Session 1: Solid State Devices

From Atoms to Transistors

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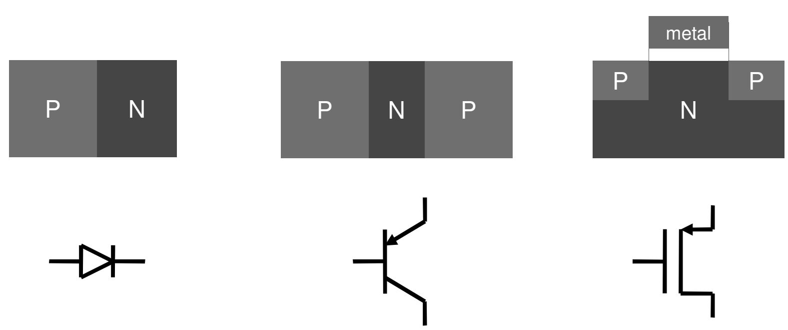
Objective

To Understand: how “Diodes,” and “Transistors” operate!



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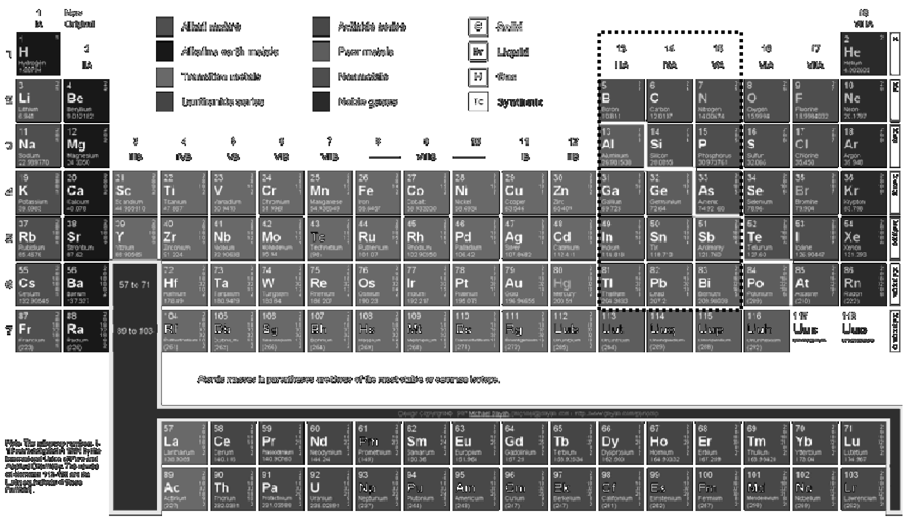
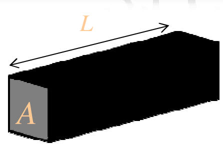
Periodic Table of the Elements



21 Century Alchemy !



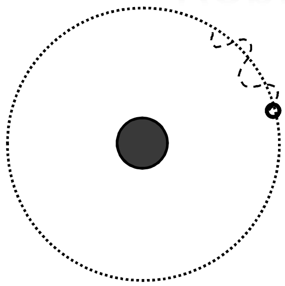
$$R = \frac{V}{I} = \rho \frac{L}{A}$$

Resistivity is characteristic of the material

$$(\rho_{Al} = 10^{-6}\,\Omega cm) \quad Cu, Al \xleftrightarrow{SiO_2} SiO_2 \quad (\rho_{SiO_2} = 10^{16}\,\Omega cm)$$

- Intel Core i7
- Today
- Clock rate 2.66GHz-3.33GHz
- 64 bit processor
- 4 cores
- 731M Transistors at **45 nm**
- Oregon 32 nm plant
- Price 273-562 $
- 263 mm2 die size

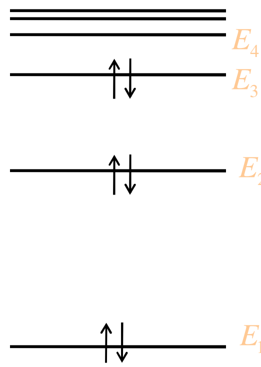
Bohr Atomic Model



wave-particle duality $\lambda = \dfrac{h}{p}$

$mvr = n\hbar$

Energy Bands:



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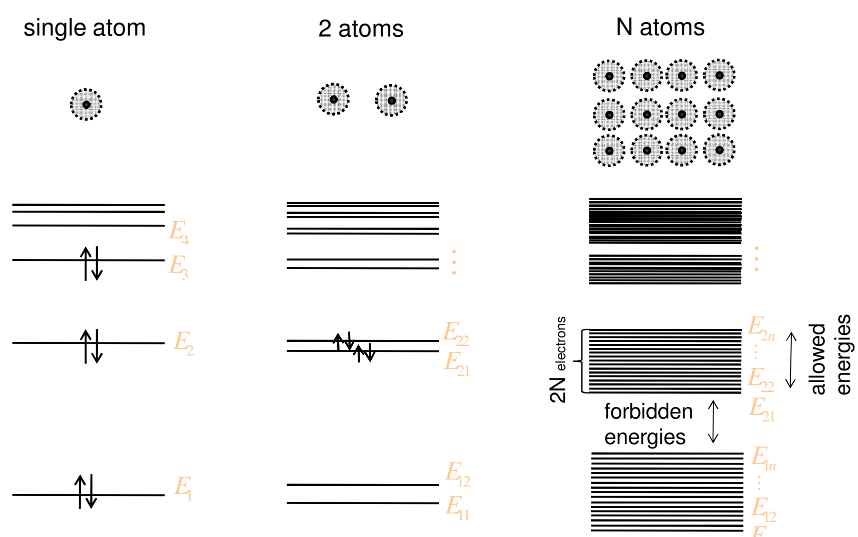
Bohr Atomic Model



Pauli exclusion principle

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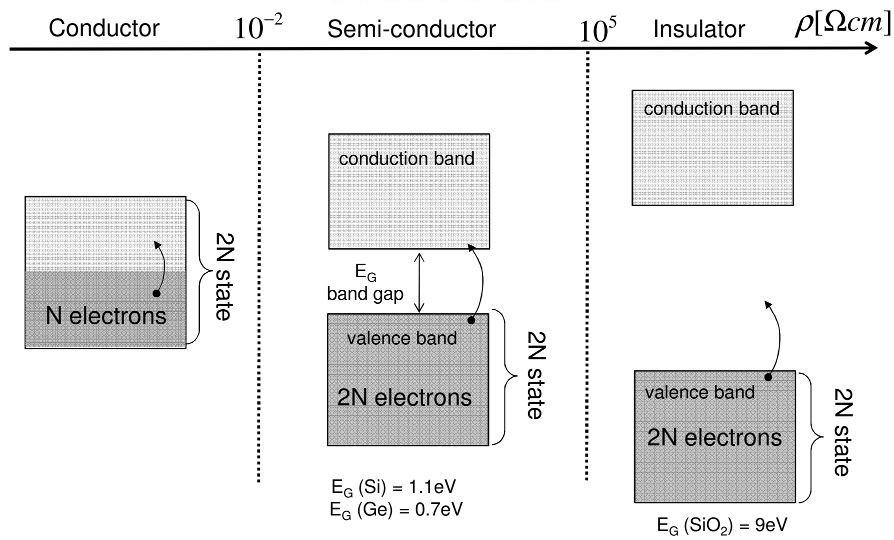
Materials



empty seat / filled seat

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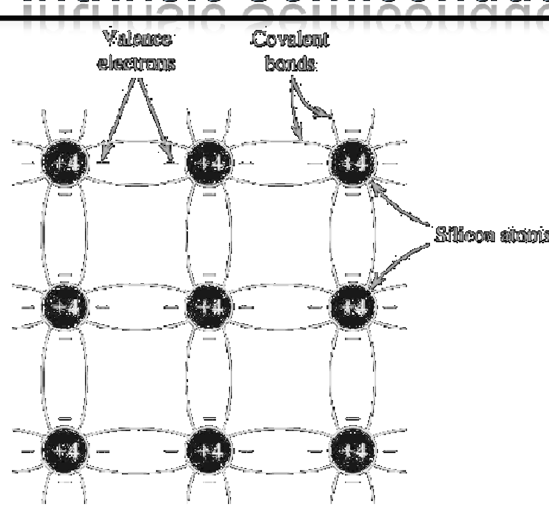
Intrinsic Semiconductor



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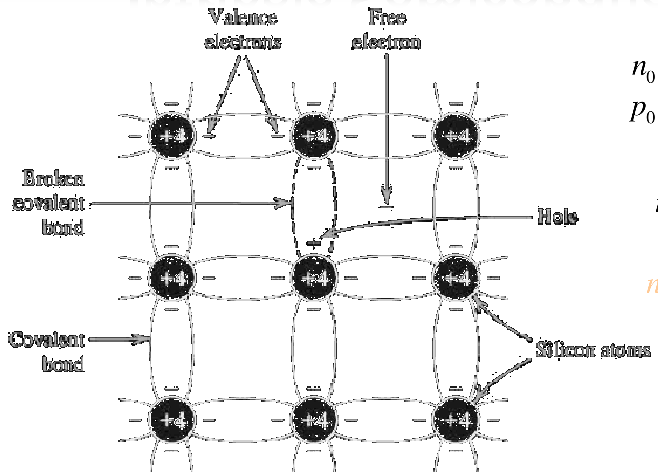
Intrinsic Semiconductor



n_0 electron density

p_0 hole density

$$n_0 = p_0 = n_i$$

$$n_i = AT^{3/2}e^{-E_G/kT}$$

$$n_i\big|_{T=300^\circ K} = 10^{10}/cm^3 \quad << \quad n(Si) = 2\times10^{23}/cm^3$$

☹ useless!!!

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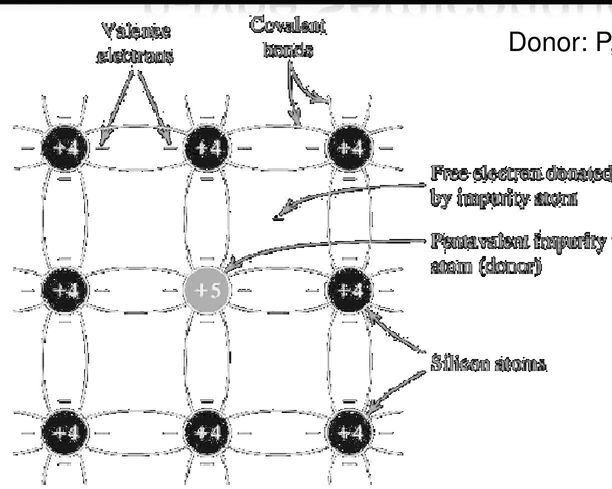
n-type Semiconductor



Donor: P, As, Sb

n_0 electron density

p_0 hole density

$$n_0 = N_D$$

$$n_0 p_0 = n_i^2$$

N_D *up to* $10^{19}/cm^3$ ☺ $n(Si) = 2\times10^{23}/cm^3$

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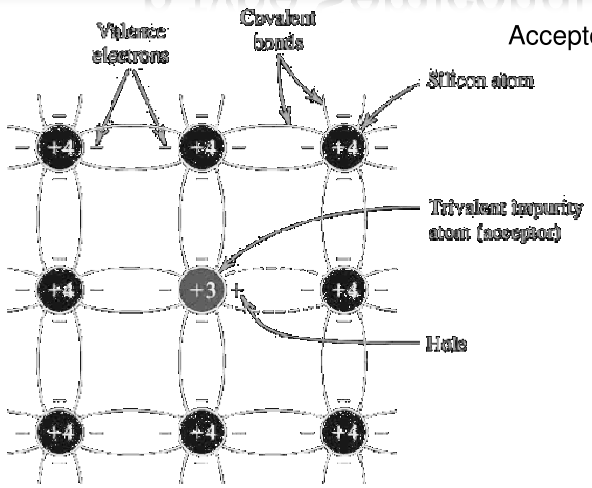
p-type Semiconductor



Acceptor: B, Ga, In

n_0 electron density

p_0 hole density

$$p_0 = N_A$$

$$n_0 p_0 = n_i^2$$

N_A *up to* $10^{19} / cm^3$ ☺ $n(Si) = 2 \times 10^{23} / cm^3$

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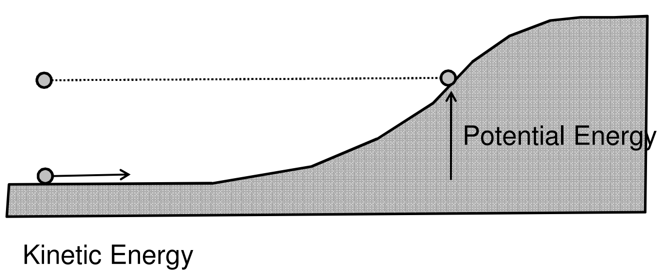
Energy Diagrams



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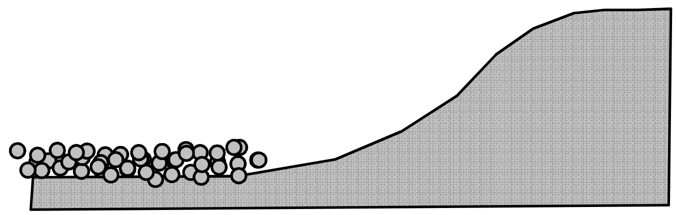
Energy Diagrams



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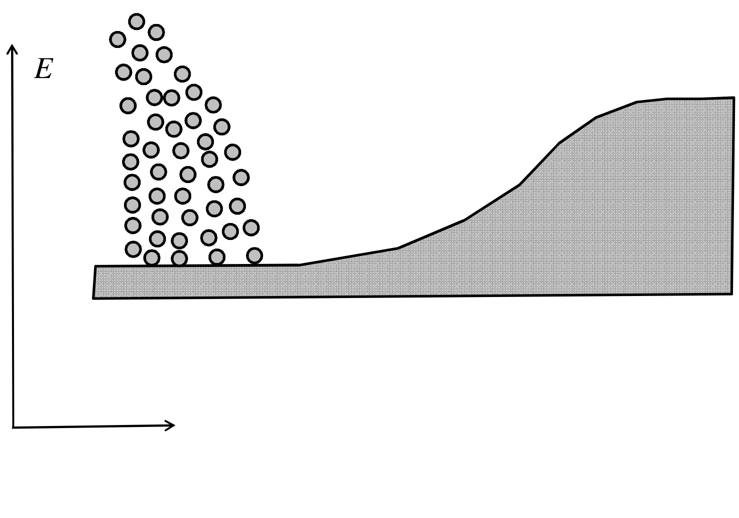
Energy Diagrams



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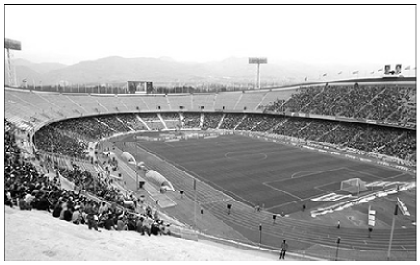
Density of States

Azadi stadium



Boxing stadium

In Stadium: Number of available seats could be a function of distance from the center so ….

N: number of available states for the electrons could be function of “Energy” : N(E)

Seats are not the same for fans so empty states for electrons!

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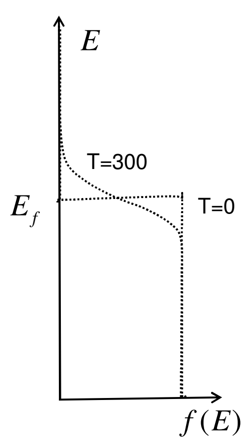
Fermi Distribution



$f(E)$ probability of occupation of state at energy E by electrons

$$f(E) = \frac{1}{1+e^{(E-E_f)/kT}}$$

$N(E)f(E) =$ # of electrons at energy E

$N(E)(1-f(E)) =$ # of holes at energy E

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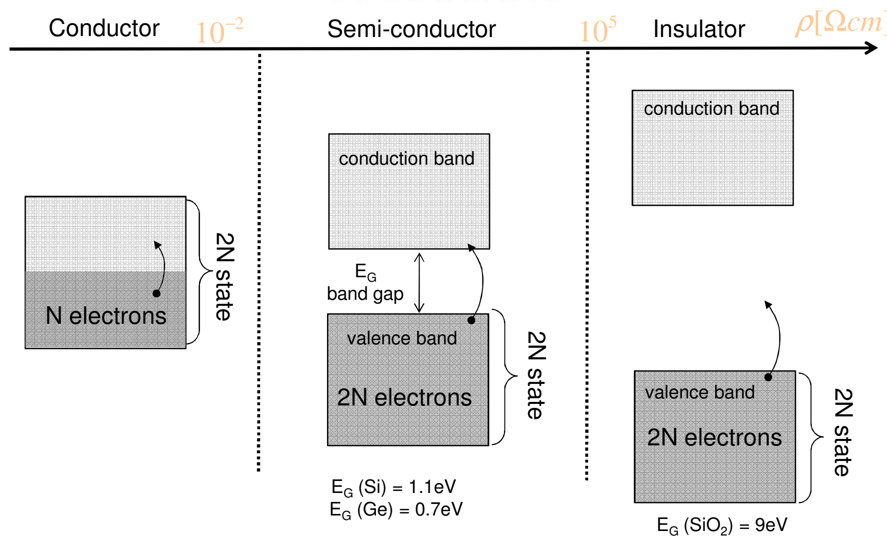
Materials



empty seat / filled seat

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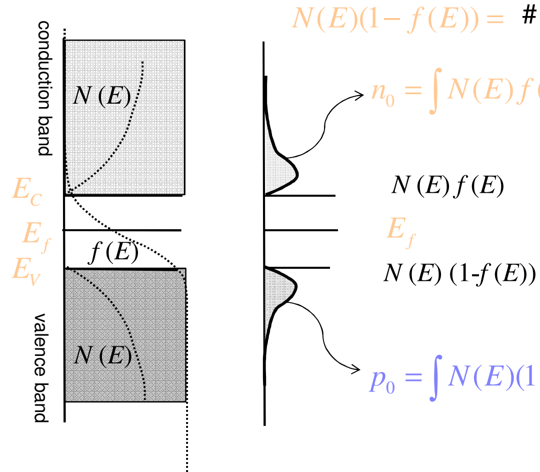
Electrons / Holes: Intrinsic

$N(E)f(E) =$ # of electrons at energy E

$N(E)(1-f(E)) =$ # of holes at energy E



$$n_0 = \int N(E)f(E)dE$$

$$p_0 = \int N(E)(1-f(E))dE$$

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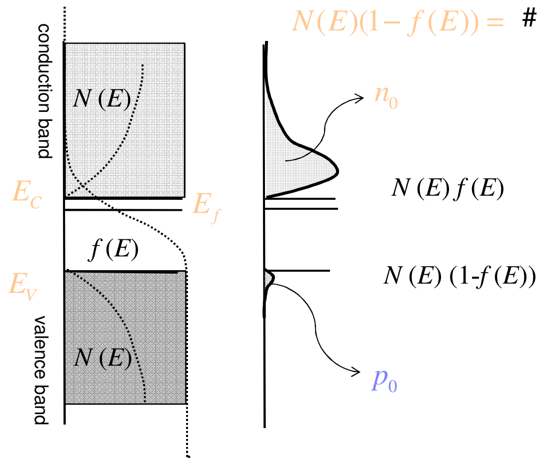
Electrons / Holes: n-type

$N(E)f(E) =$ # of electrons at energy E

$N(E)(1-f(E)) =$ # of holes at energy E

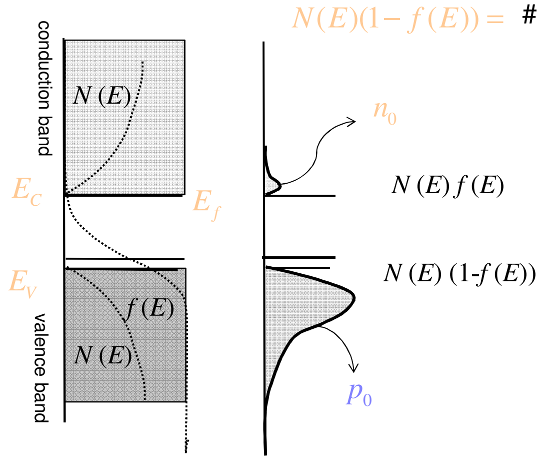


$n_0 >> p_0$

Electrons / Holes: p-type

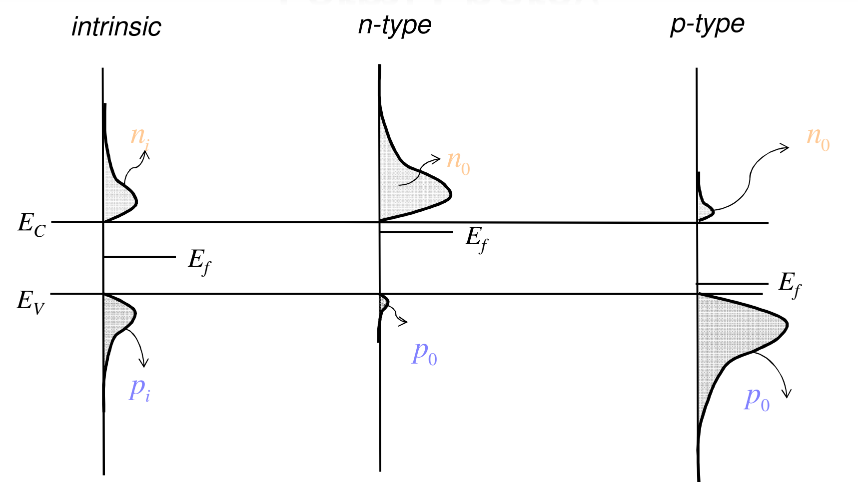
$N(E)f(E) =$ # of electrons at energy E

$N(E)(1-f(E)) =$ # of holes at energy E



$p_0 >> n_0$

Fermi Energy



$$n_0 = n_i e^{(E_f - E_i)/kT} \qquad p_0 = n_i e^{(E_i - E_f)/kT}$$

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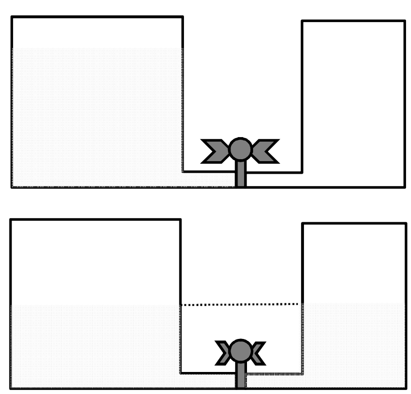
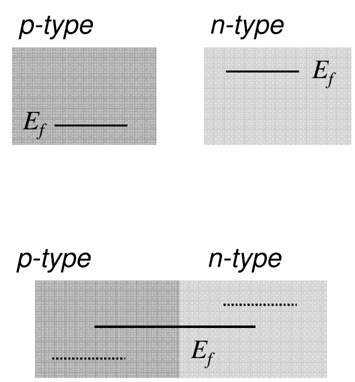
Fermi Energy





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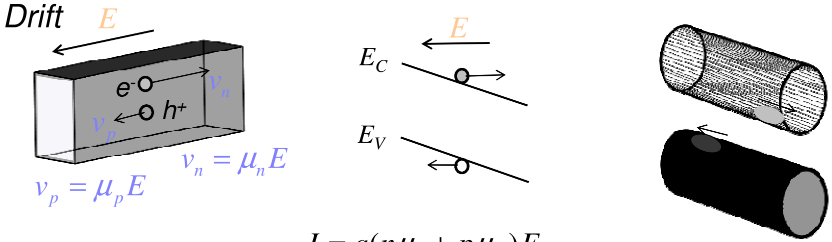
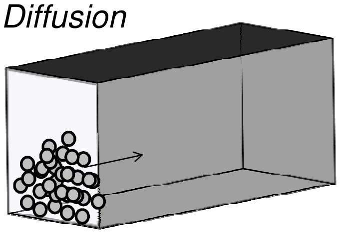
Flow of Charge

Drift



$$J = q(n\mu_n + p\mu_p)E$$

Diffusion



Charges move to be evenly distributed throughout space
Similar to perfume in room or heat in a solid

$$J_n = qD_n \frac{dn}{dx}$$

$$J_p = -qD_p \frac{dp}{dx}$$

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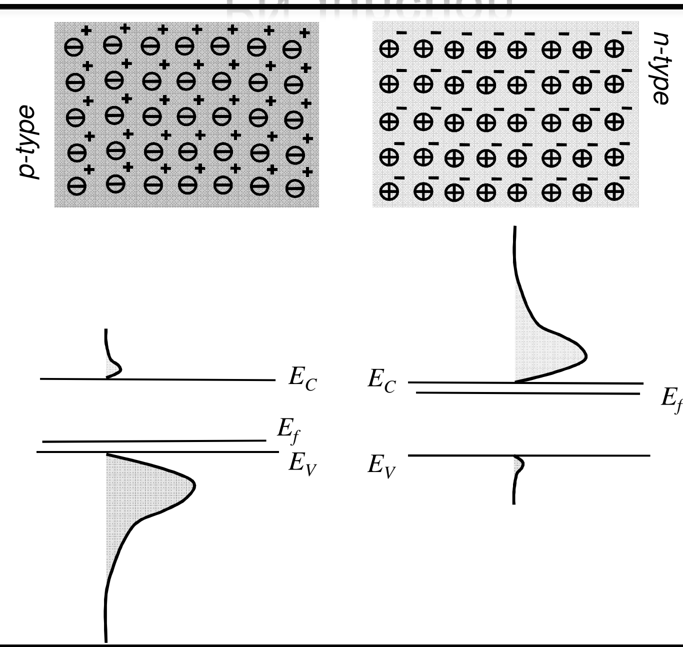
PN Junction



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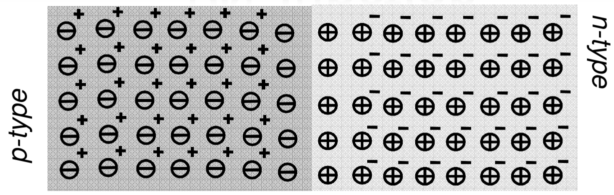
PN Junction



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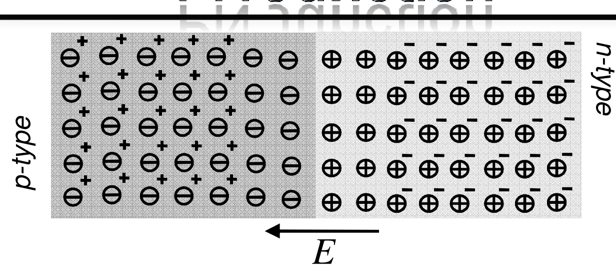
PN Junction



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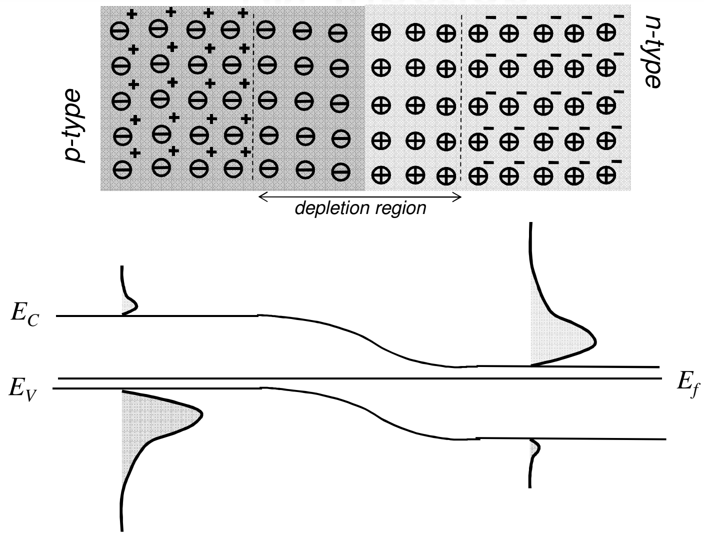
PN Junction



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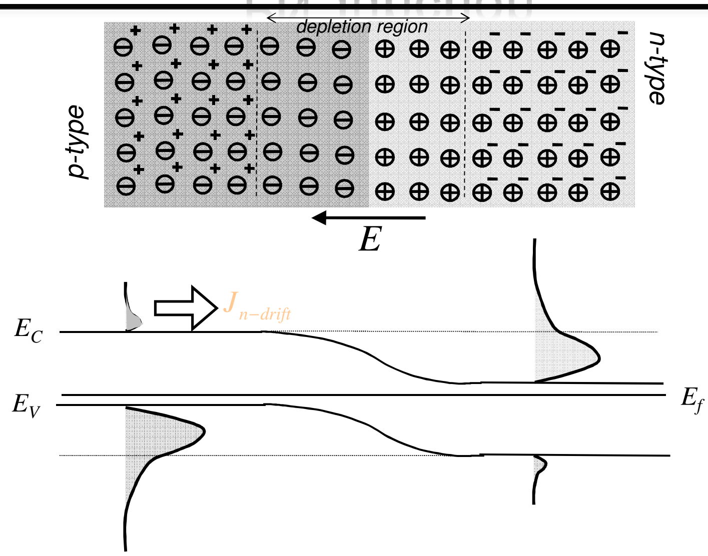
PN Junction



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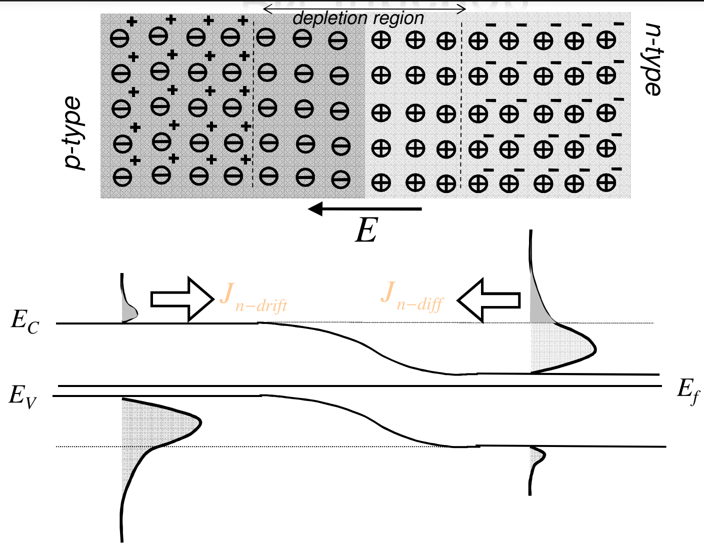
PN Junction



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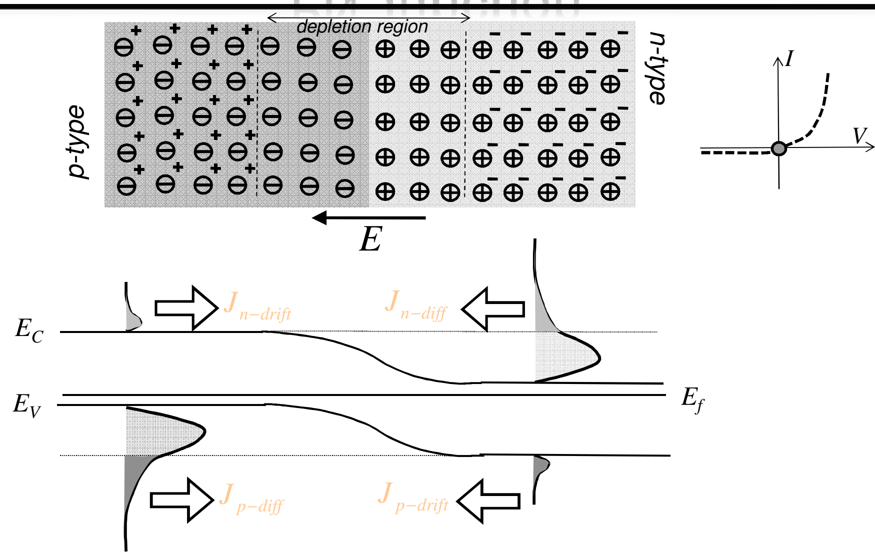
PN Junction



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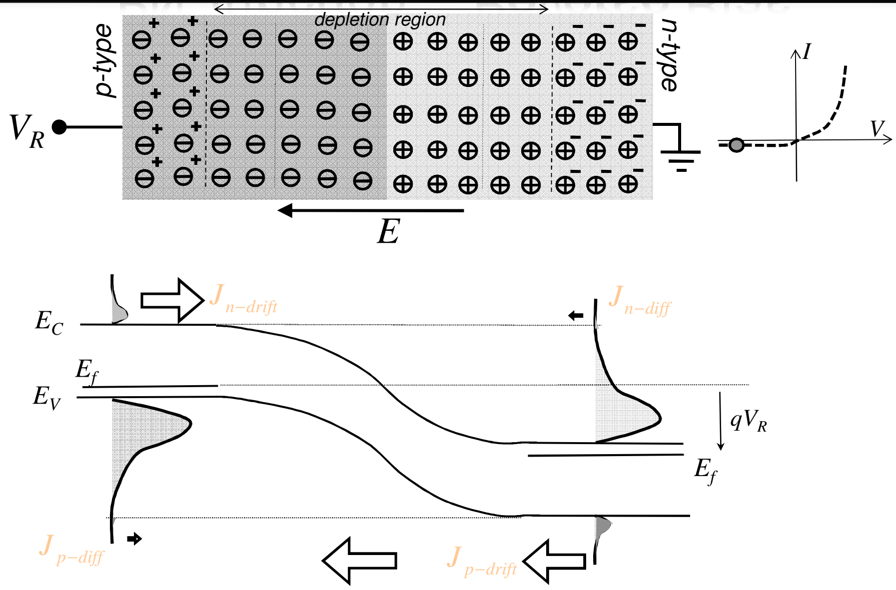
PN Junction – Reverse Bias



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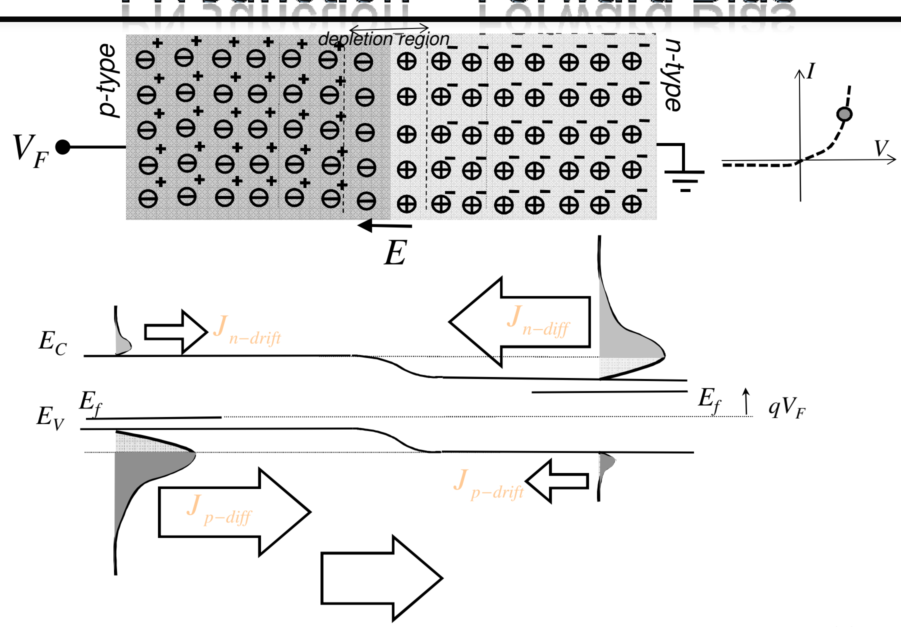
PN Junction – Forward Bias



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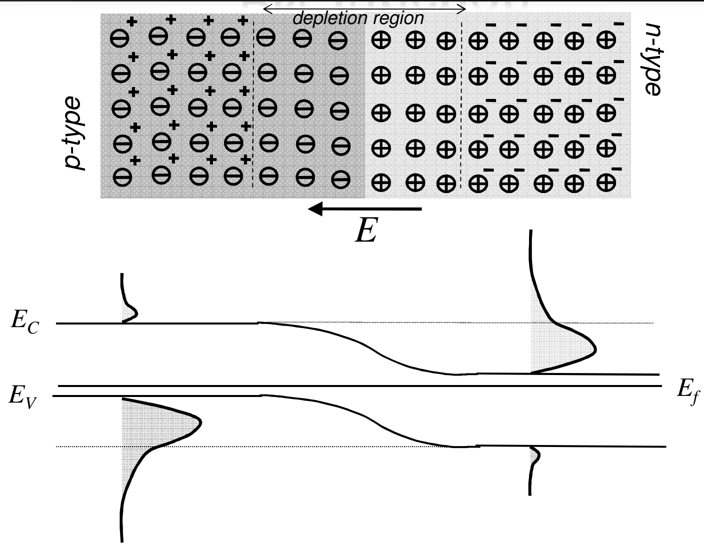
PN Junction



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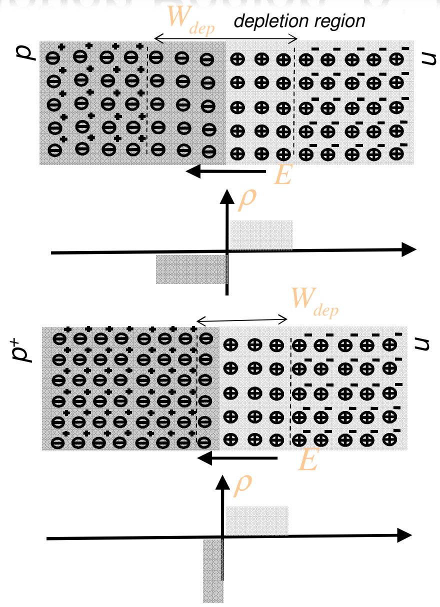
Depletion Region, p⁺-n diode



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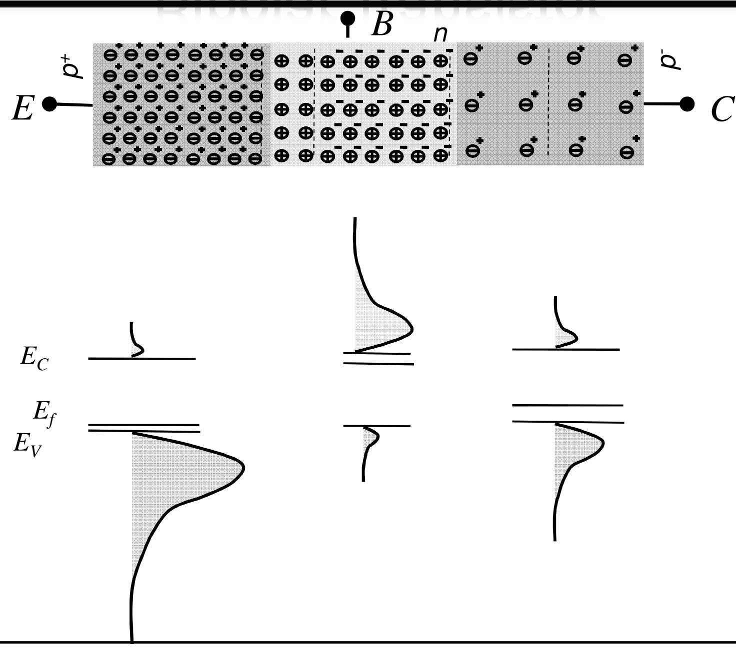
Bipolar Transistor



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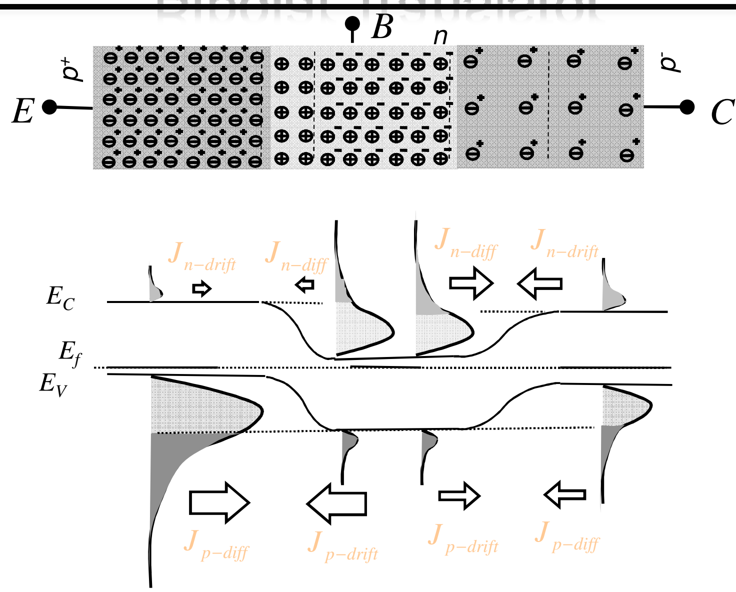
Bipolar Transistor



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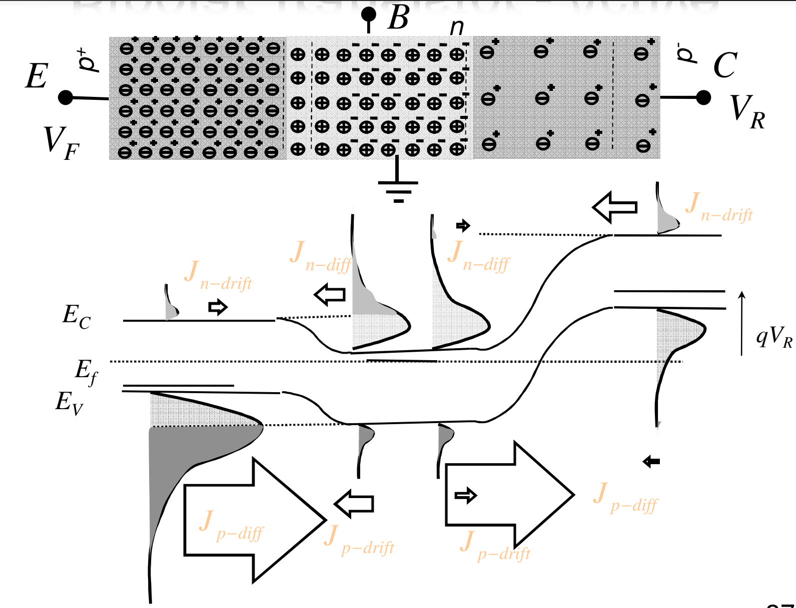
Bipolar Transistor - Active



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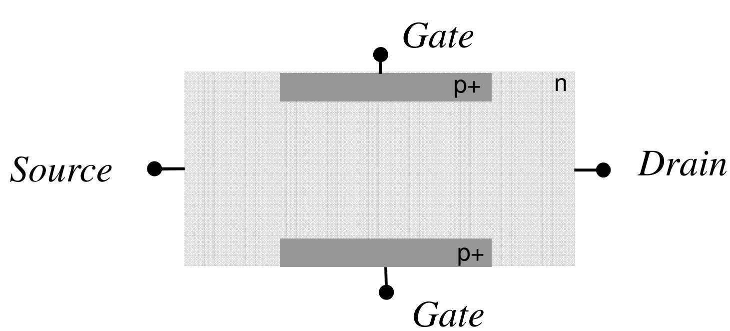
JFET

Junction FET



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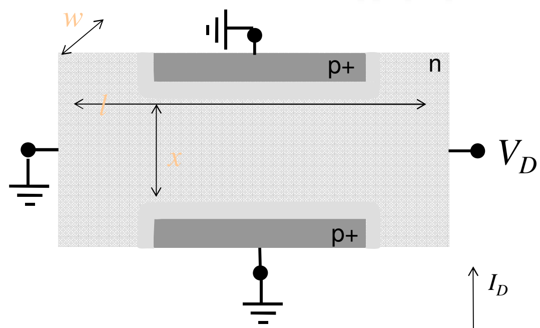
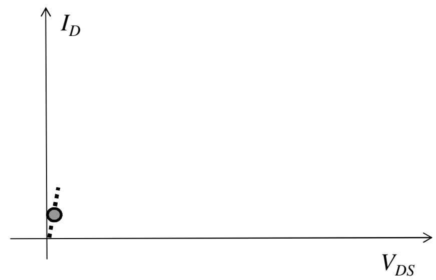
JFET



$$R = \rho \frac{l}{wx}$$



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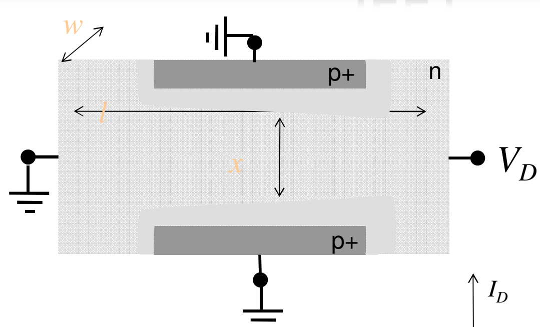
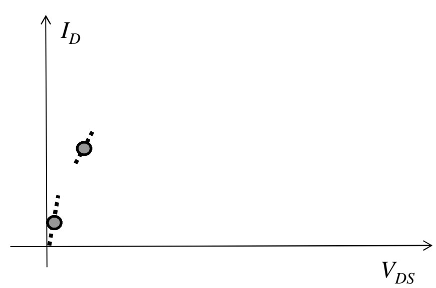
JFET



$$R = \rho \frac{l}{wx}$$



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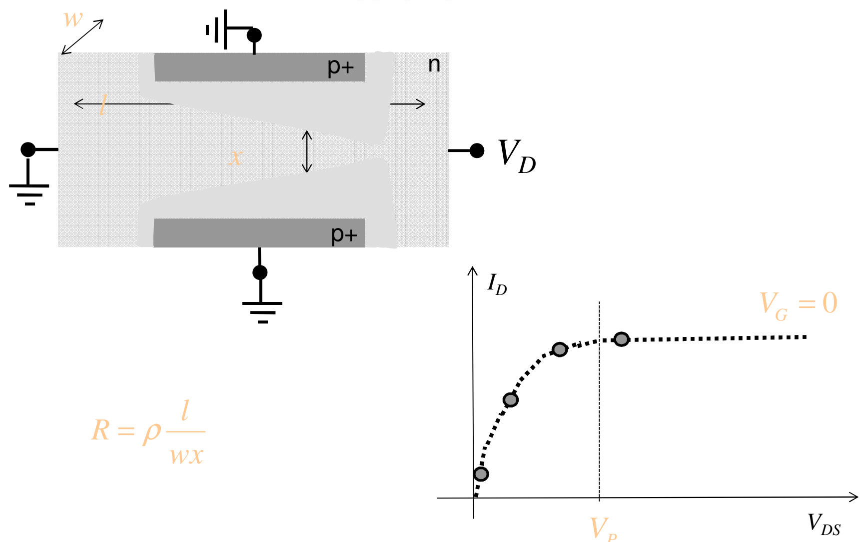
JFET



$$R = \rho \frac{l}{wx}$$

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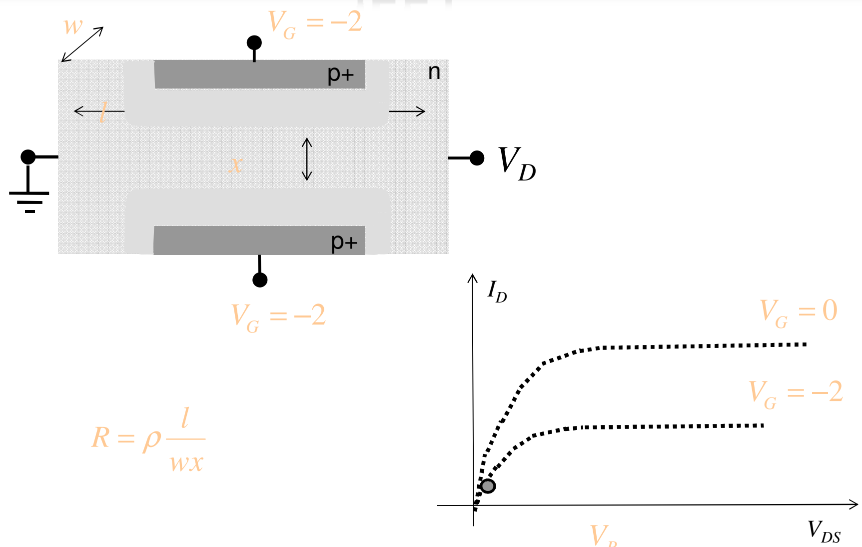
JFET



$$R = \rho \frac{l}{wx}$$

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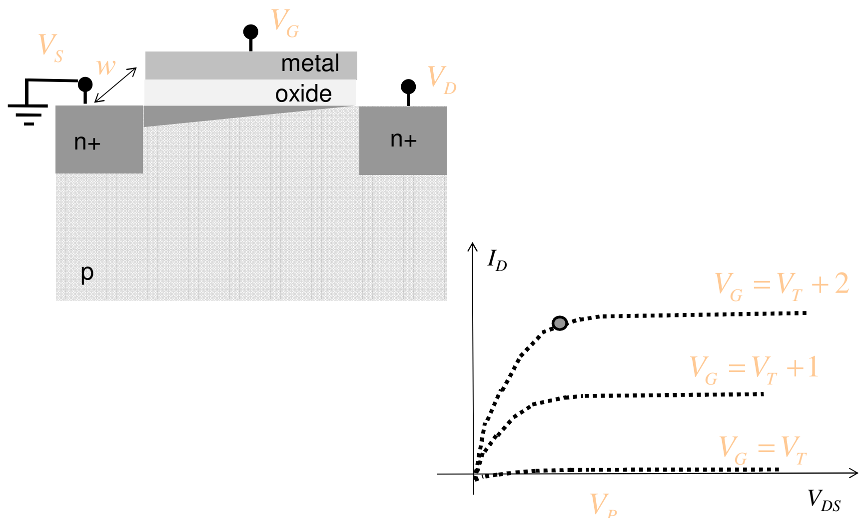
MOSFET



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Thank you

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