

# EE 105

## Semiconductors

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# Active Devices

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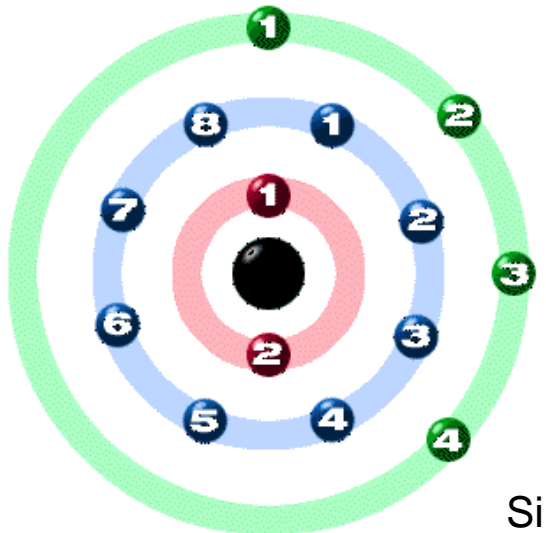
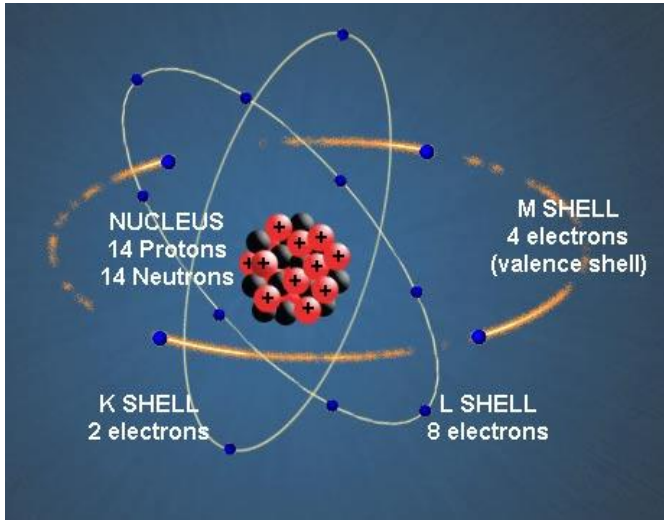
- Control (current) flow
- Cascadeable:
  - Compatible inputs and outputs including
  - Same physical domain, e.g.
    - Electrical
    - Pneumatic
    - Chemical
    - Mechanical
  - Compatible signal levels, e.g.
    - Switch with 5V control signal must be able to switch 5V at output
- Examples:
  - Transistor
  - Relays
  - Vacuum tube

# Semiconductors

# Electrical Conduction

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# Atom Shells



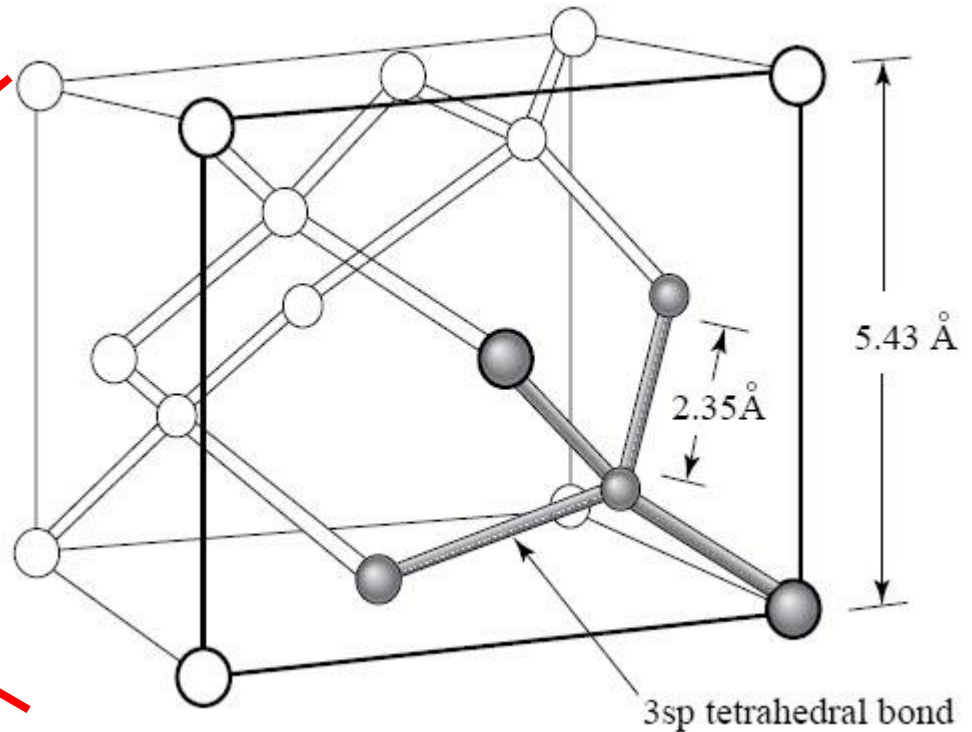
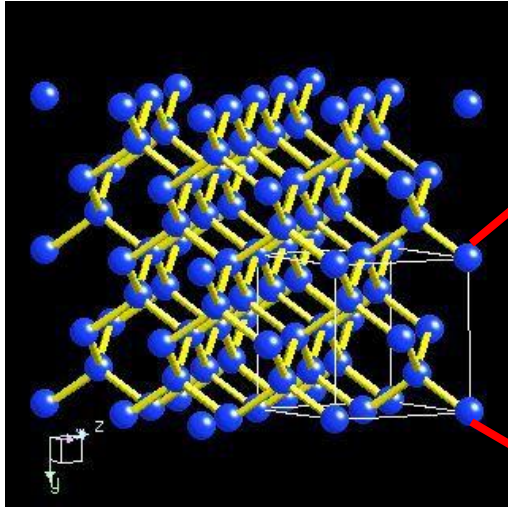
# Semiconductors

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 <b>H</b> 1.008																	2 <b>He</b> 4.0026
3 <b>Li</b> 6.94	4 <b>Be</b> 9.0122											5 <b>B</b> 10.81	6 <b>C</b> 12.011	7 <b>N</b> 14.007	8 <b>O</b> 15.999	9 <b>F</b> 18.998	10 <b>Ne</b> 20.180
11 <b>Na</b> 22.990	12 <b>Mg</b> 24.305											13 <b>Al</b> 26.982	14 <b>Si</b> 28.085	15 <b>P</b> 30.974	16 <b>S</b> 32.06	17 <b>Cl</b> 35.45	18 <b>Ar</b> 39.948
19 <b>K</b> 39.098	20 <b>Ca</b> 40.078	21 <b>Sc</b> 44.956	22 <b>Ti</b> 47.867	23 <b>V</b> 50.942	24 <b>Cr</b> 51.996	25 <b>Mn</b> 54.938	26 <b>Fe</b> 55.845	27 <b>Co</b> 58.933	28 <b>Ni</b> 58.693	29 <b>Cu</b> 63.546	30 <b>Zn</b> 65.38	31 <b>Ga</b> 69.723	32 <b>Ge</b> 72.63	33 <b>As</b> 74.922	34 <b>Se</b> 78.96	35 <b>Br</b> 79.904	36 <b>Kr</b> 83.798
37 <b>Rb</b> 85.468	38 <b>Sr</b> 87.62	39 <b>Y</b> 88.906	40 <b>Zr</b> 91.224	41 <b>Nb</b> 92.906	42 <b>Mo</b> 95.96	43 <b>Tc</b> [97.91]	44 <b>Ru</b> 101.07	45 <b>Rh</b> 102.91	46 <b>Pd</b> 106.42	47 <b>Ag</b> 107.87	48 <b>Cd</b> 112.41	49 <b>In</b> 114.82	50 <b>Sn</b> 118.71	51 <b>Sb</b> 121.76	52 <b>Te</b> 127.60	53 <b>I</b> 126.90	54 <b>Xe</b> 131.29
55 <b>Cs</b> 132.91	56 <b>Ba</b> 137.33	* 71 <b>Lu</b> 174.97	72 <b>Hf</b> 178.49	73 <b>Ta</b> 180.95	74 <b>W</b> 183.84	75 <b>Re</b> 186.21	76 <b>Os</b> 190.23	77 <b>Ir</b> 192.22	78 <b>Pt</b> 195.08	79 <b>Au</b> 196.97	80 <b>Hg</b> 200.59	81 <b>Tl</b> 204.38	82 <b>Pb</b> 207.2	83 <b>Bi</b> 208.98	84 <b>Po</b> [208.98]	85 <b>At</b> [209.99]	86 <b>Rn</b> [222.02]
87 <b>Fr</b> [223.02]	88 <b>Ra</b> [226.03]	** 103 <b>Lr</b> [262.11]	104 <b>Rf</b> [265.12]	105 <b>Db</b> [268.13]	106 <b>Sg</b> [271.13]	107 <b>Bh</b> [270]	108 <b>Hs</b> [277.15]	109 <b>Mt</b> [276.15]	110 <b>Ds</b> [281.16]	111 <b>Rg</b> [280.16]	112 <b>Cn</b> [285.17]	113 <b>Uut</b> [284.18]	114 <b>Fl</b> [289.19]	115 <b>Uup</b> [288.19]	116 <b>Lv</b> [293]	117 <b>Uus</b> [294]	118 <b>Uuo</b> [294]

# Silicon Crystal



# Silicon Crystal



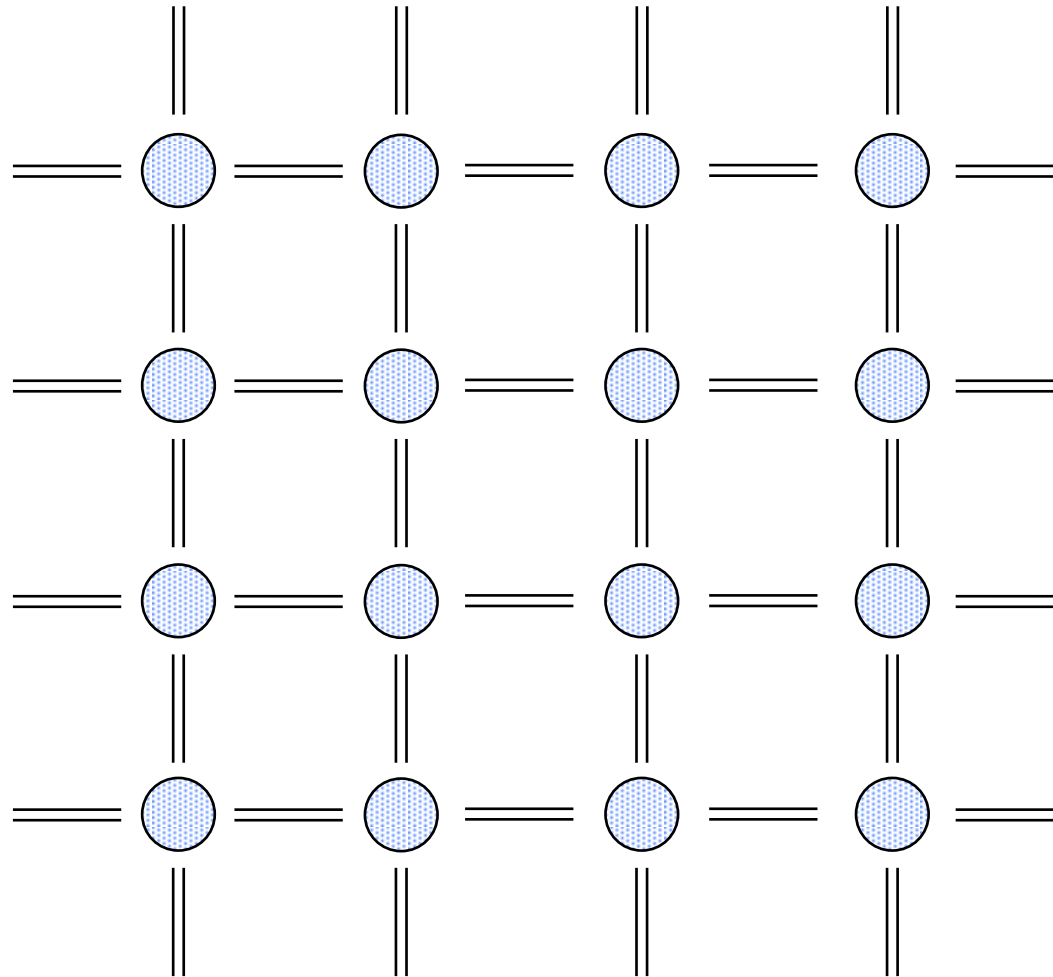
Density:  
 $5 \times 10^{22}$  atoms / cm<sup>3</sup>

Distance between atoms:  
0.235 nm



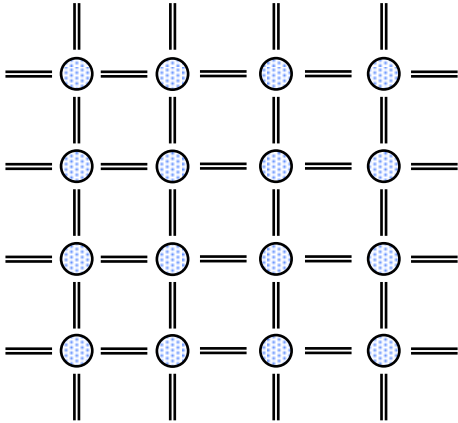
# 2D Representation for Simplicity

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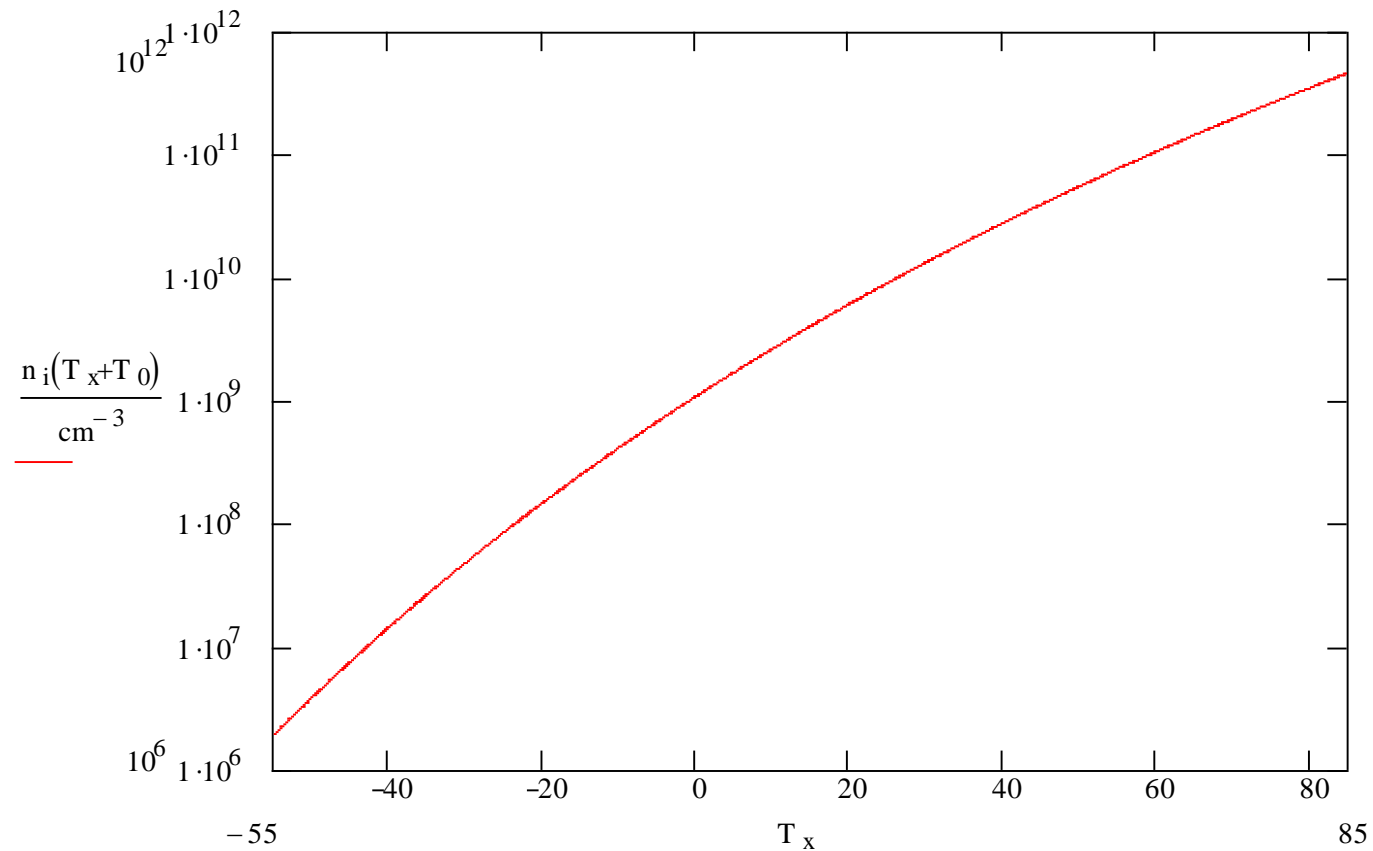


# Bandgap

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# Intrinsic Carrier Concentration $n_i$

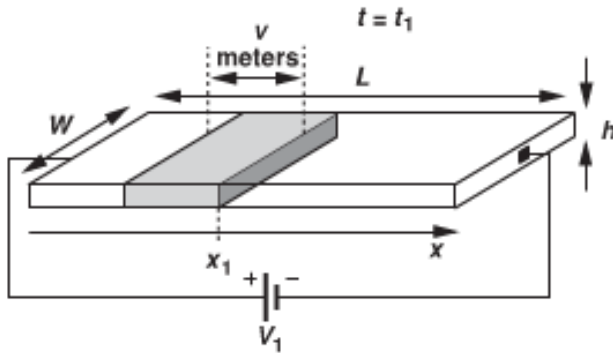


# Semiconductors Summary

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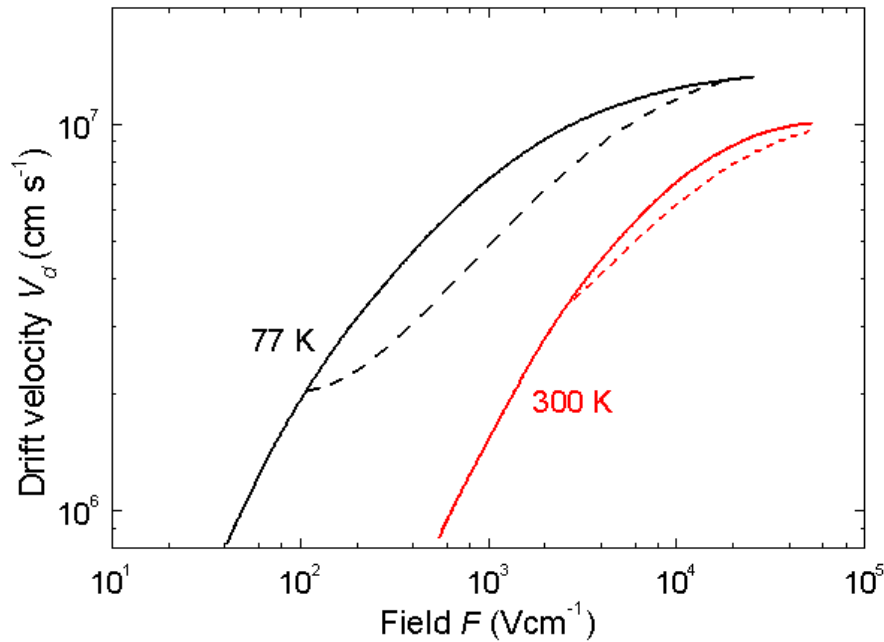
# Drift Current

# Current Flow



# Mobility

Jacoboni, C., C. Canali, G. Ottaviani, and A. A. Quaranta,  
*Solid State Electron.* **20**, **2**(1977) 77-89.



Electron drift velocity in Si

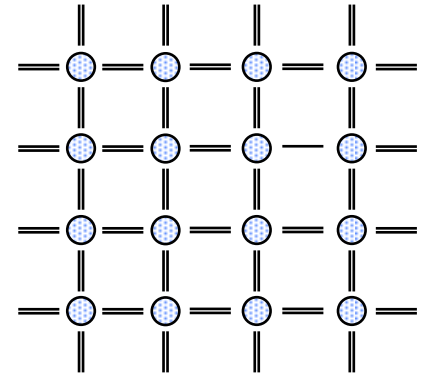
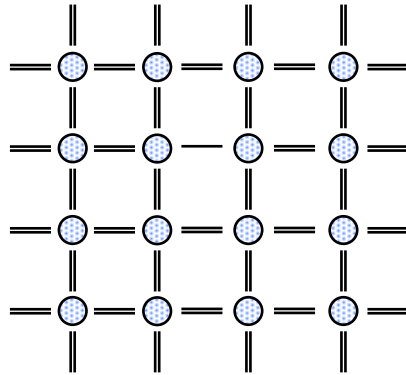
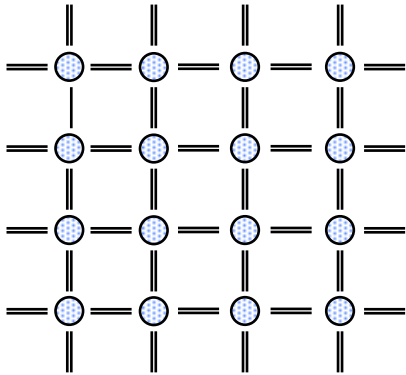
# Drift Current Example

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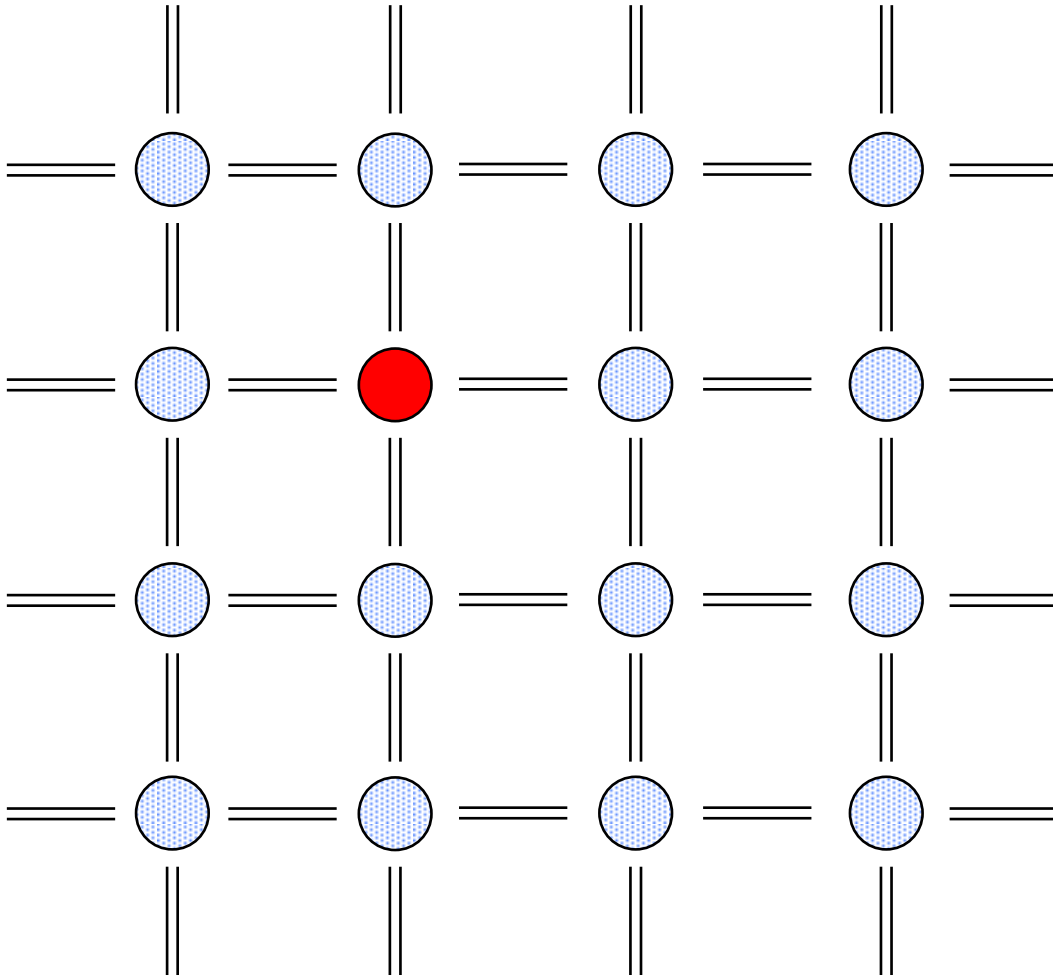


# Holes

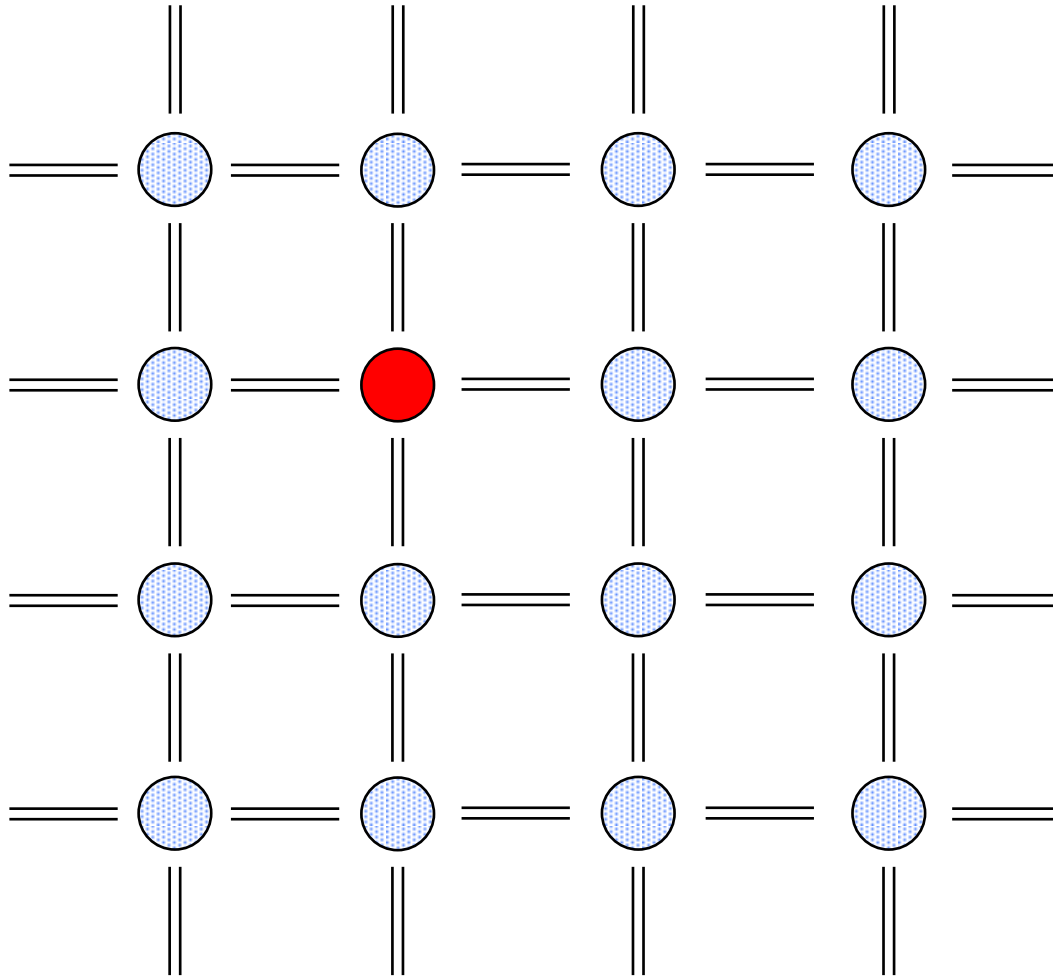
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# ~~“Semi”~~ Conductor?



# Donors



# Question

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Is a doped semiconductor charge neutral?

# Uniform Semiconductors Summary

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# ***pn* Junction**

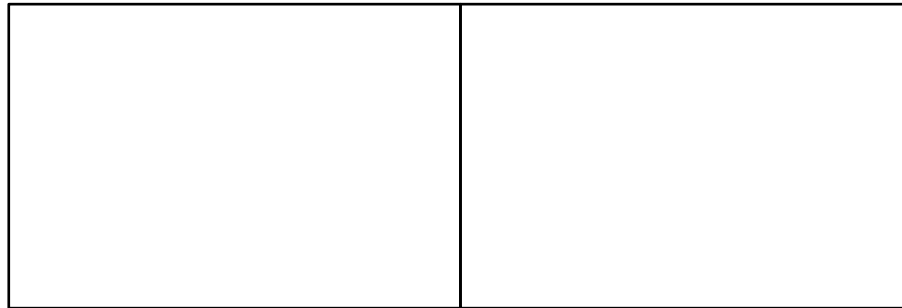
## **(Diode)**

# *pn* Junction

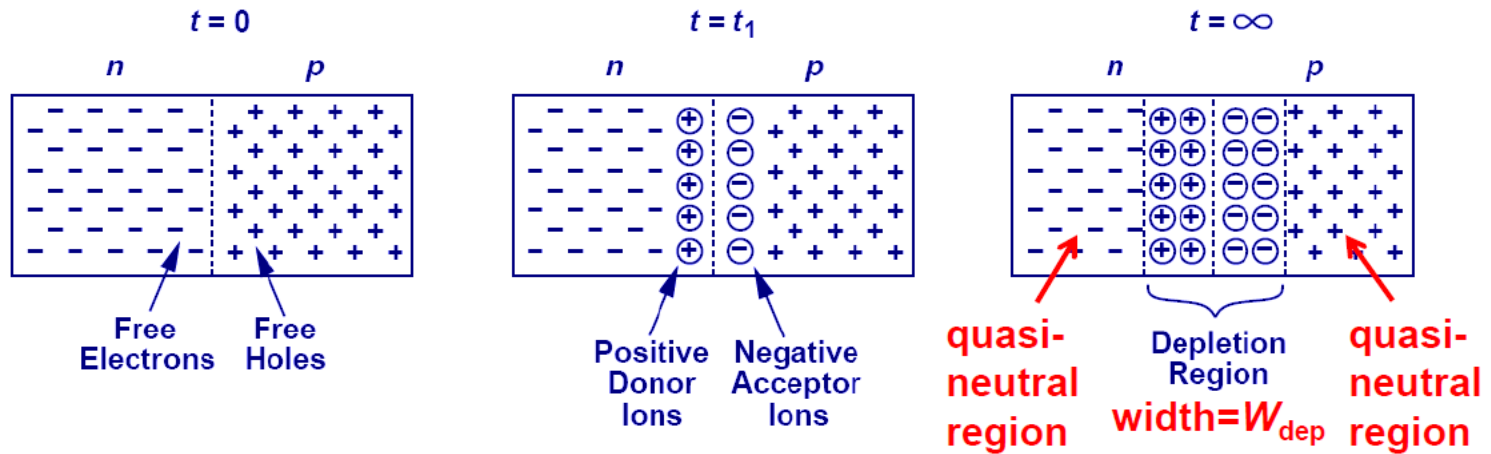
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$$p = N_A$$

$$n = N_D$$



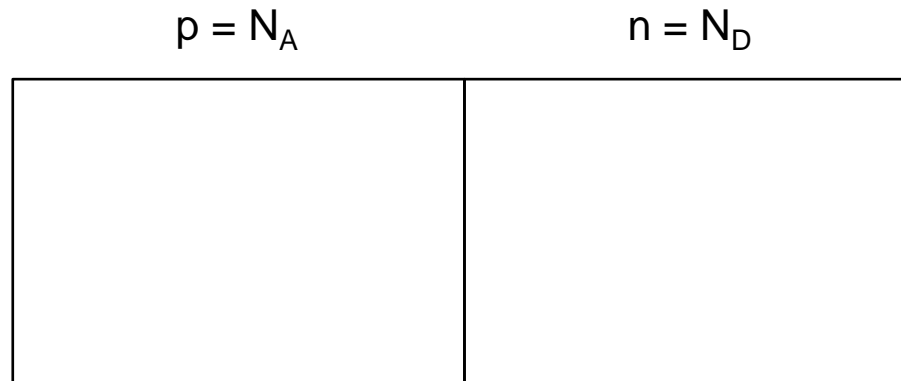
# Depletion Region





# Drift and Diffusion Currents

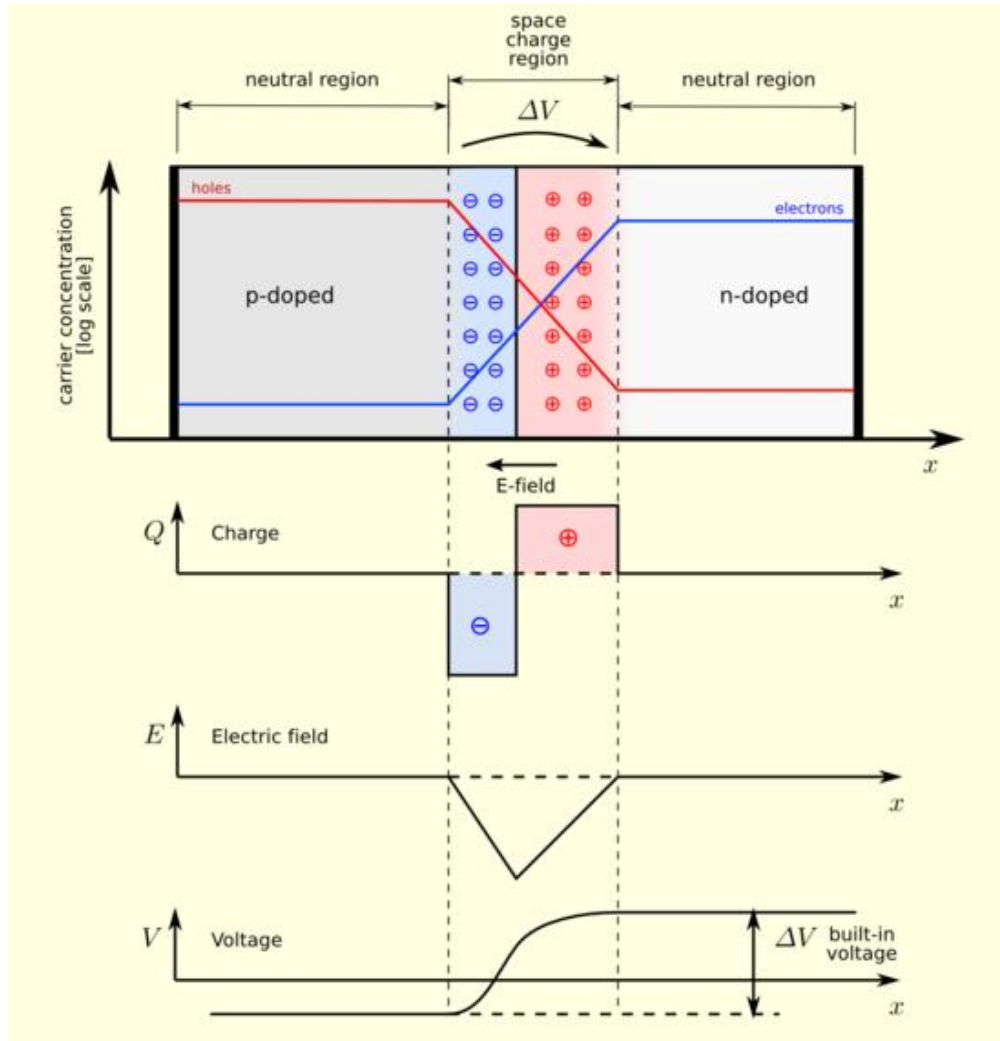
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$\longleftarrow$                        $I_{diffusion,n}$

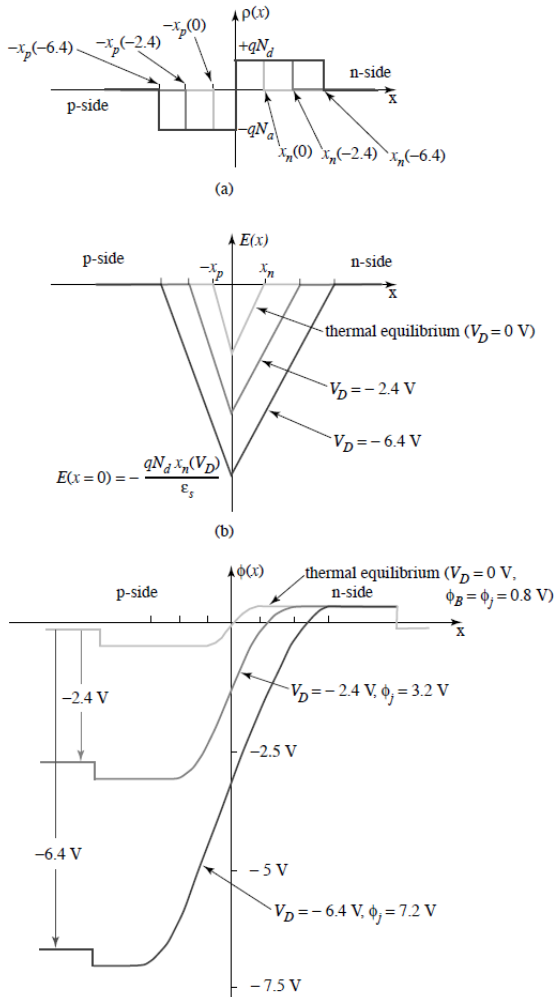
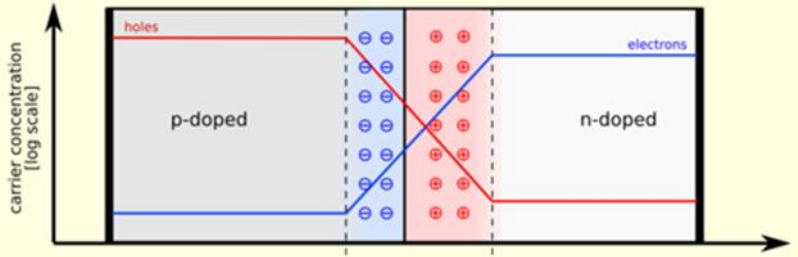
$\longrightarrow$                        $+ I_{drift,n} = 0A$

# Junction Potential

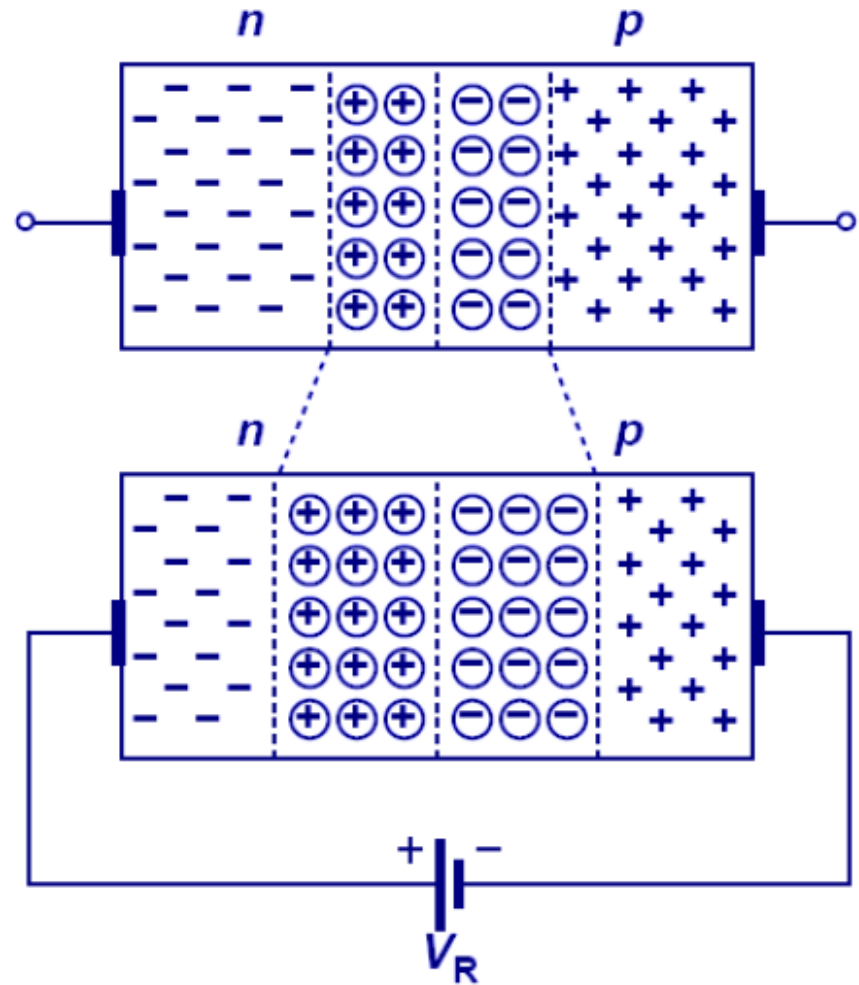


[http://en.wikipedia.org/wiki/P-n\\_junction](http://en.wikipedia.org/wiki/P-n_junction)

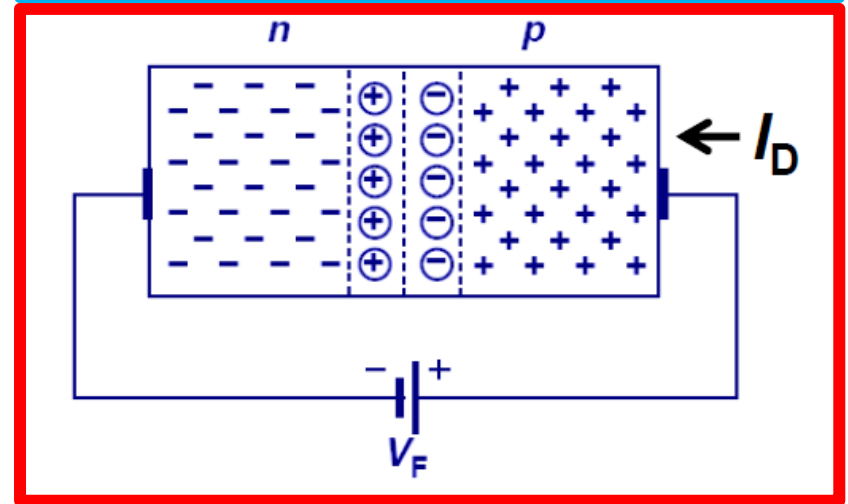
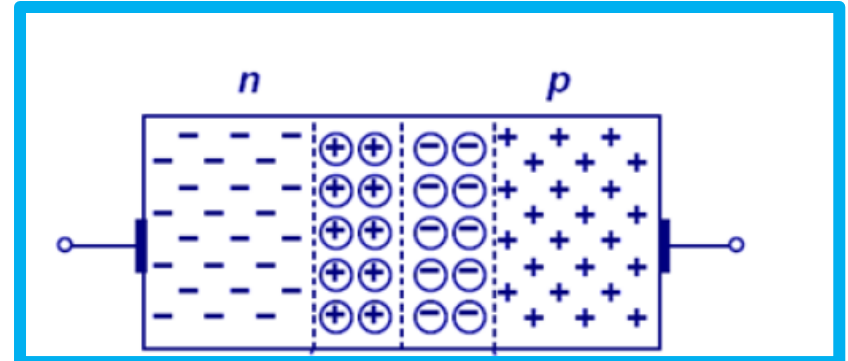
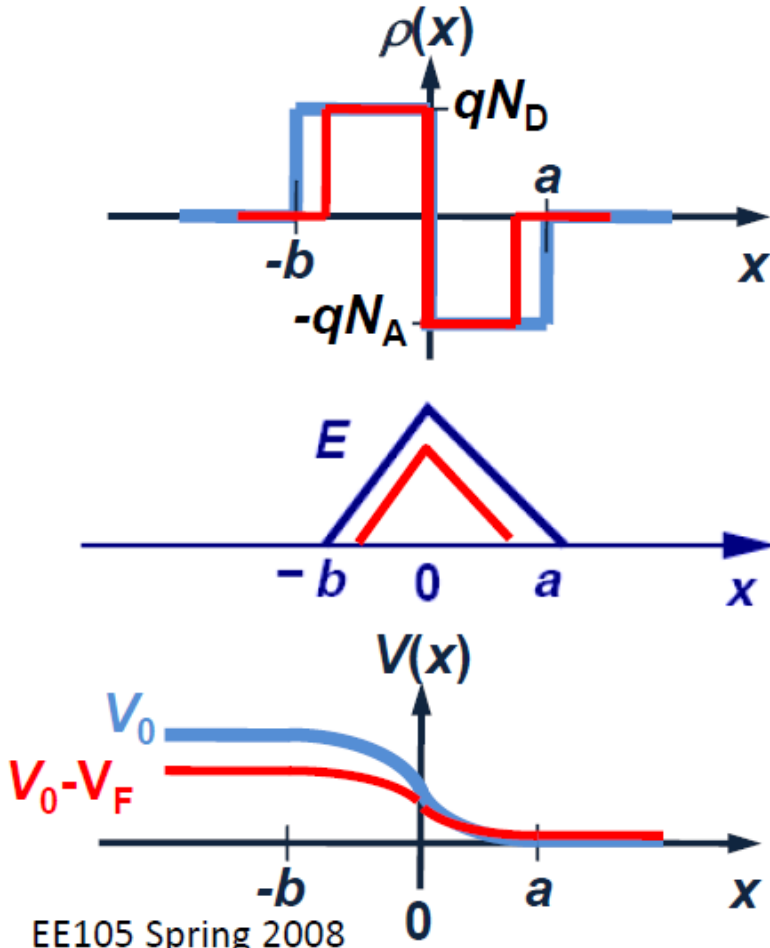
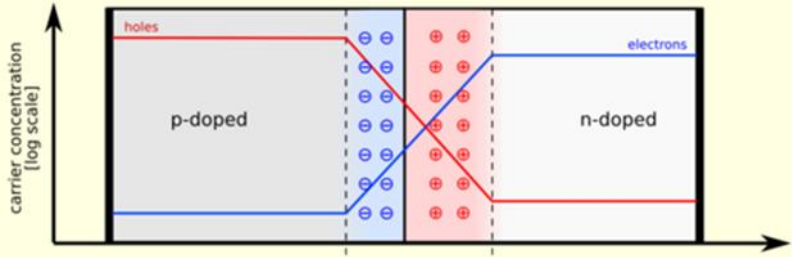
# Reverse Bias



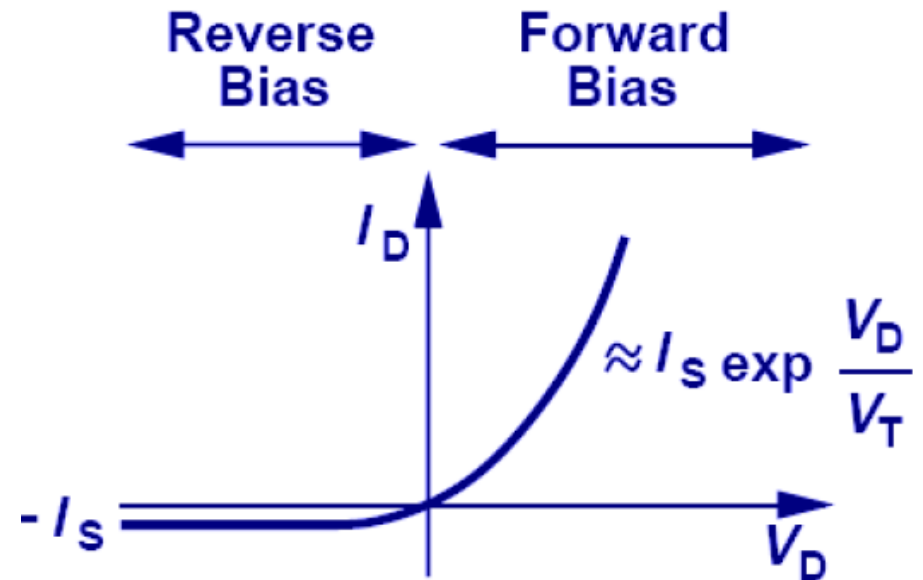
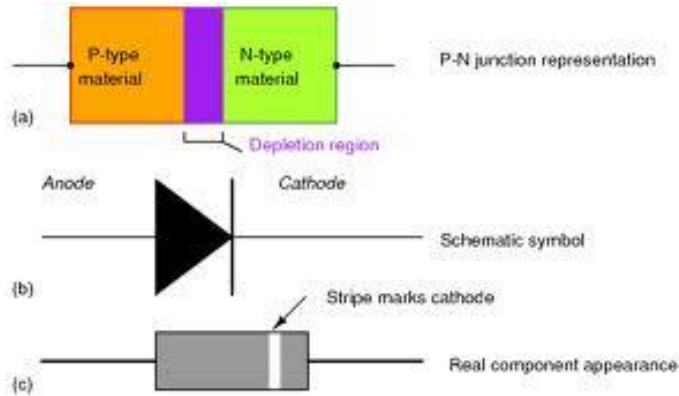
Ref: R. Howe, Prentice Hall. (c)



# Forward Bias



# Putting it all Together



**“Ideal diode” equation:**

$$I_D = I_S \left( e^{V_D/V_T} - 1 \right)$$
$$I_S = A J_S = A q n_i^2 \left( \frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p} \right)$$