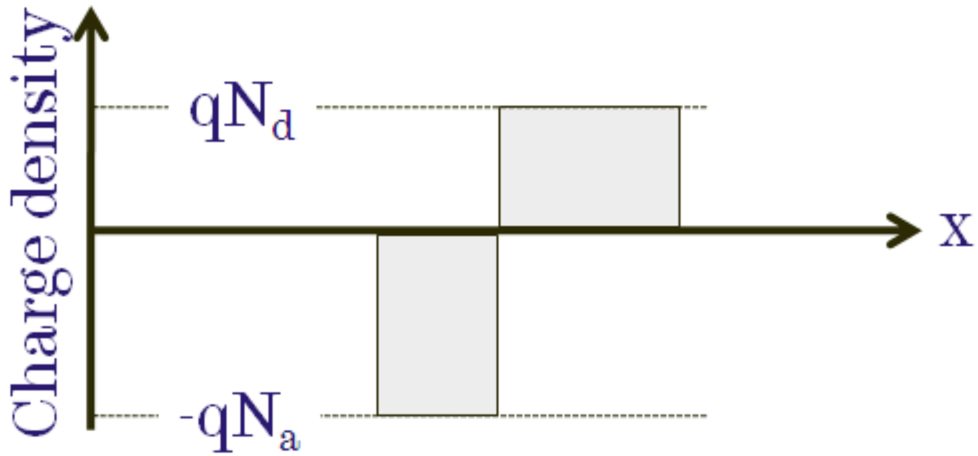
E-fields - Poisson's Equation

$$\frac{dE}{dx} = \frac{\rho}{\varepsilon}$$

ρ is the space charge density

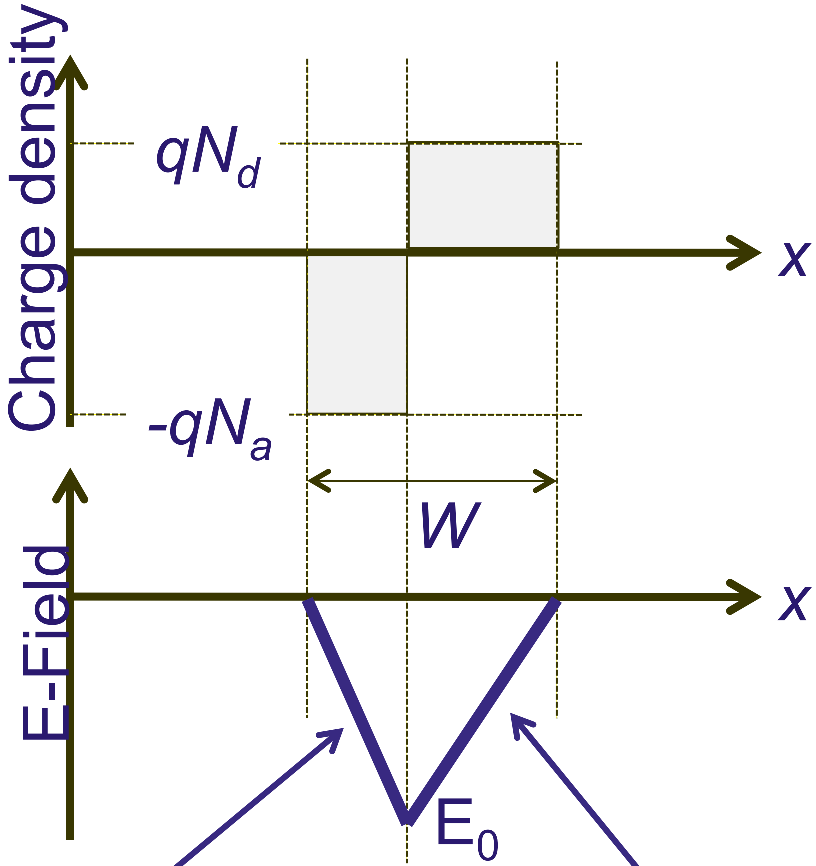
So generally

$$\frac{dE}{dx} = \frac{e}{\varepsilon}\left(p - n + N_d - N_a\right)$$



- We can neglect n and N_d terms in this equation in the case of p-type regions and visa versa for n-type
- In neutral doped material $p = -N_a$ or $n = -N_d$ and $\frac{dE}{dx} = 0$

E-fields - Poisson's Equation



$$\frac{dE}{dx} = -\frac{e}{\varepsilon}(N_a) \qquad \frac{dE}{dx} = \frac{e}{\varepsilon}(N_d)$$

- ***E***-field only present in 'space charge' region
- We know ***E***-field is negative (in direction of –ve *x*)
- 2 regions, one +ve *dE/dx* and one –*ve dE/dx*
- Maximum ***E***-field at physical junction between doped regions

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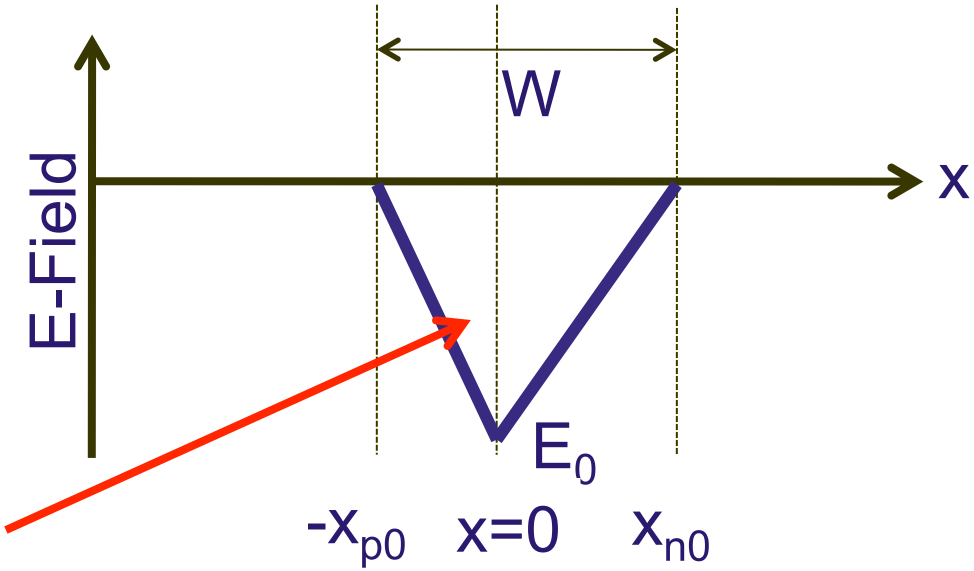
Depletion Region – Built-in Voltage, V_o

$$E = -\frac{dV}{dx}$$ or alternatively,

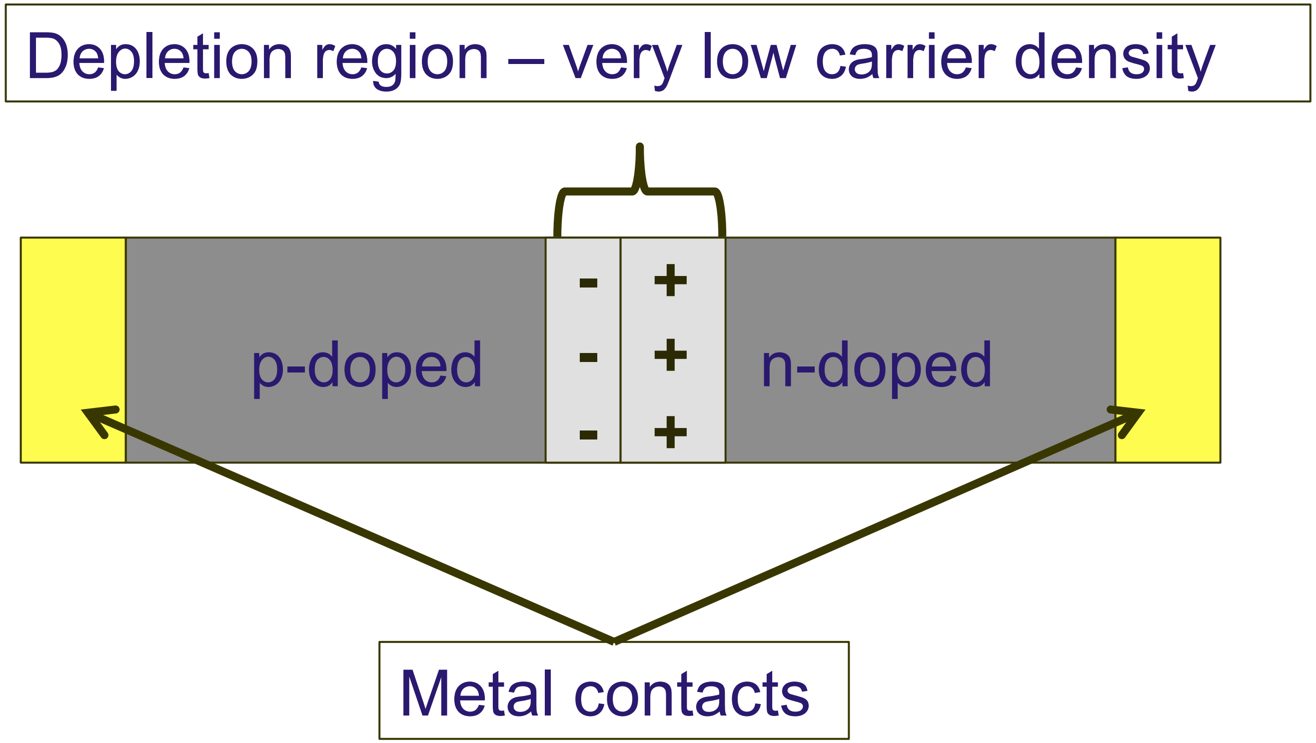
$$-V_0 = \int_{-x_{p0}}^{x_{n0}} E(x)\, dx$$

So V_0 is area of this triangle

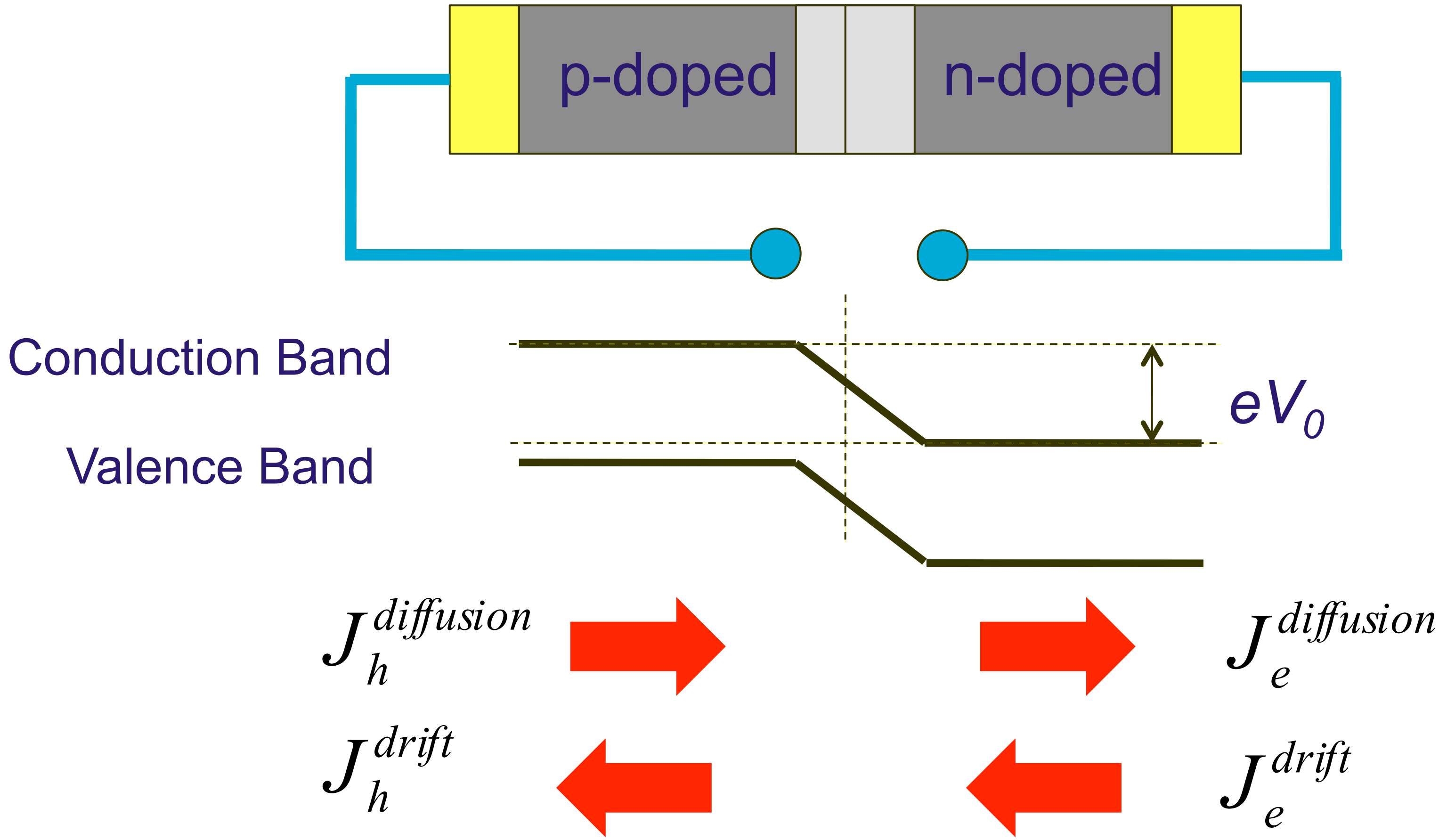


$$V_0 = -\frac{1}{2}E_0 W = \frac{1}{2}\frac{e}{\varepsilon}N_d x_{n0} W = \frac{1}{2}\frac{e}{\varepsilon}N_a x_{p0} W$$

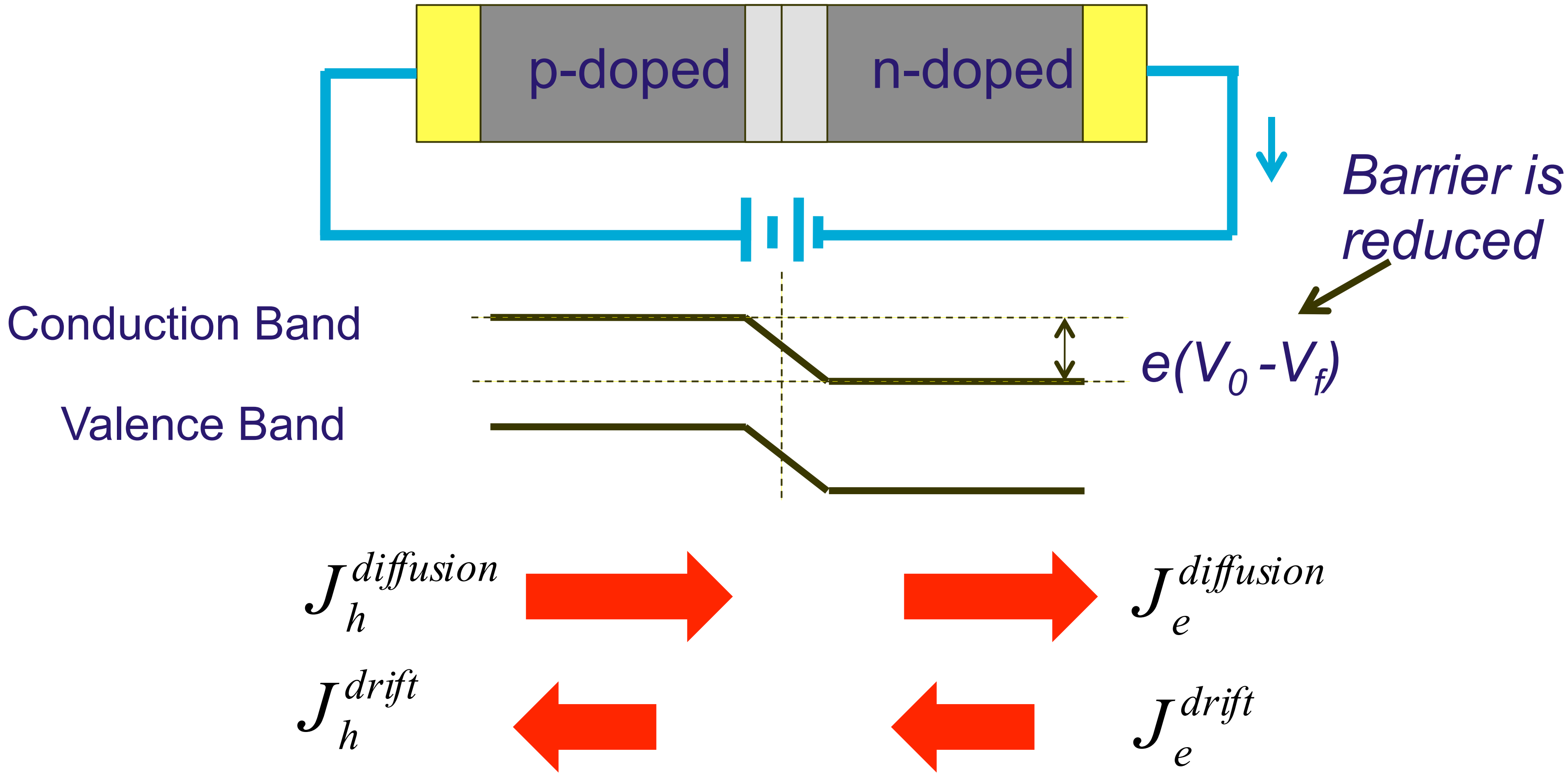
Complete Diode Structure



Zero External Applied Voltage



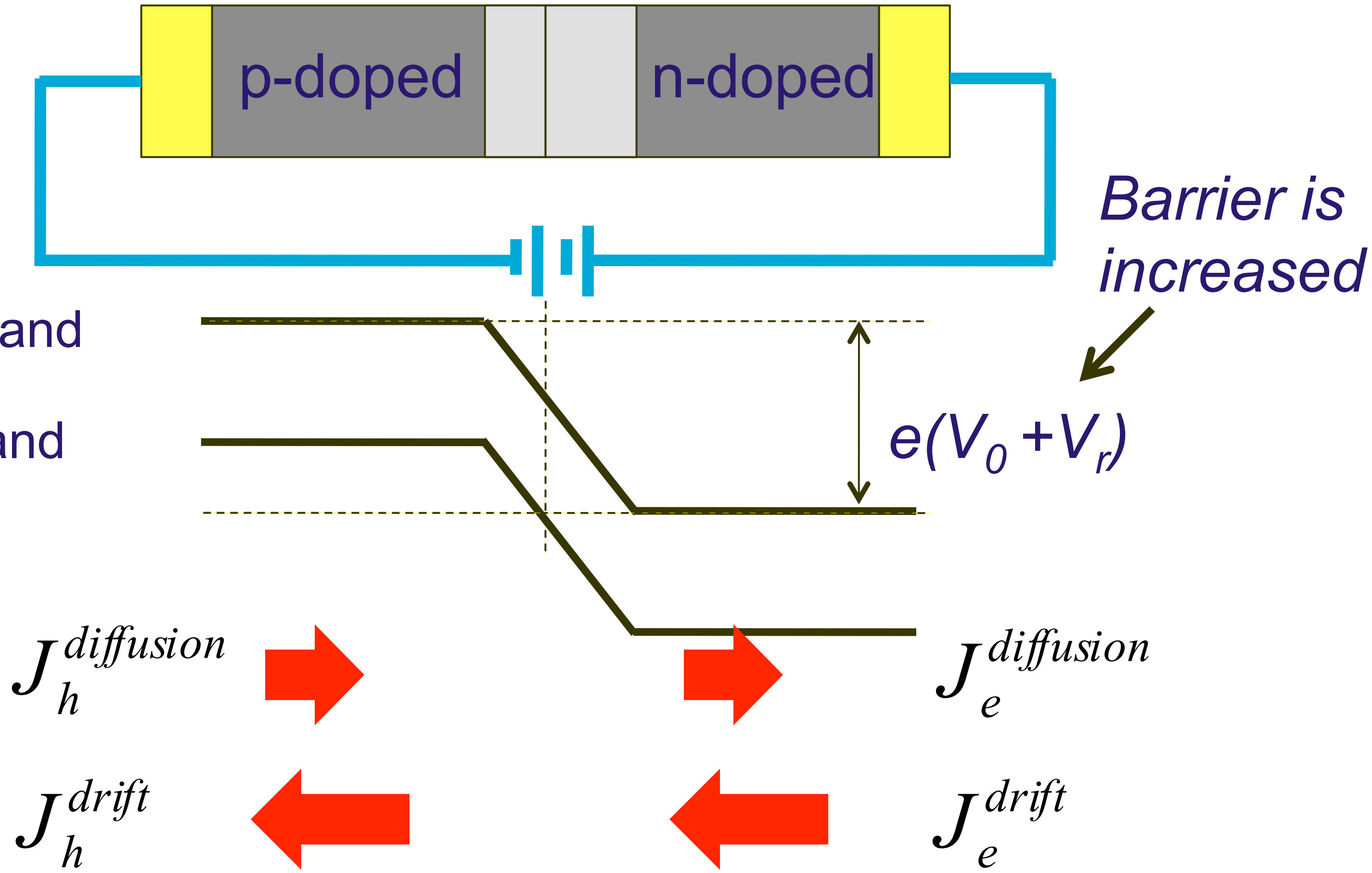
Forward Bias, V_f



Forward Bias, V_f - Current Imbalance

- Applied voltage changes the potential barrier and thus ***E***-field within junction region - as we have forward bias the potential barrier is reduced
- The electric field in the transition region reduces
- This reduces the depletion region width (need fewer "exposed" ionized dopants to achieve this lower ***E***-field)
- <u>Diffusion Current</u> is increased – potential barrier smaller – main current mechanism in diode
- <u>Drift Current</u> essentially same as zero bias - very few minority carriers to contribute to drift – so very small

Reverse Bias, V_r



Reverse Bias, V_r

- Applied voltage changes the potential barrier and thus ***E***-field within junction region
- As we have reverse bias - the potential and the electric field is increased
- This increases the transition region width (need more "exposed" ionized dopants to achieve this higher E-field
- Diffusion Current – potential barrier bigger – so reduced diffusion current
- Drift Current – same as zero bias - very few minority carriers to contribute to drift – so very small

Summary

- Poisson's equation relates electrostatic potential to charges present

- Space charge at the p-n junction determines the depletion region width, penetration into the n and p-doped regions, Electric-field and built in potential

