PN Junction Diode

Figures

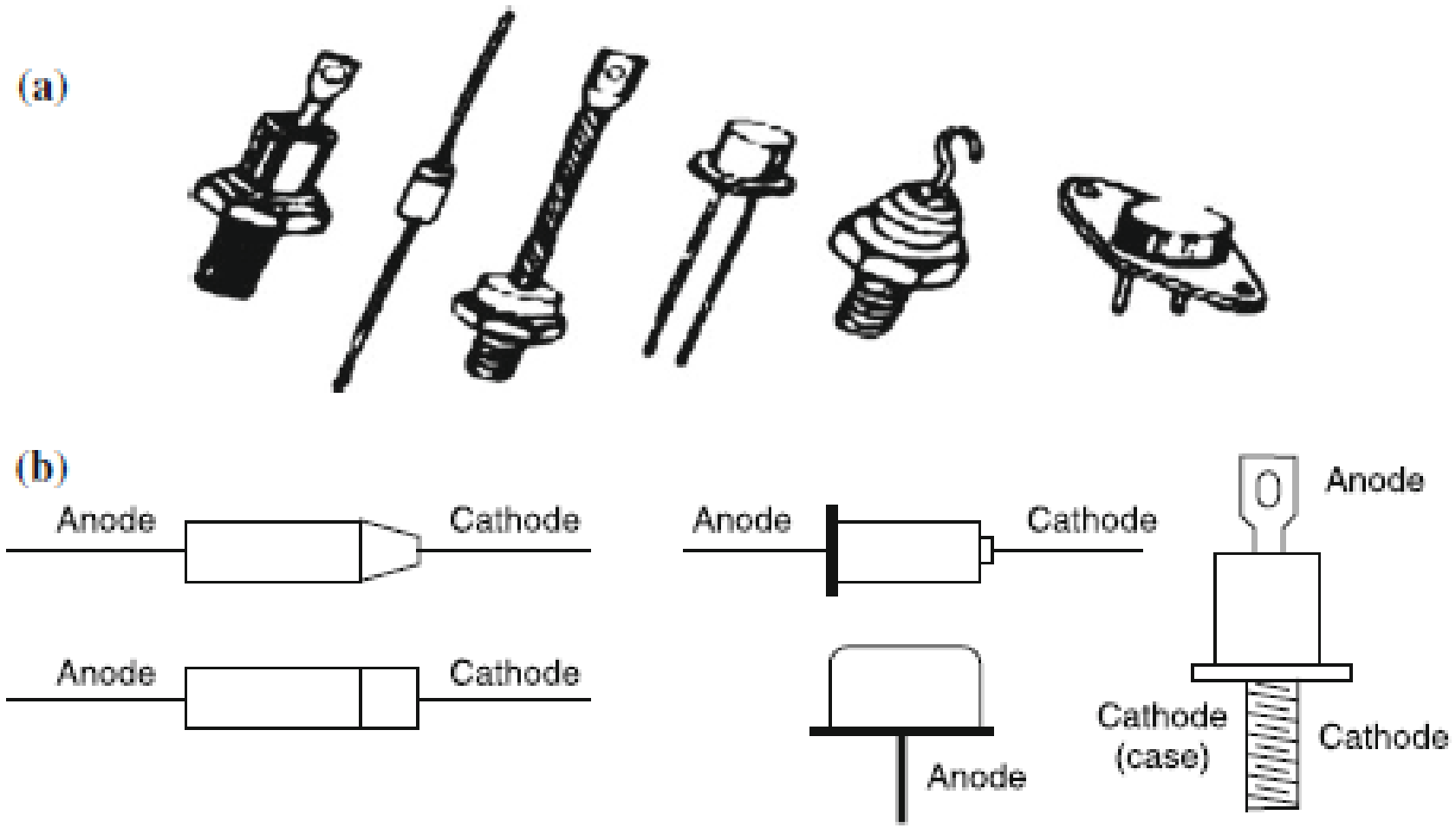


Fig. 5.22 **a** Physical structures of diodes. **b** their terminal identifications

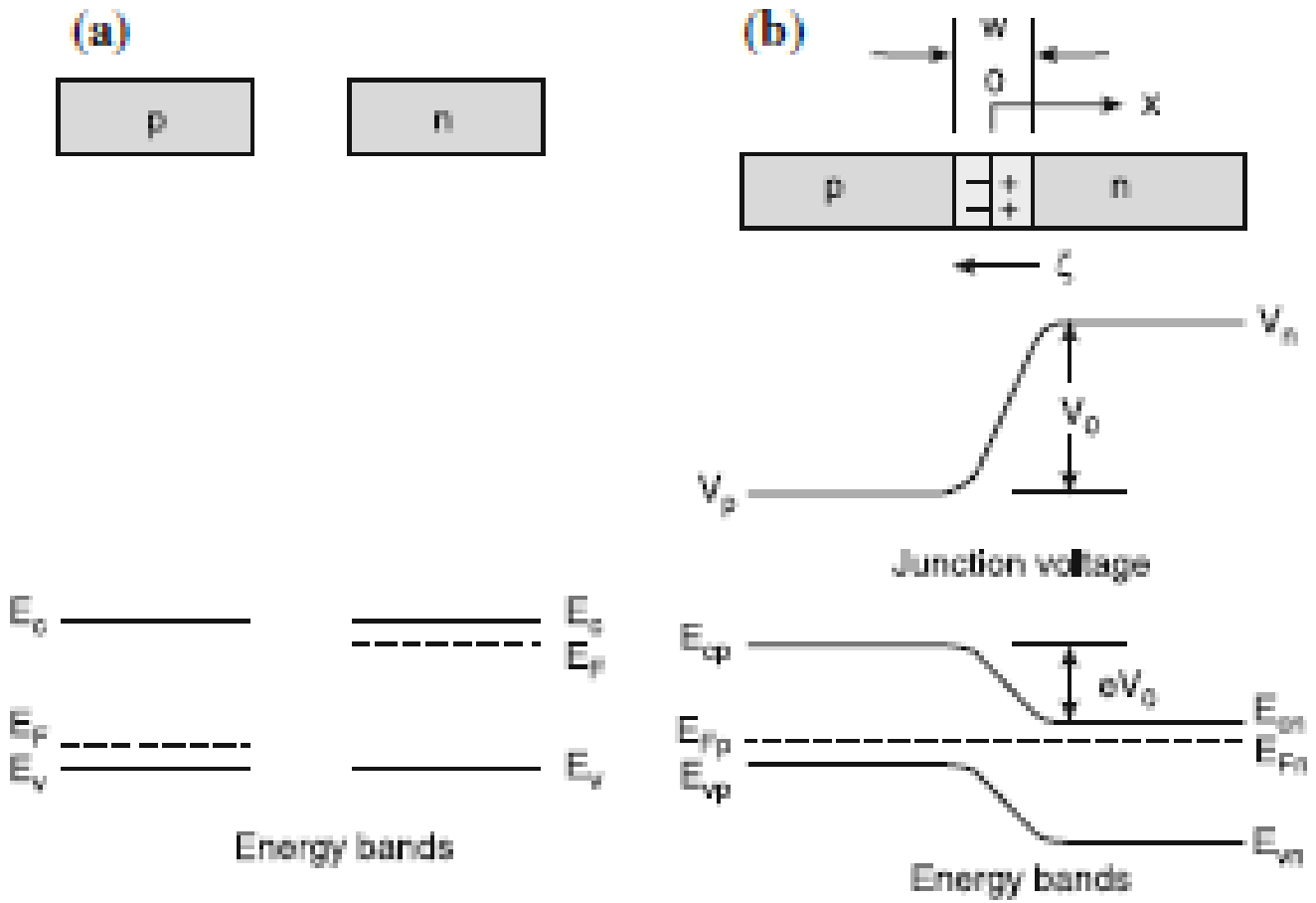


Fig. 5.1 Properties of a p-n junction under equilibrium showing **a** isolated n and p type semiconductors along with their energy bands, and **b** space charge, electric field, contact potential and the changed energy bands

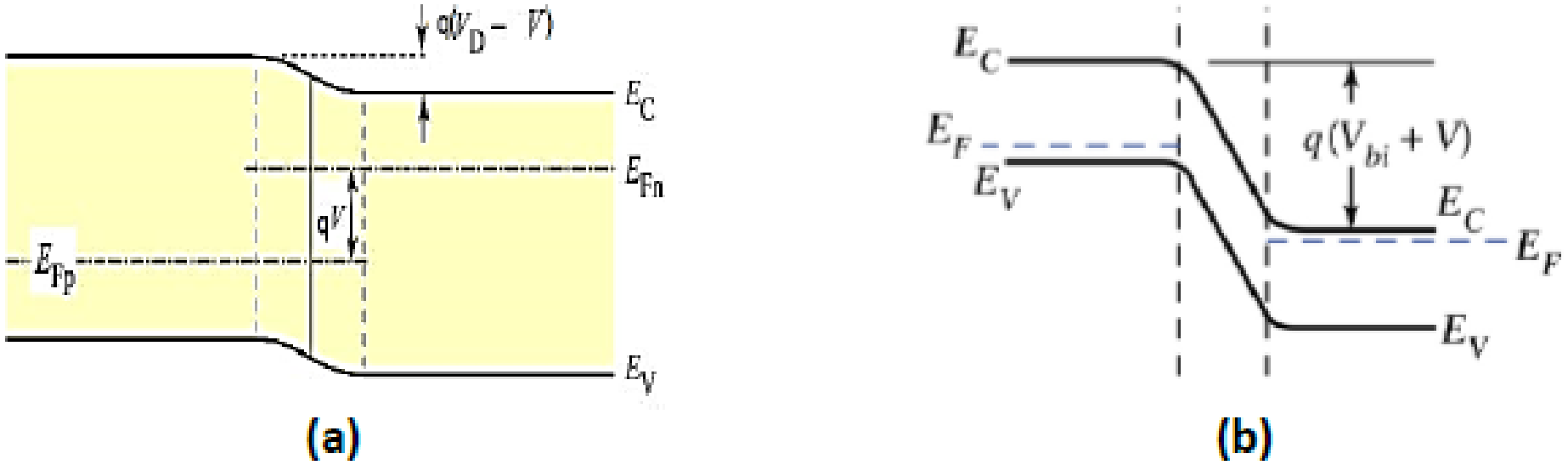


Fig. 3.9. Band structure of a PN junction in (a) forward bias and (b) reverse bias.

$$qV_b = E_{fn} - E_{fp}$$

The diode equation is given below.

$$I = eA\left(\frac{D_{xh}}{L_h}p_n + \frac{D_{xe}}{L_e}n_p\right)\left(e^{\frac{eV}{kT}} - 1\right) = I_0\left(e^{\frac{eV}{kT}} - 1\right) \tag{5.26a}$$

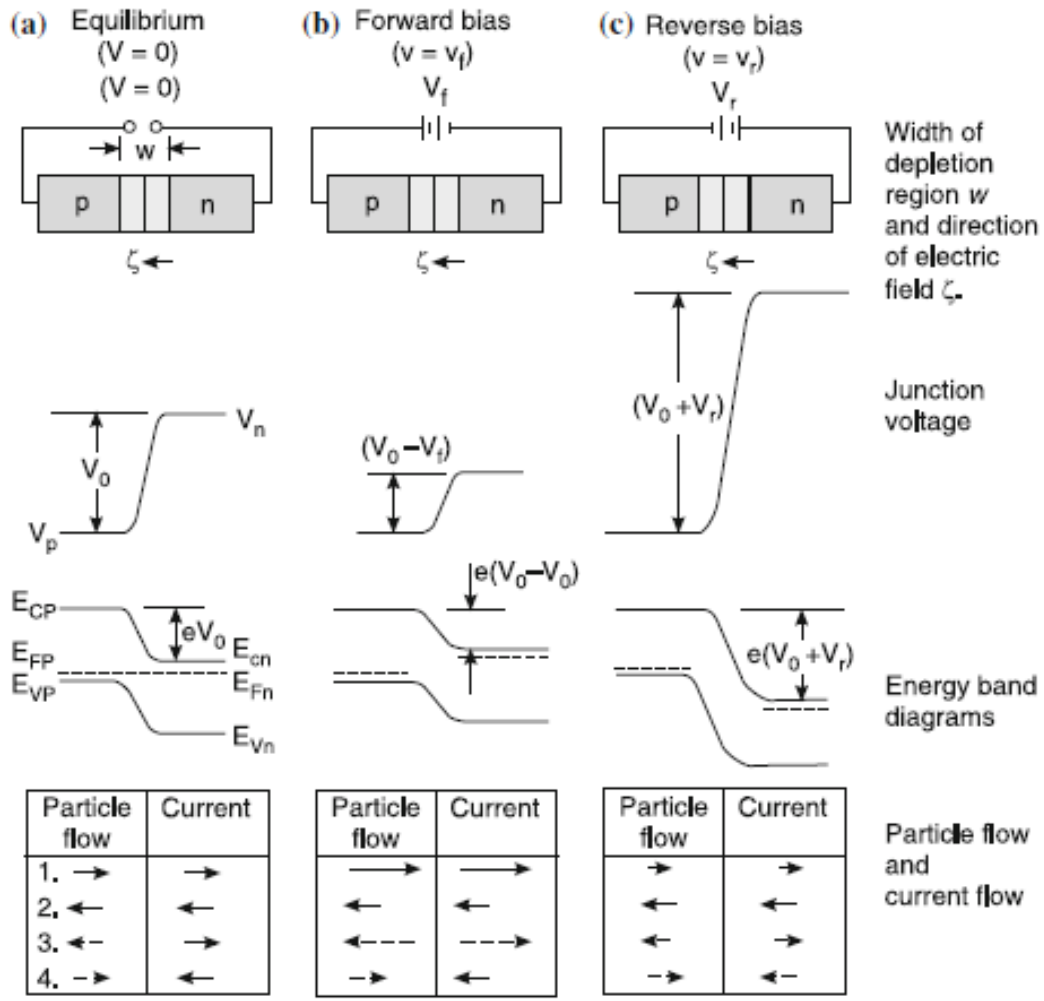
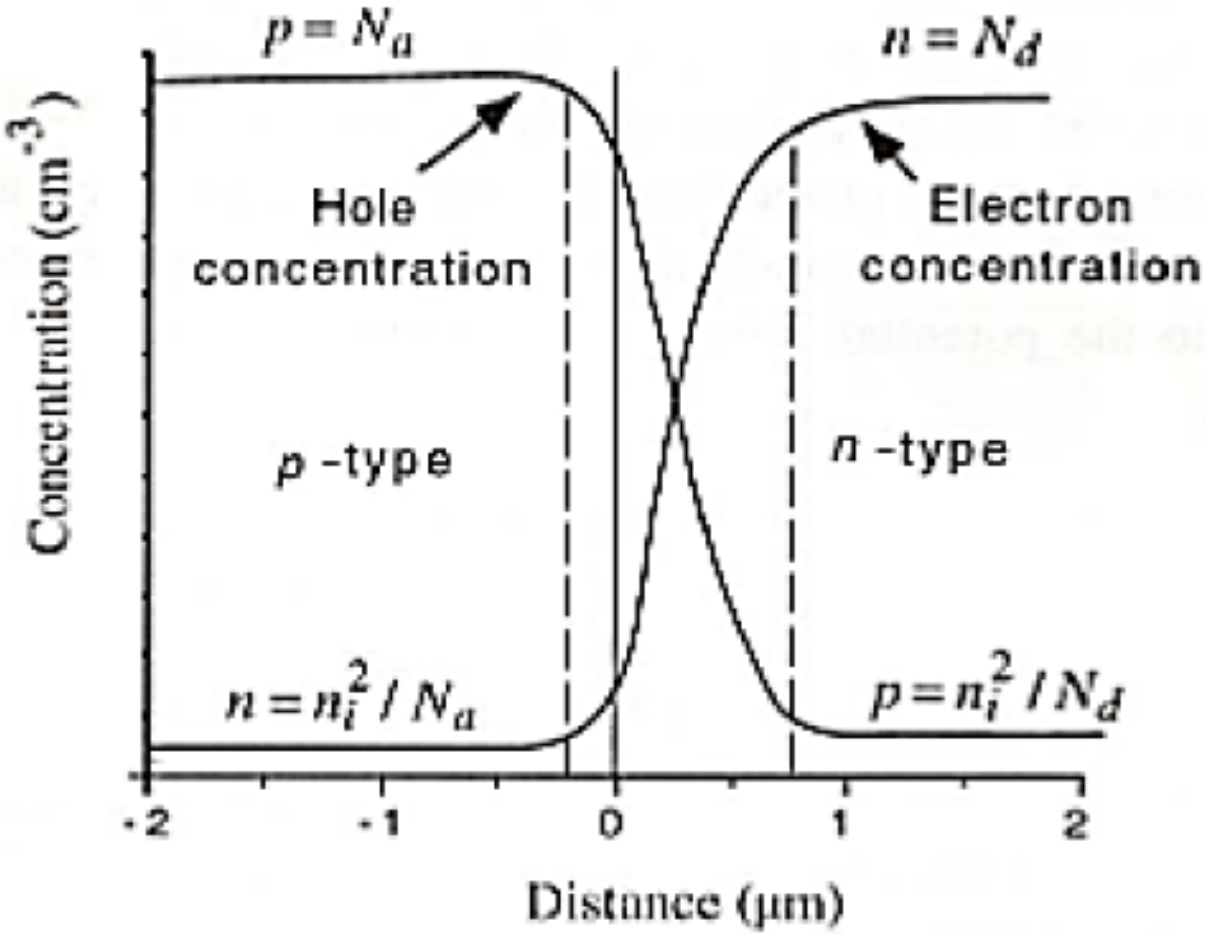


Fig. 5.12 Effects of no-bias (**a**), forward-bias (**b**), and reverse-bias (**c**) at a P-N junction



Charge-carrier distribution in p-type and n-type semiconductors.

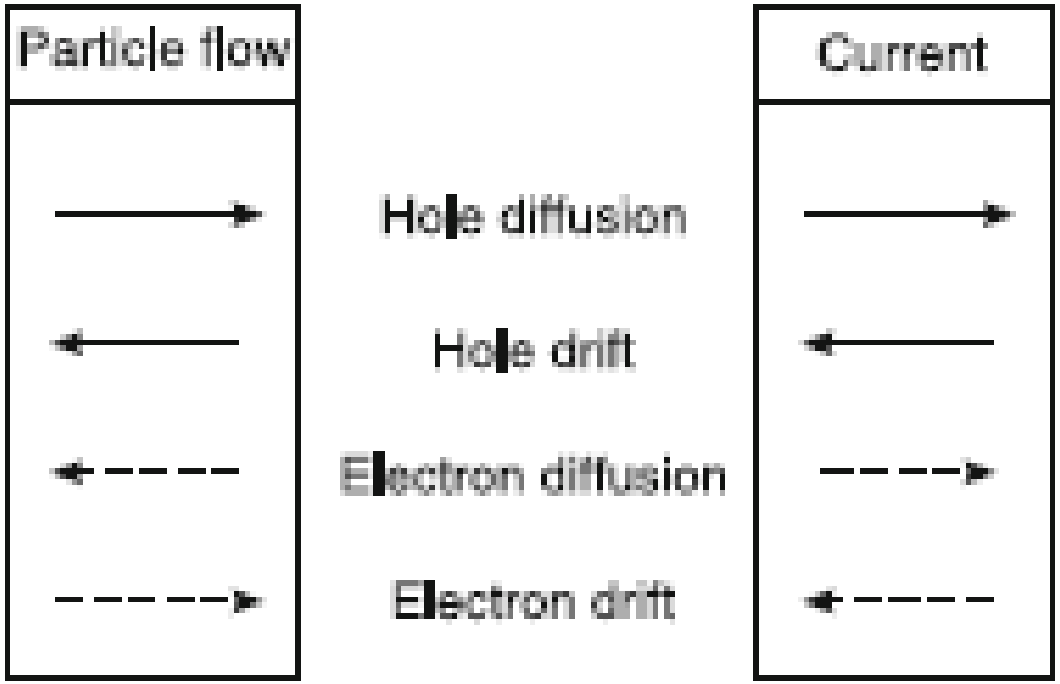


Fig. 5.2 Directions of flow of holes and electrons within depletion region under diffusion and drift, and the directions of resulting currents

Fig. 5.3 Distribution of space charge and electric field within depletion region a space charge extended more towards p-side, and b electric field distribution

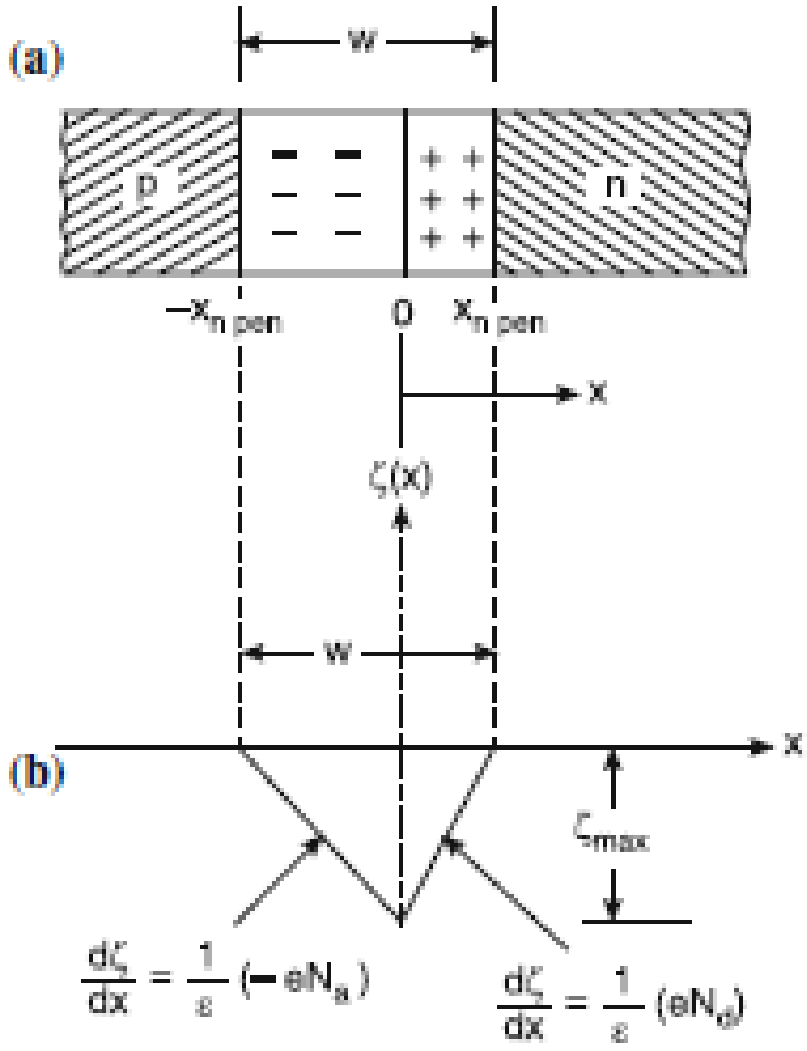
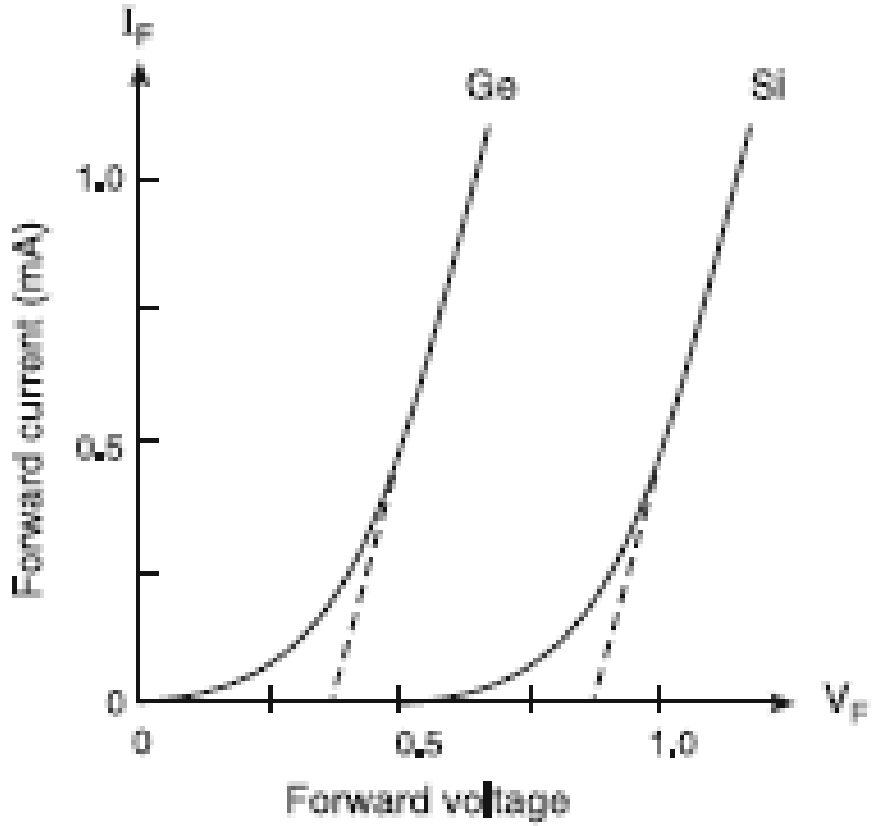
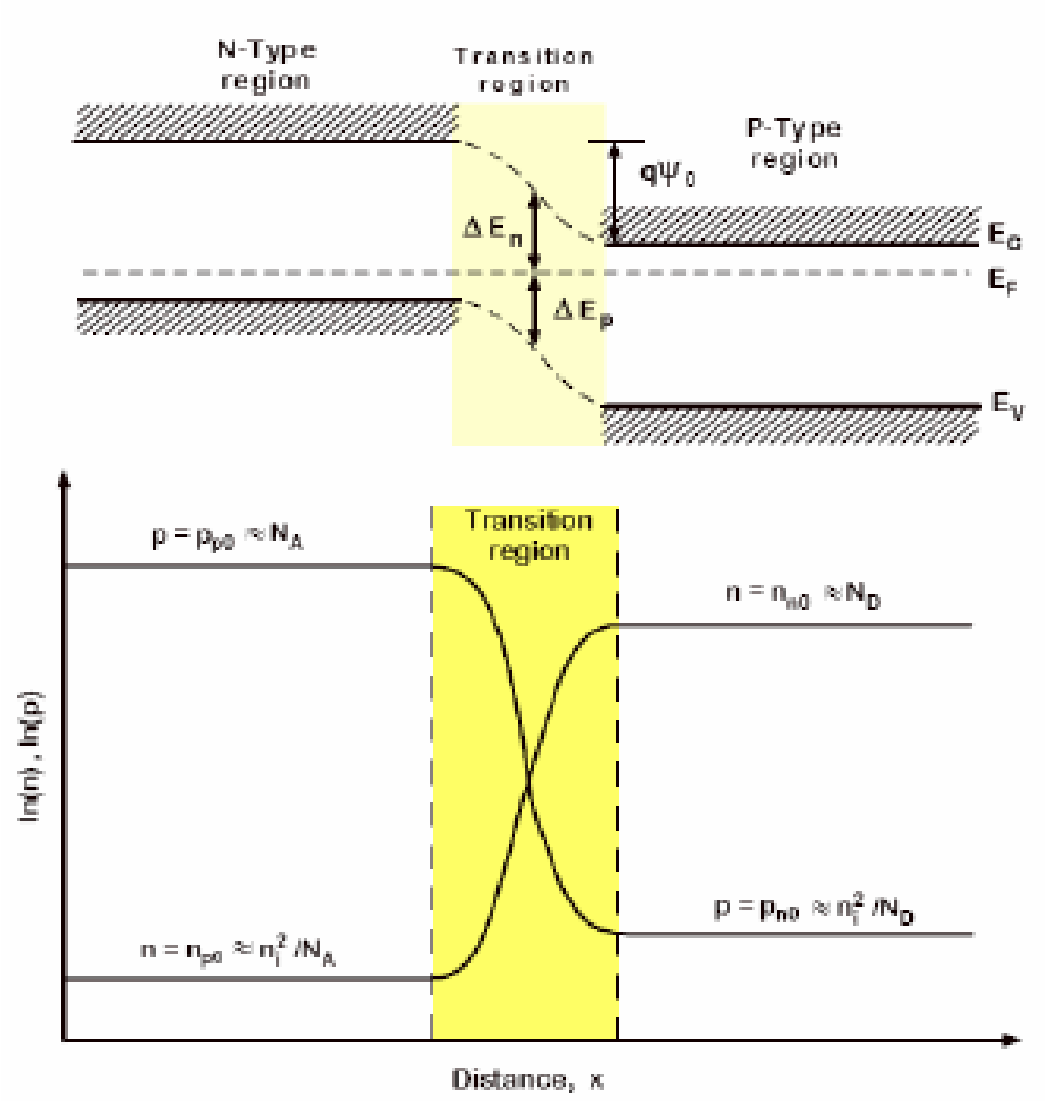
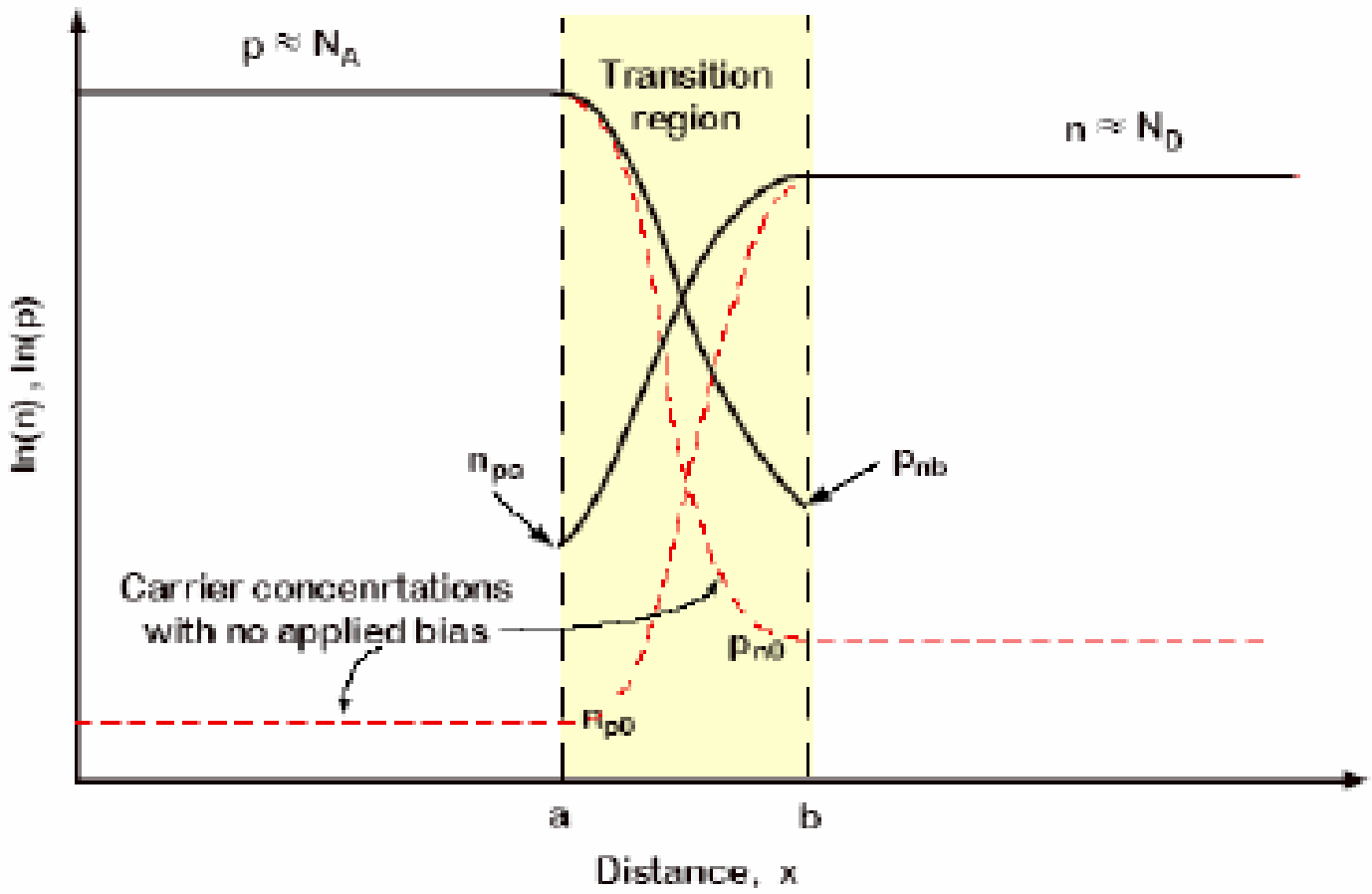
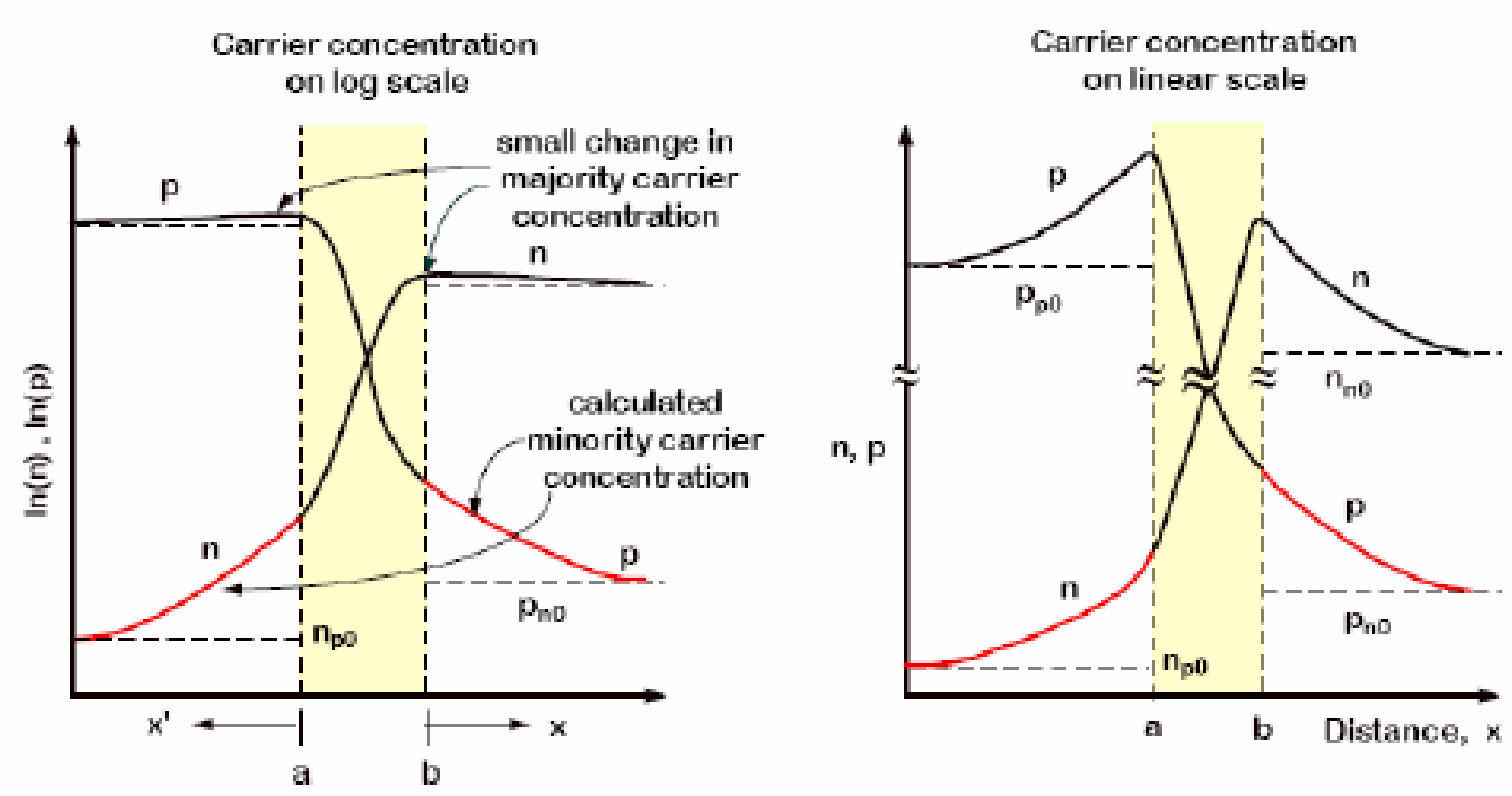


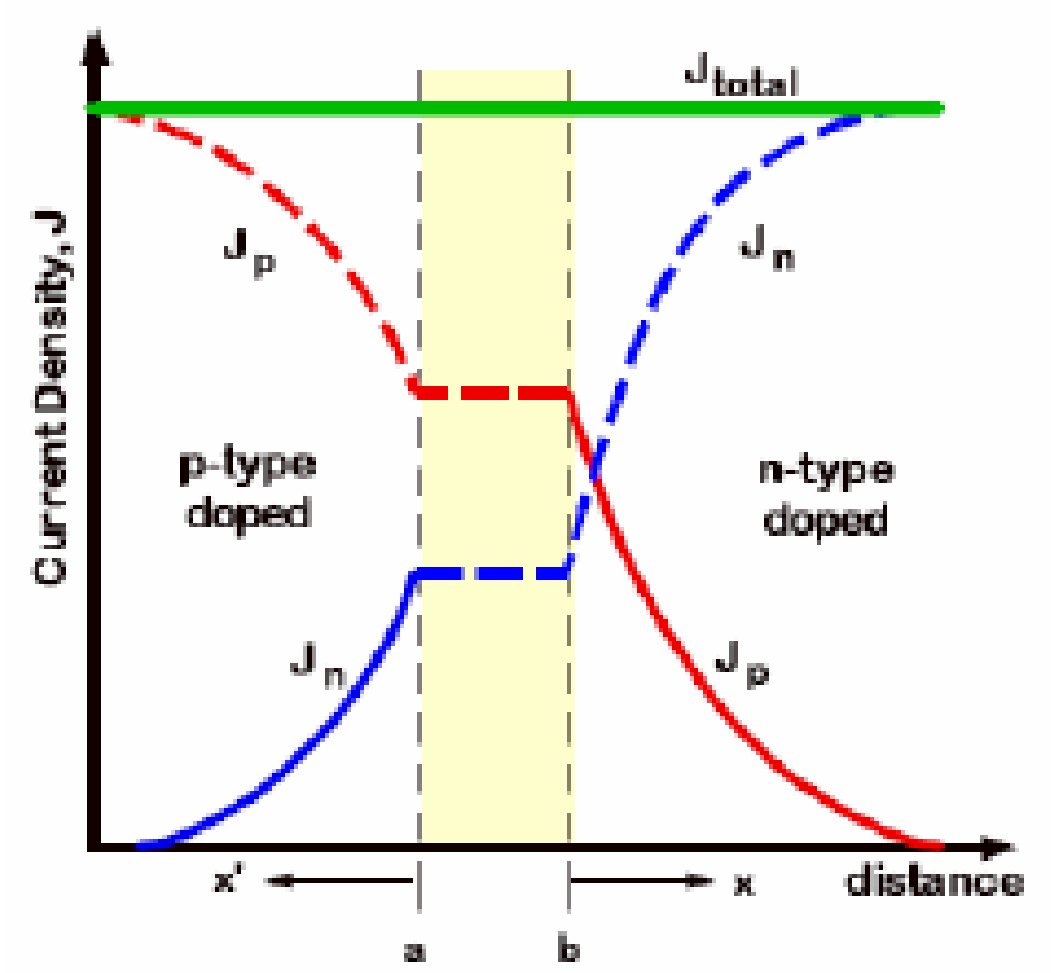
Fig. 5.7 Volt-current characteristic in forward biasing




N-Type region
Transition region
P-Type region
$q\psi_0$
ΔE_n
ΔE_p
E_C
E_F
E_V
$p = p_{p0} \approx N_A$
$n = n_{n0} \approx N_D$
$n = n_{p0} \approx n_i^2 / N_A$
$p = p_{n0} \approx n_i^2 / N_D$
Transition region
ln(n) , ln(p)
Distance, x


$p \approx N_A$
Transition region
$n \approx N_D$
n_{po}
p_{nb}
Carrier concenrtations with no applied bias
p_{n0}
n_{p0}
ln(n) , ln(p)
a
b
Distance, x


Carrier concentration
on log scale
small change in
majority carrier
concentration
p
n
calculated
minority carrier
concentration
n
p
p_{n0}
n_{p0}
ln(n) , ln(p)
x'
x
a
b
Carrier concentration
on linear scale
p
p_{p0}
n
n_{n0}
n, p
n
p
p_{n0}
n_{p0}
a
b
Distance, x


J total
J p
J n
Current Density, J
p-type
doped
n-type
doped
J n
J p
x'
x
distance
a
b

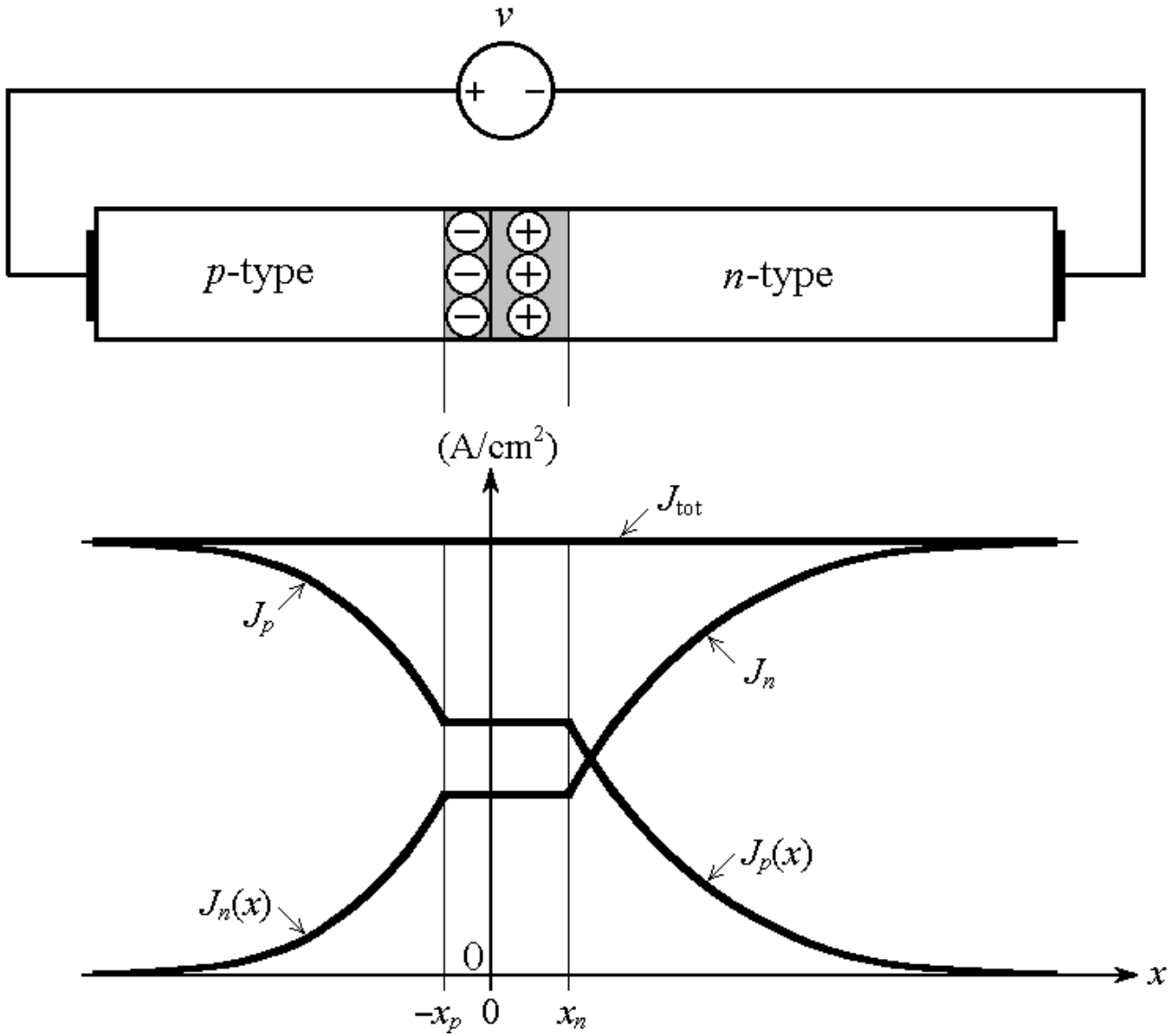
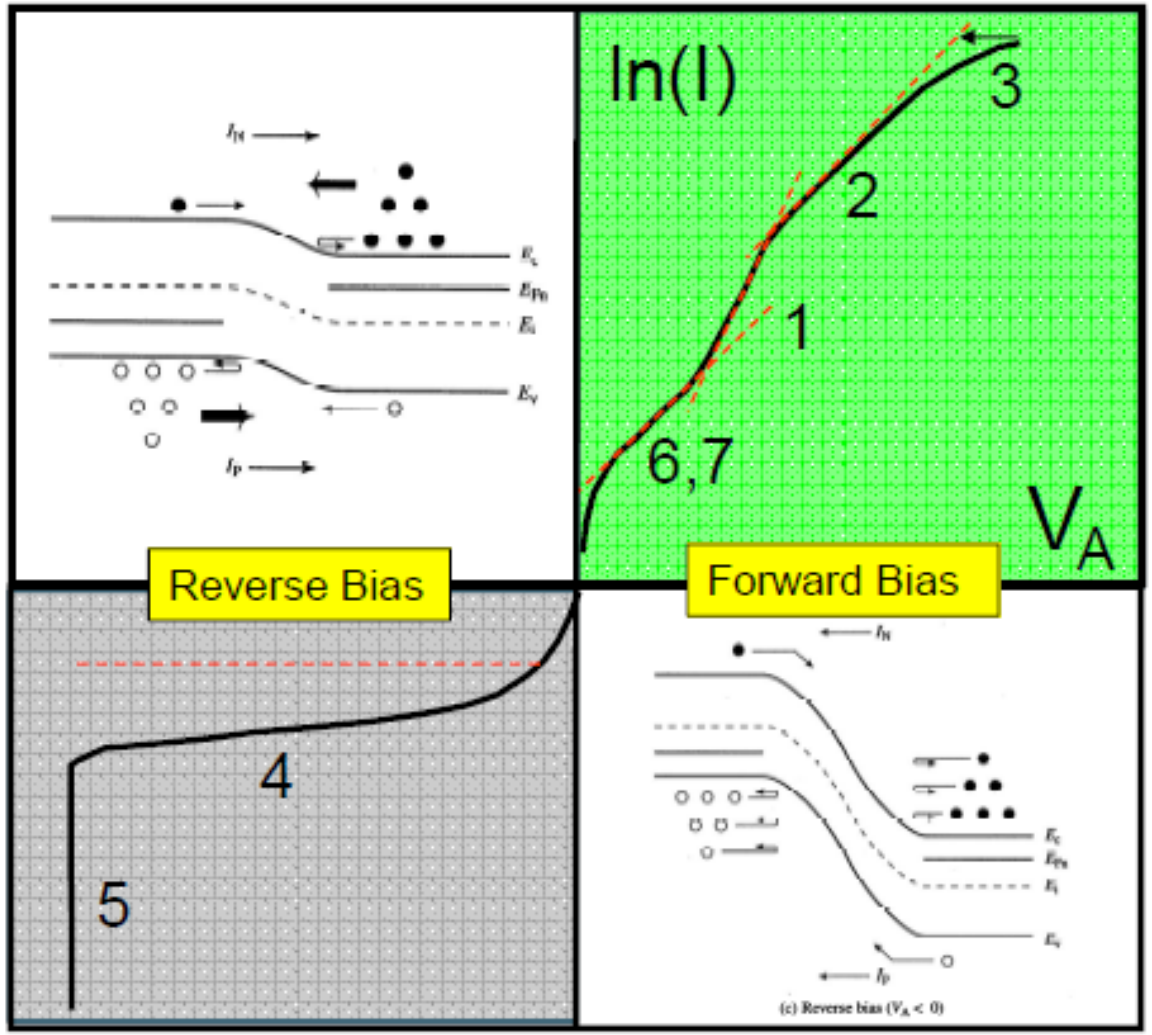


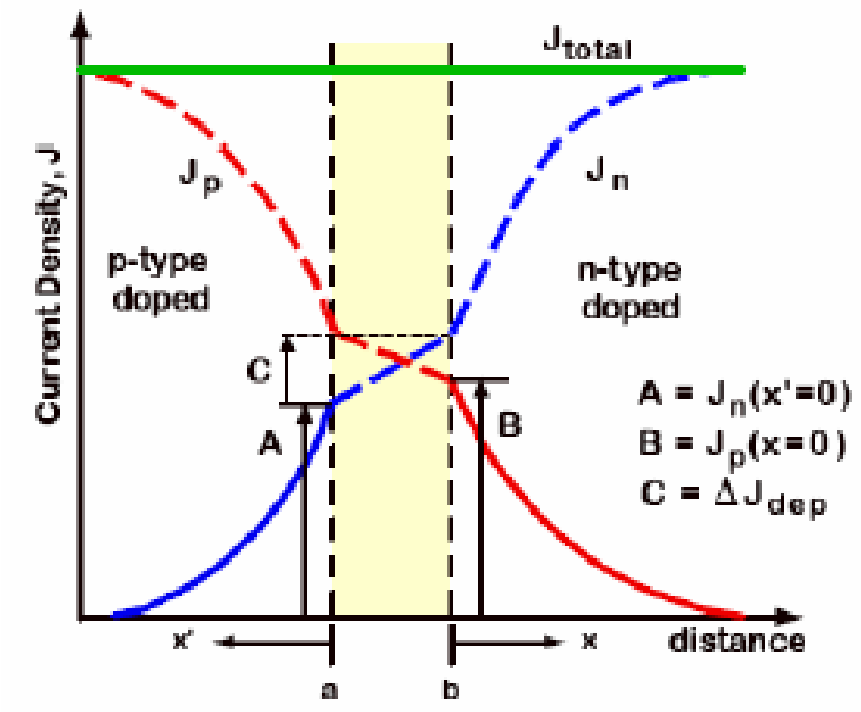
Fig. 10 – Minority as well as majority current densities inside a *pn* bar.

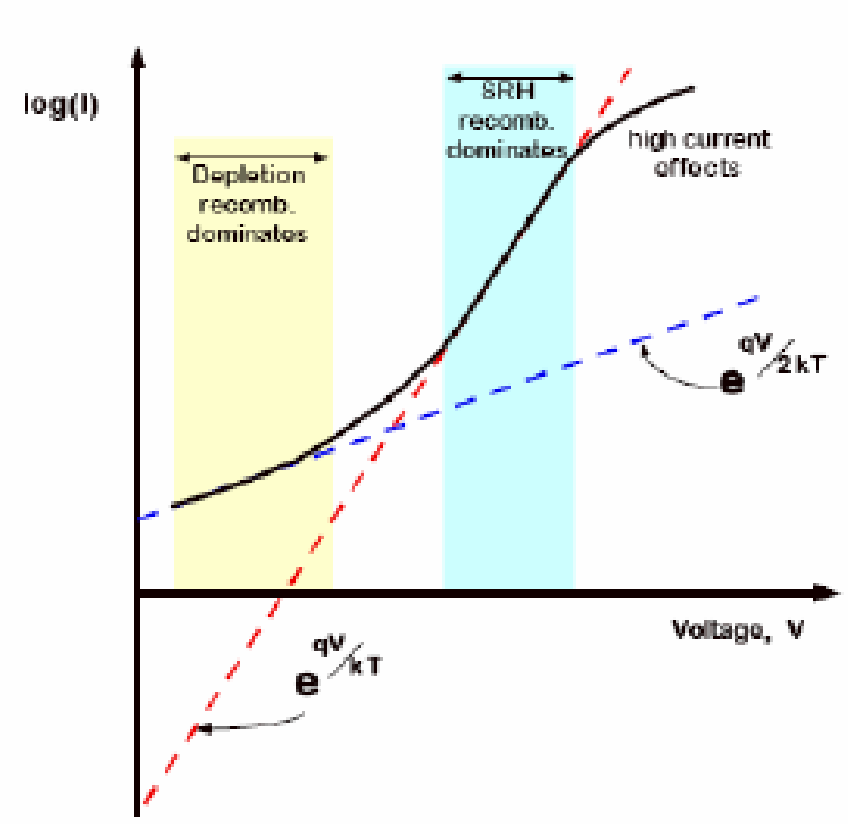
IV characteristics of a Diode



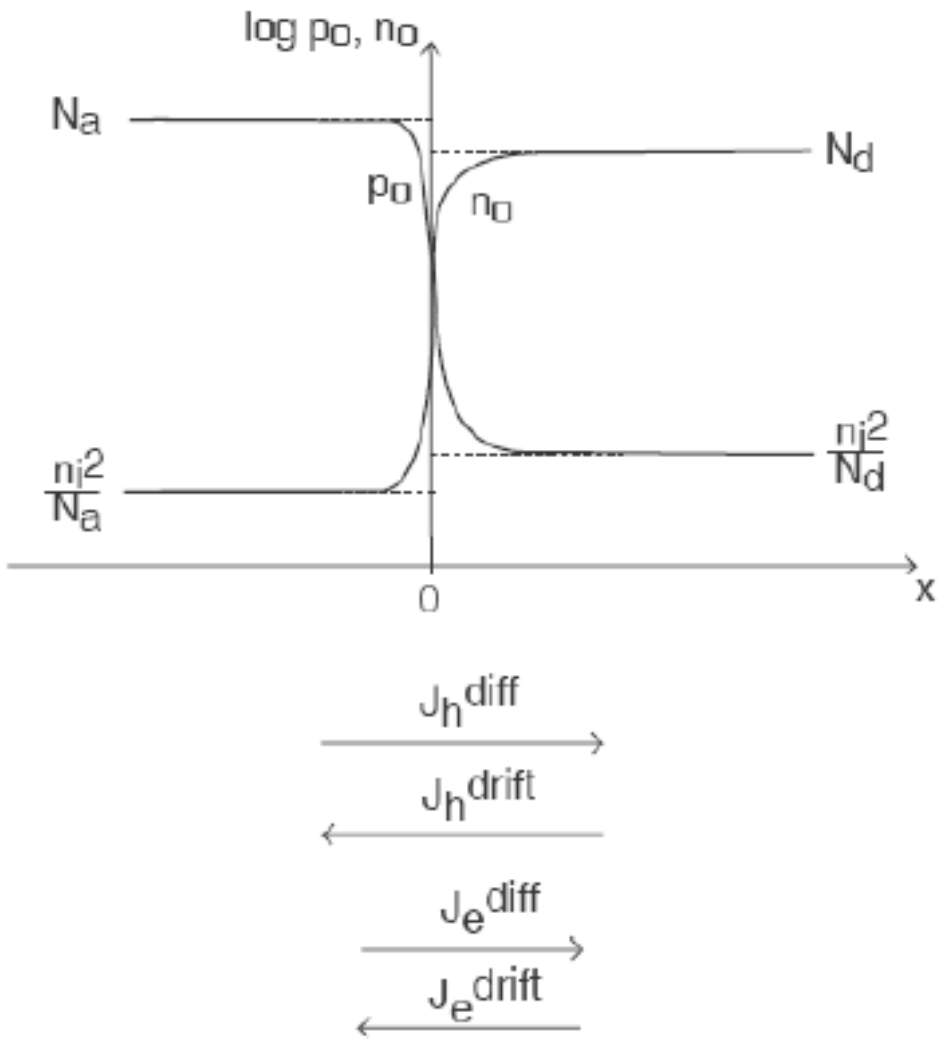
To be discussed in detail

1. *Diffusion limited*
2. *Ambipolar transport*
3. *High injection*
4. *R-G in depletion*
5. *Breakdown*
6. *Trap-assisted R-G*
7. *Esaki Tunneling*


Current Density, J
J_{total}
J_p
J_n
p-type
doped
n-type
doped
C
A
B
A = $J_n(x'=0)$
B = $J_p(x=0)$
C = ΔJ_{dep}
x'
x
distance
a
b


log(I)
Depletion
recomb.
dominates
SRH
recomb.
dominates
high current
effects
$e^{qV/2kT}$
$e^{qV/kT}$
Voltage, V

Carrier profiles in thermal equilibrium:



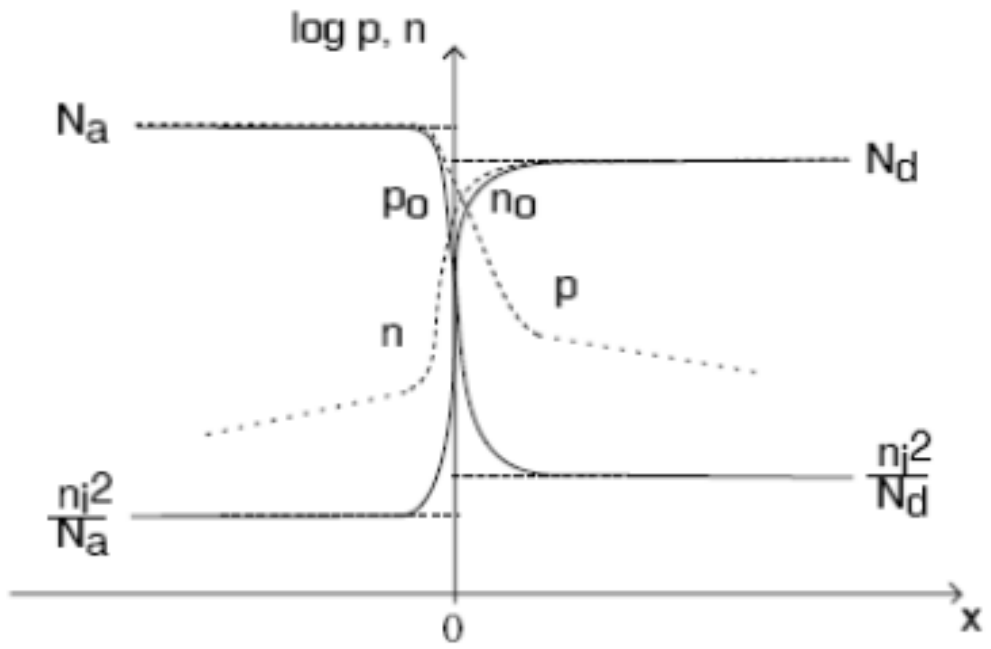
Inside SCR in thermal equilibrium:
dynamic balance between drift and diffusion for electrons and holes.

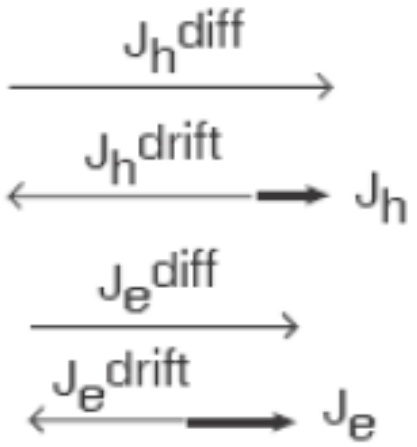
$$\left|J_{drift}\right| = \left|J_{diff}\right|$$

Carrier concentrations in pn junction under bias:

Forward bias $\quad for\ V > 0, \phi_B - V \downarrow \Rightarrow |E_{SCR}| \downarrow \Rightarrow |J_{drift}| \downarrow$

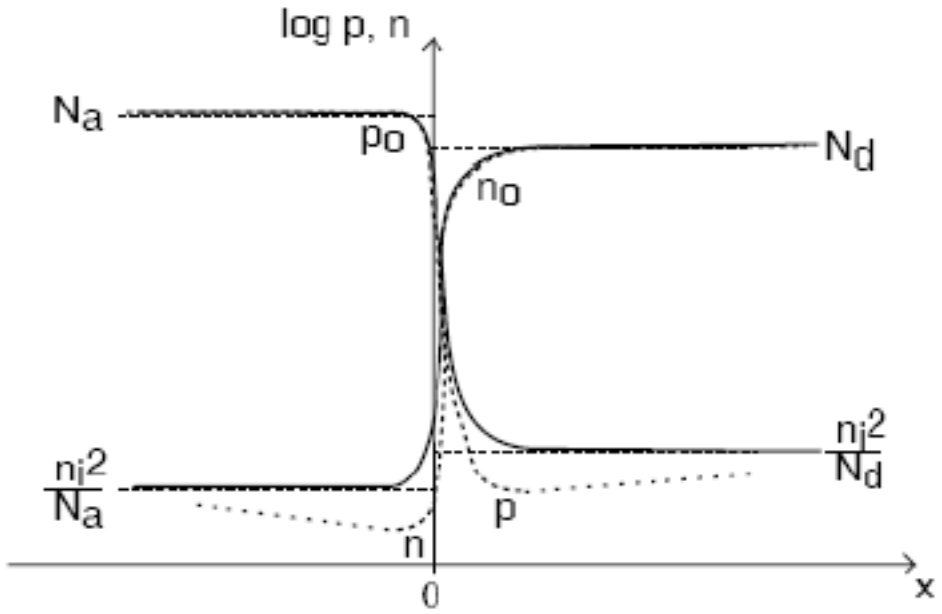
$$|E_0| = \sqrt{\frac{2q\phi_B N_a N_d}{\varepsilon_s (N_a + N_d)}} \qquad J_{p-drift} = qp\mu_p E \qquad J_{n-drift} = qn\mu_n E$$

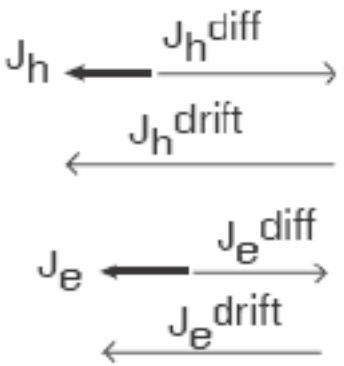




Reverse bias

$$for\ V<0, \phi_B - V \uparrow \Rightarrow \left|E_{SCR}\right| \uparrow \Rightarrow \left|J_{drift}\right| \uparrow$$





Current balance in SCR broken:

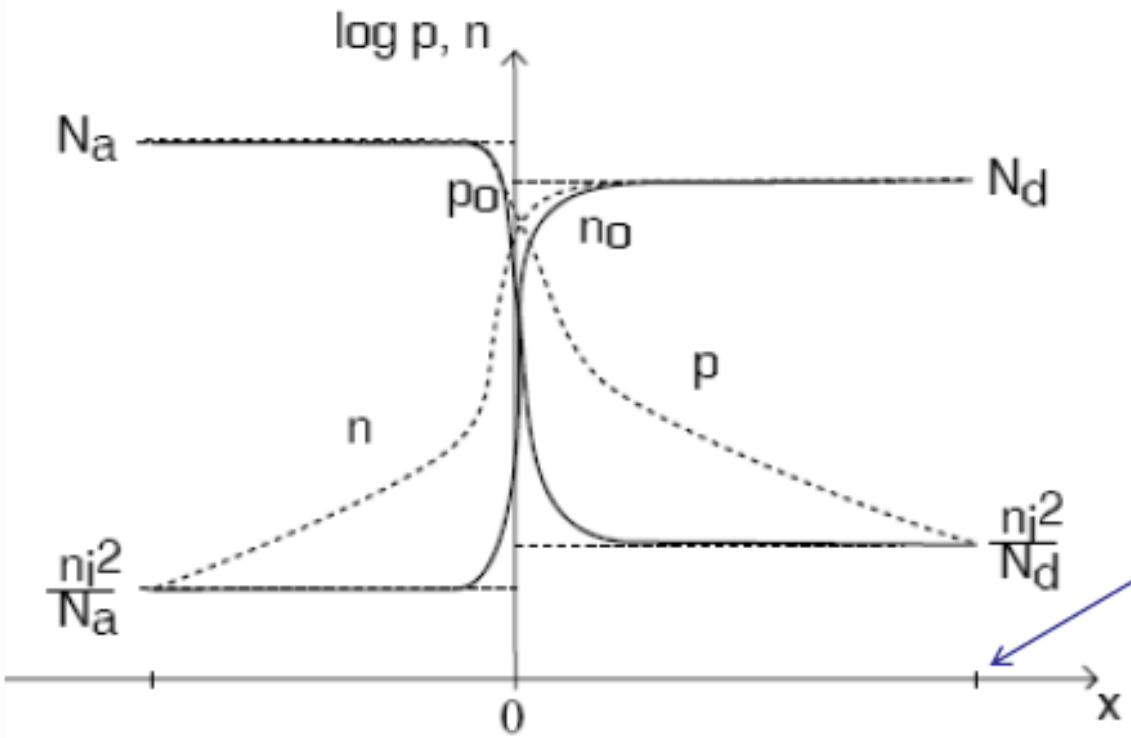
$$\left|J_{drift}\right| > \left|J_{diff}\right|$$

Net drift current in SCR
=> minority carrier extraction from QNR's
⇒deficit of minority carrier concentrations in QNR's

Few minority carriers in QNR's
=>current small.

Complete physical picture for pn diode under bias:

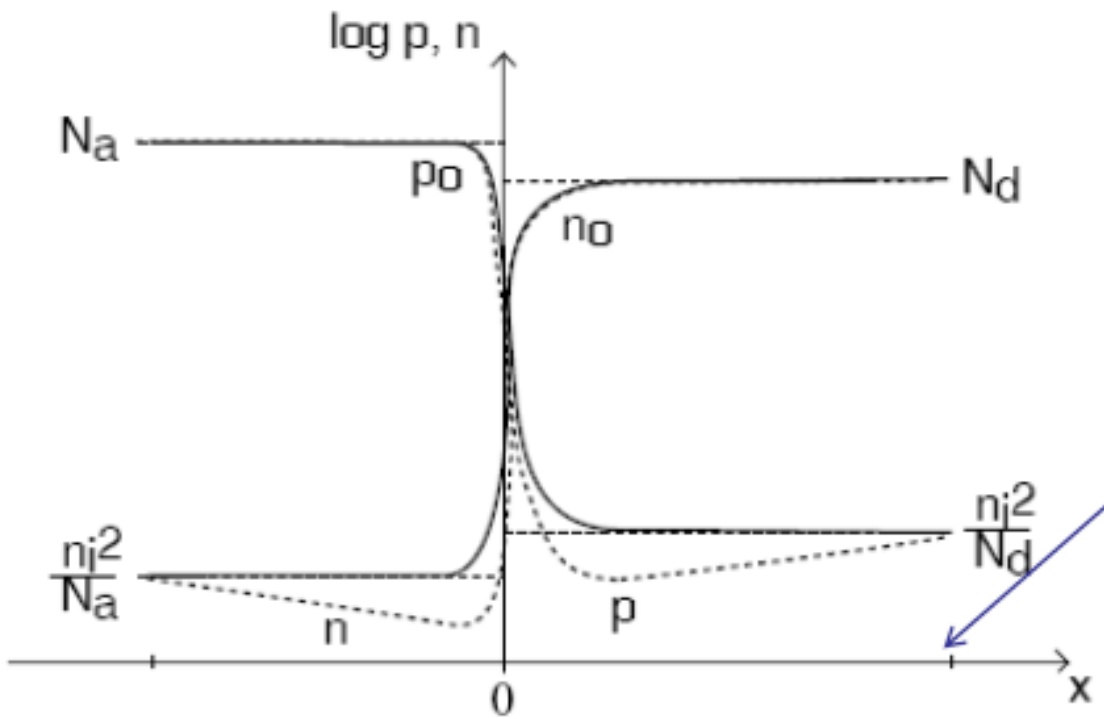
• Forward bias: injected minority carriers diffuse through QNR => recombine at semiconductor surface



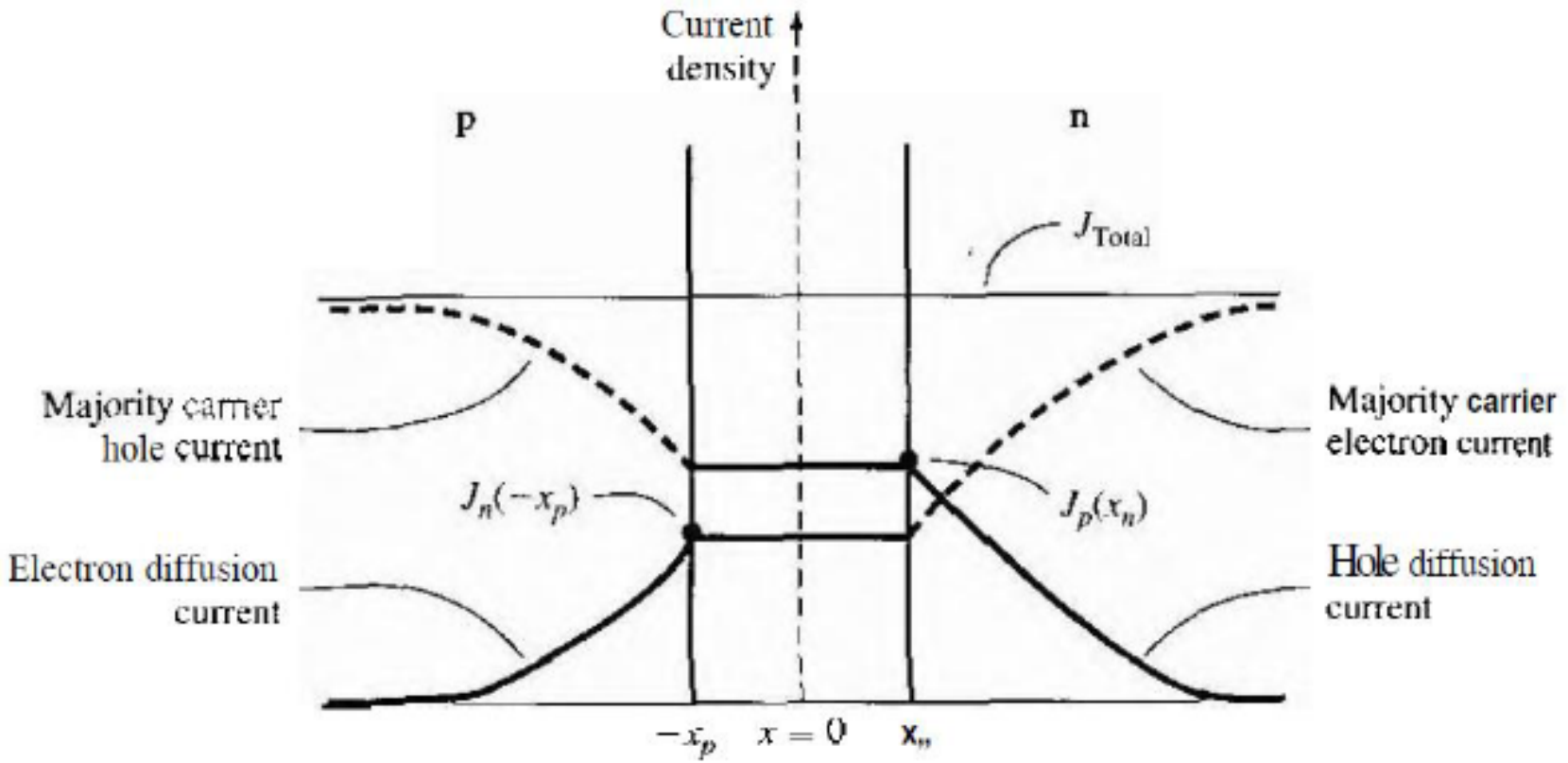
At semiconductor surface: carrier concentration unchanged from equilibrium.

• Reverse bias: minority carriers extracted by SCR

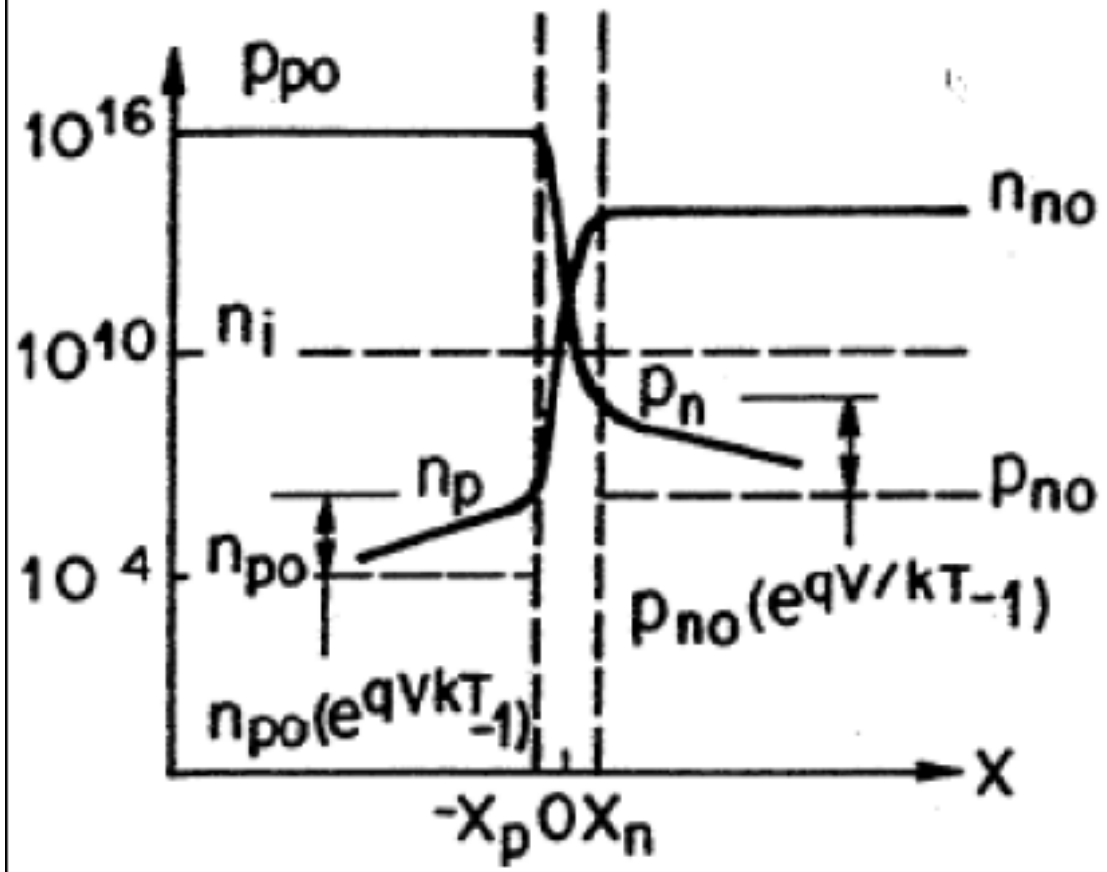
=> generated at surface and diffuse through QNR



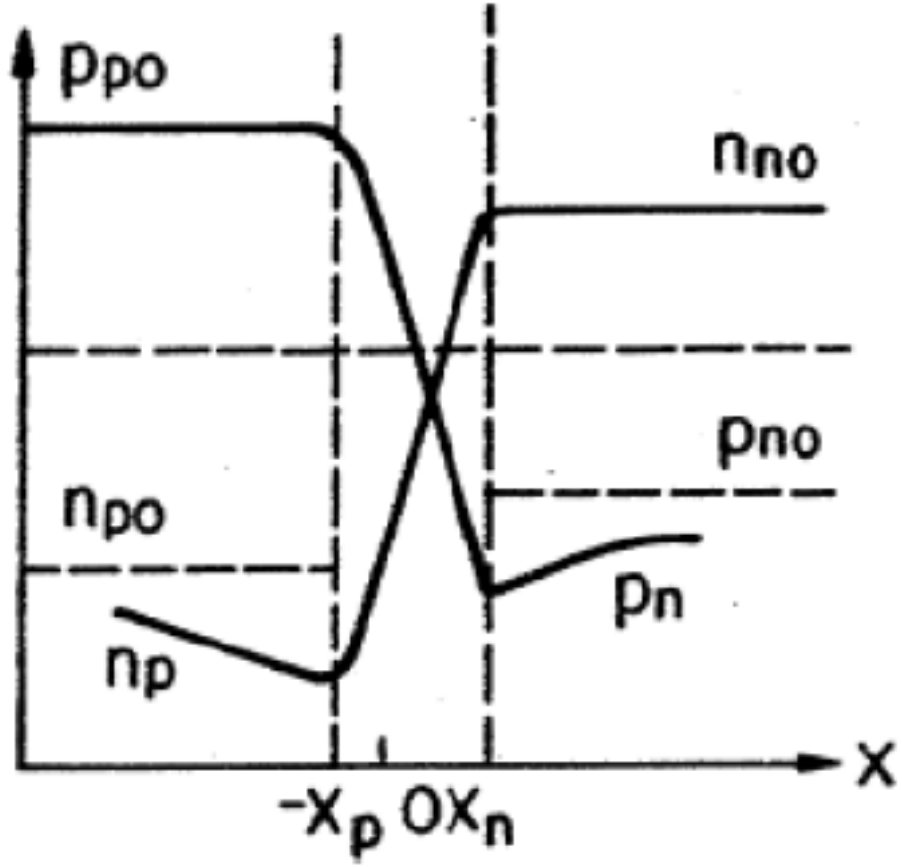
At semiconductor surface: carrier concentration unchanged from equilibrium.



Ideal electron and hole current components through a pn junction under forward bias.



Forward Bias



Reverse Bias

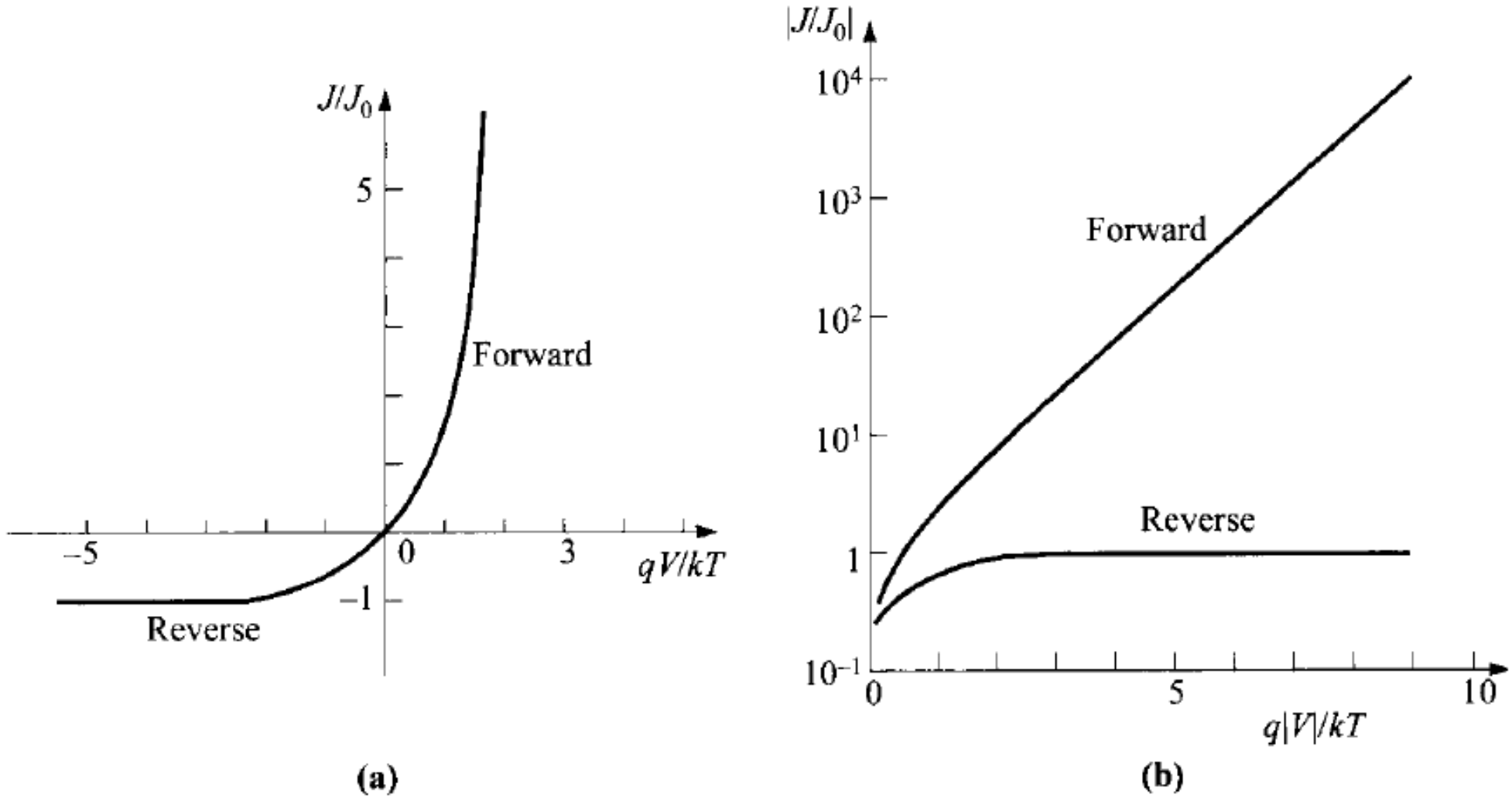


Fig. 10 Ideal current-voltage characteristics. (a) Linear plot. (b) Semilog plot.

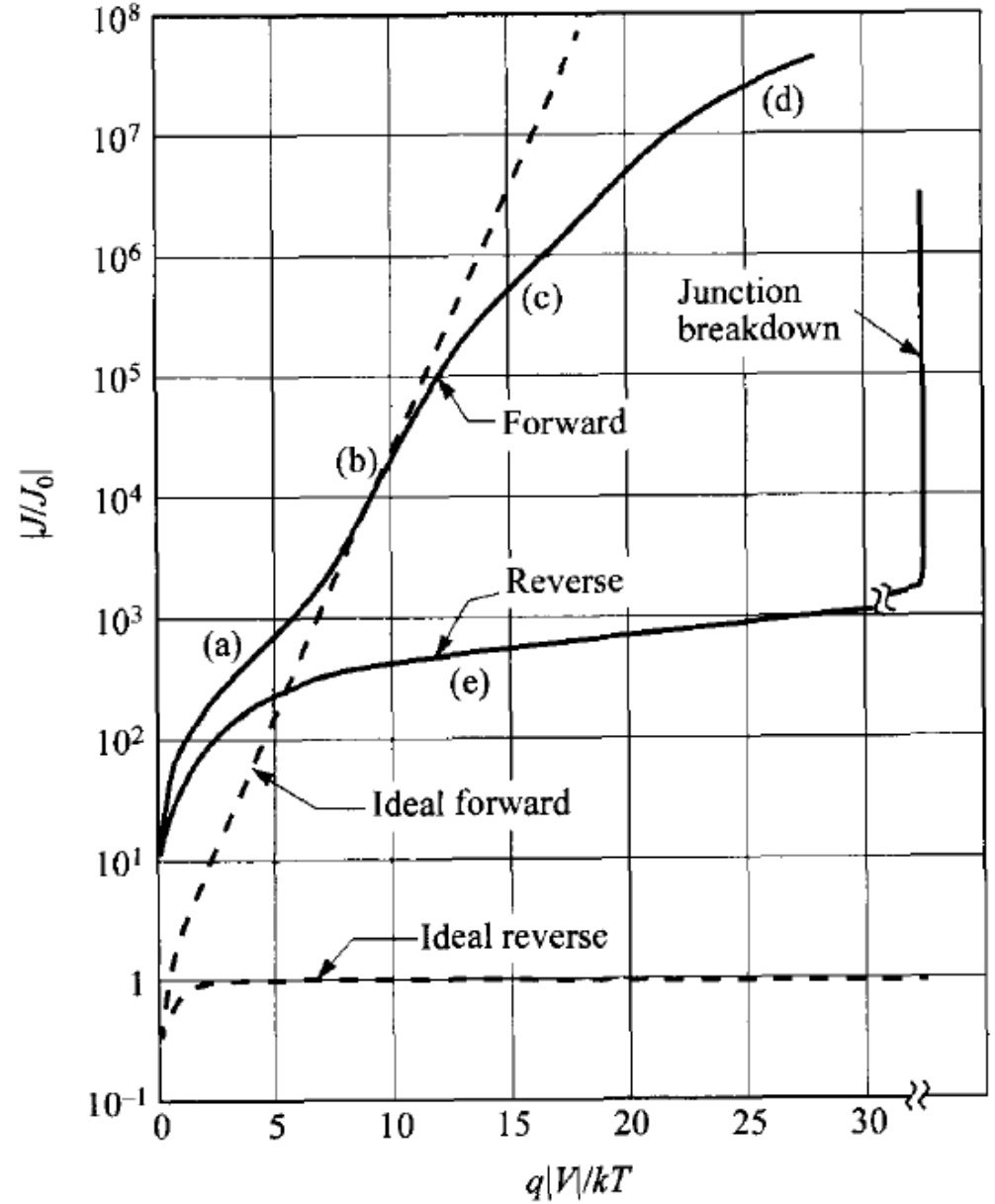
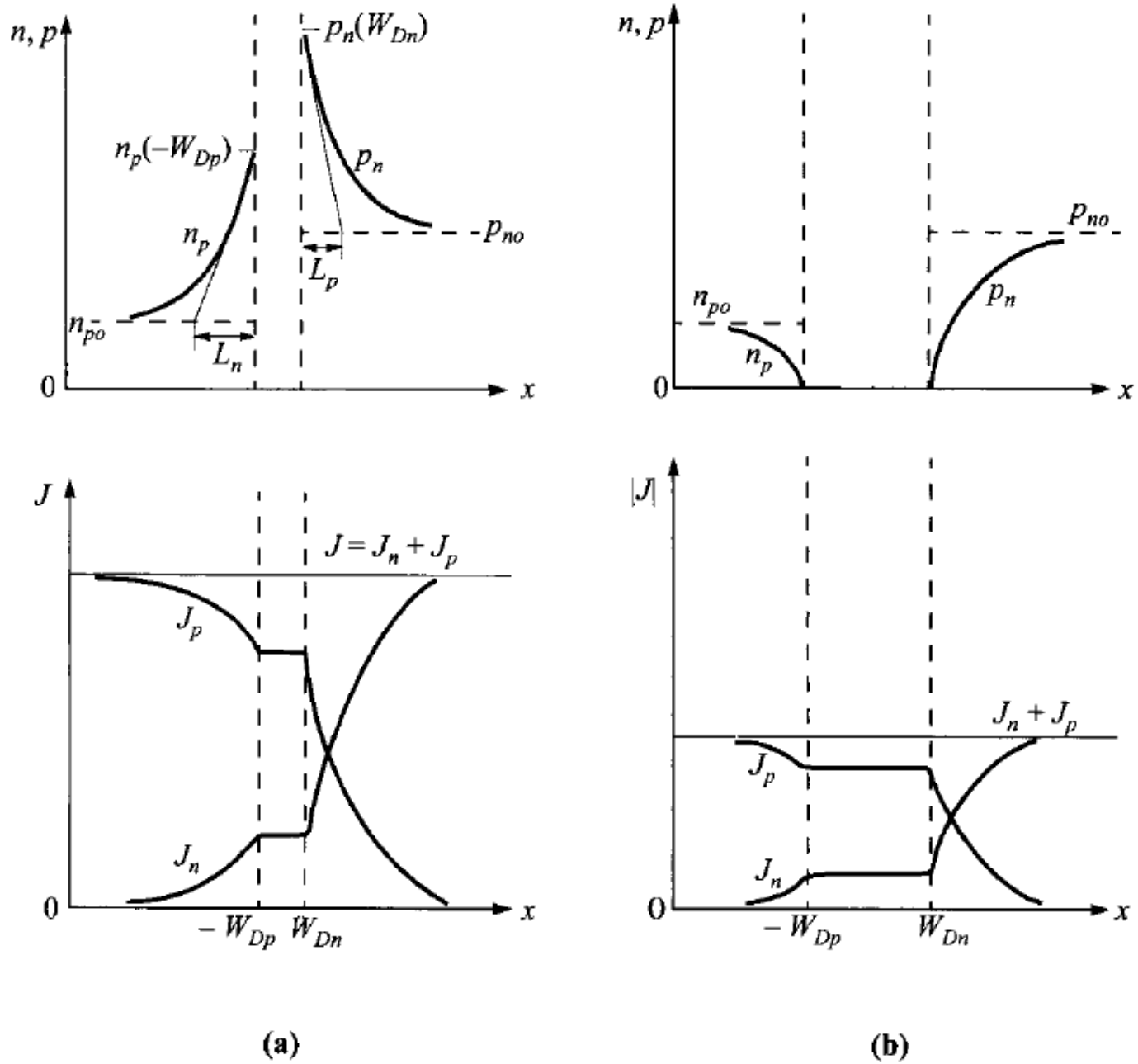


Fig. 11 Current-voltage characteristics of a practical Si diode. (a) Generation-recombination current region. (b) Diffusion-current region. (c) High-injection region. (d) Series-resistance effect. (e) Reverse leakage current due to generation-recombination and surface effects.



(a) (b)

Fig. 9 Carrier distributions and current densities (both linear plots) for (a) forward-biased conditions and (b) reverse-biased conditions.

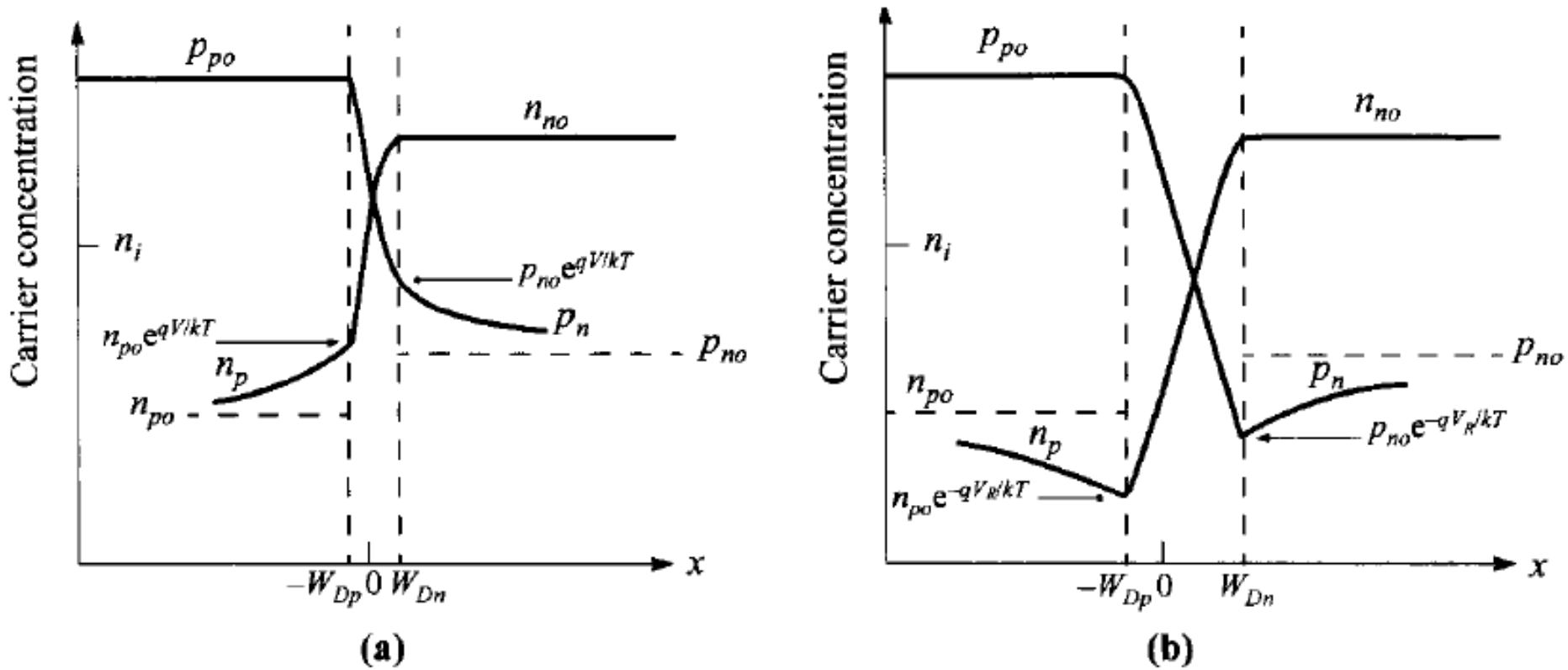


Fig. 8 Energy-band diagram, with quasi-Fermi levels for electrons and holes, and carrier distributions under (a) forward bias and (b) reverse bias.

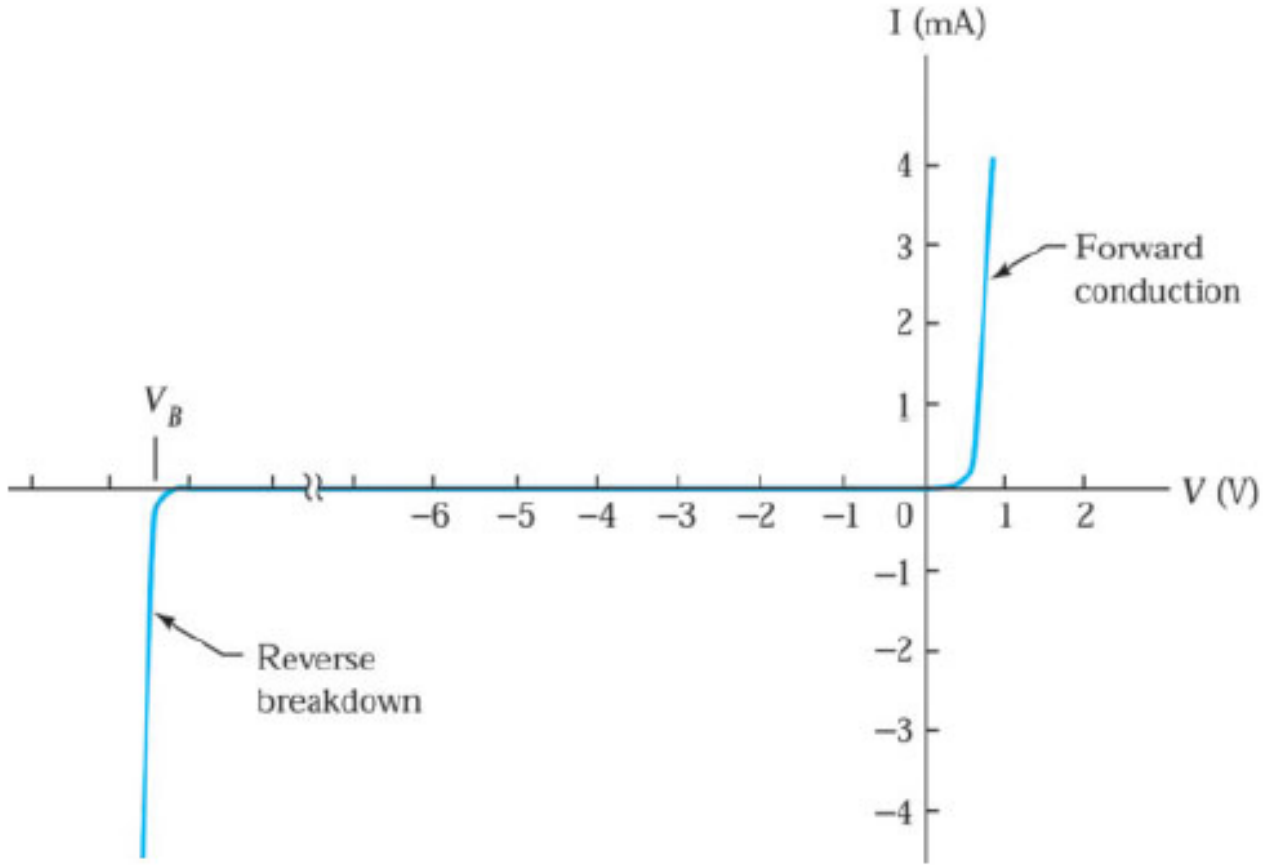


Fig. 1 **Current-voltage characteristics of a typical silicon *p–n* junction.**

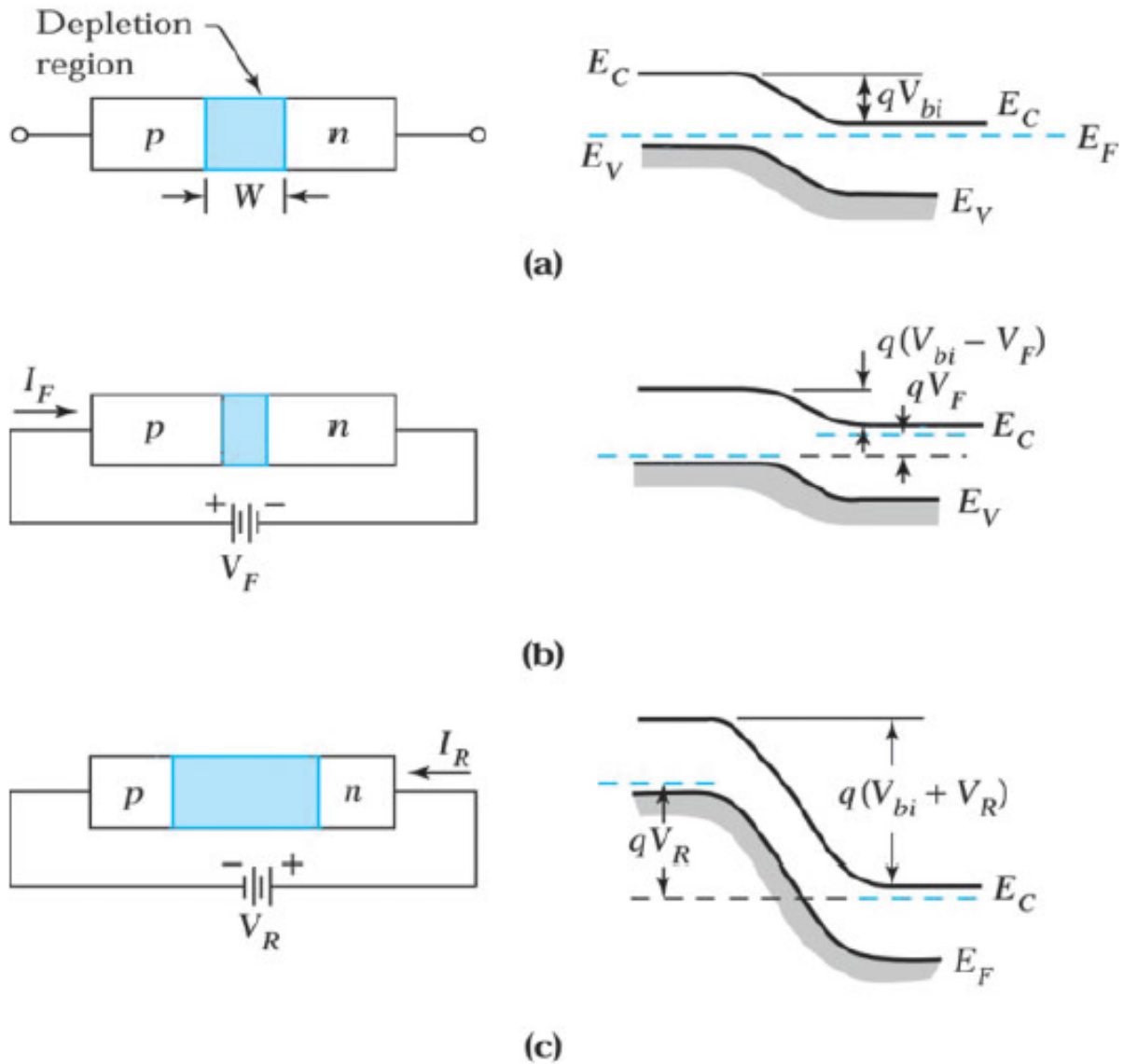


Fig. 8 **Schematic representations of depletion layer width and energy band diagrams of a *p–n* junction under various biasing conditions. (*a*) Thermal-equilibrium condition. (*b*) Forward-bias condition. (*c*) Reverse-bias condition.**

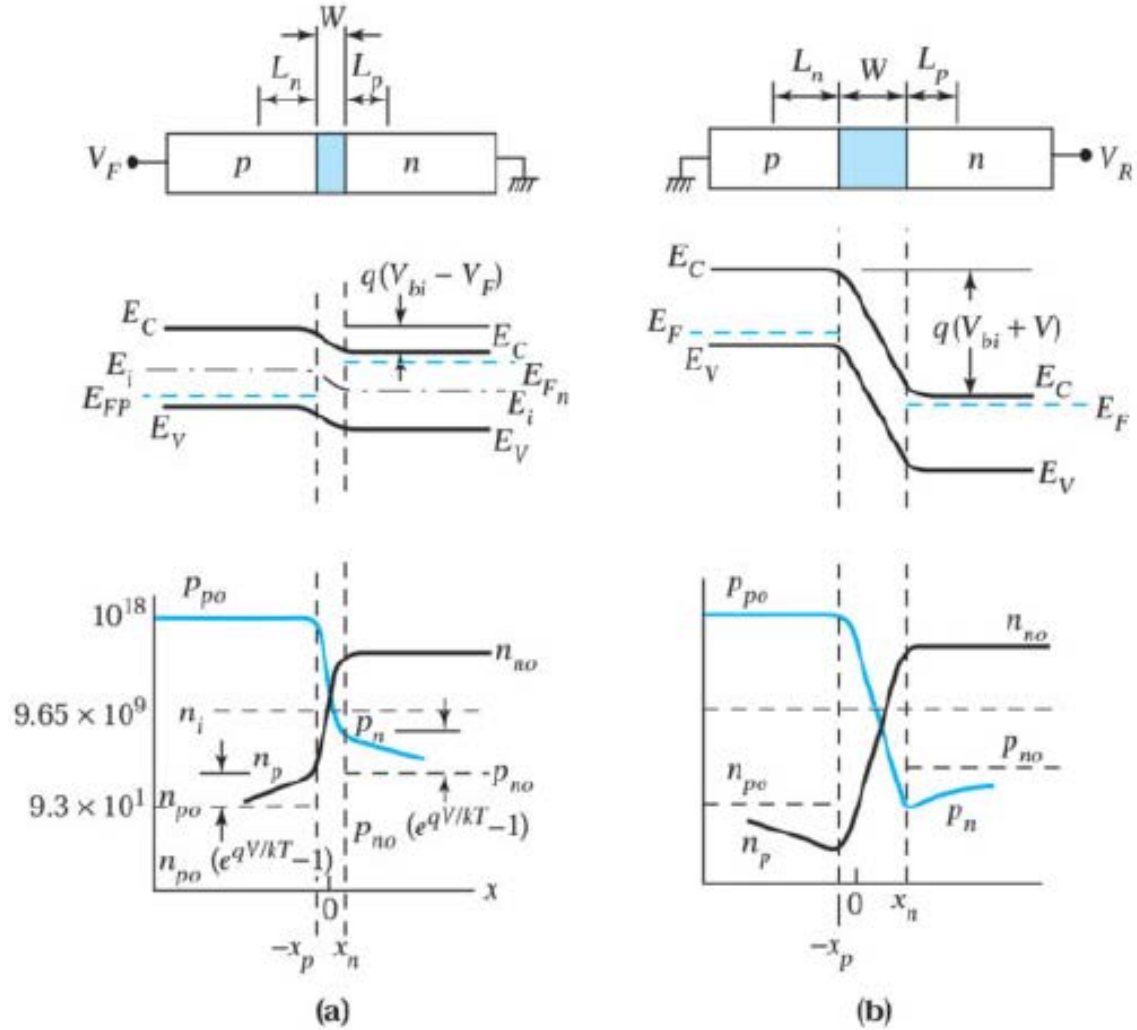


Fig. 14 **Depletion region, energy band diagram and carrier distribution. (*a*) Forward bias. (*b*) Reverse bias.**

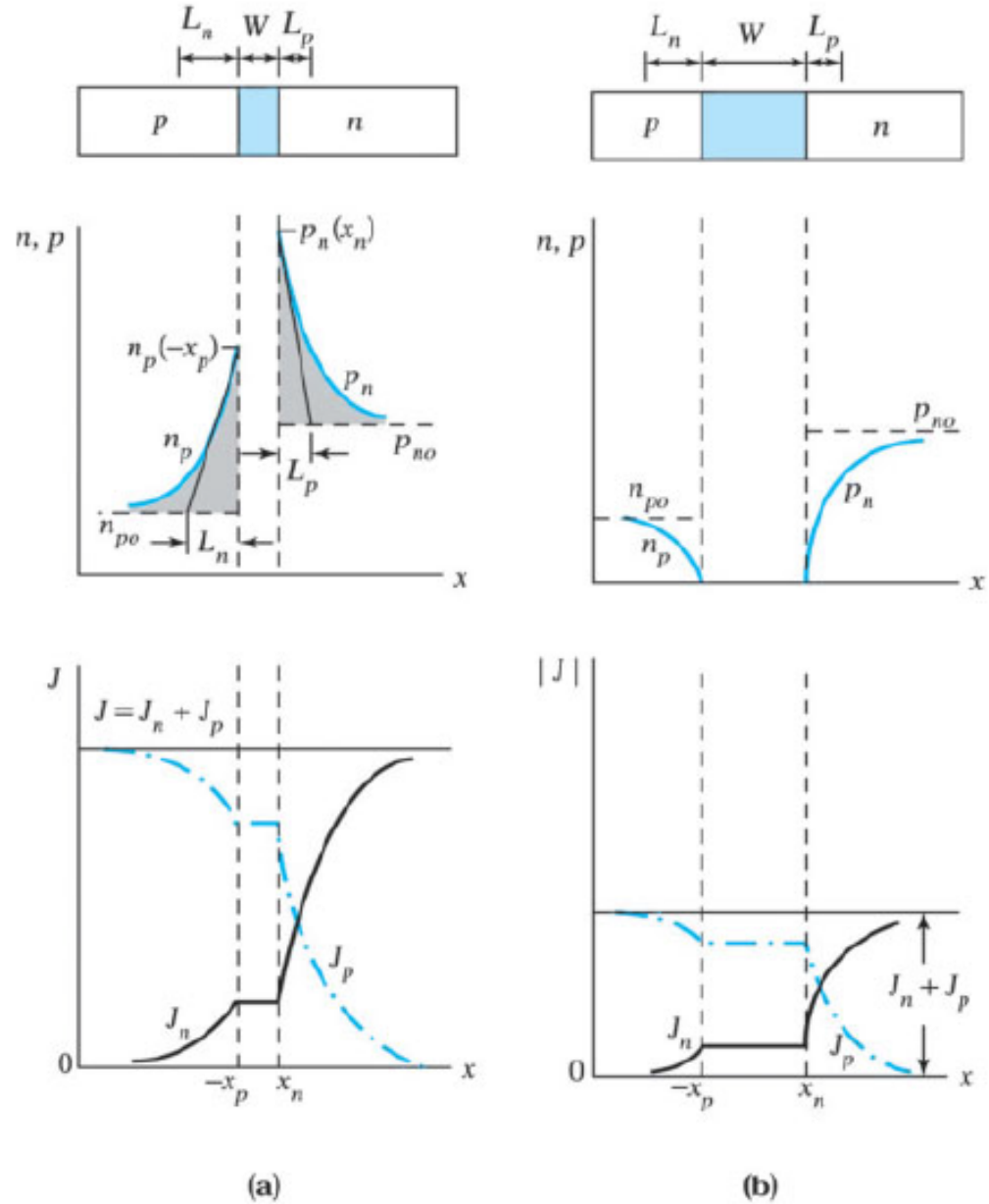
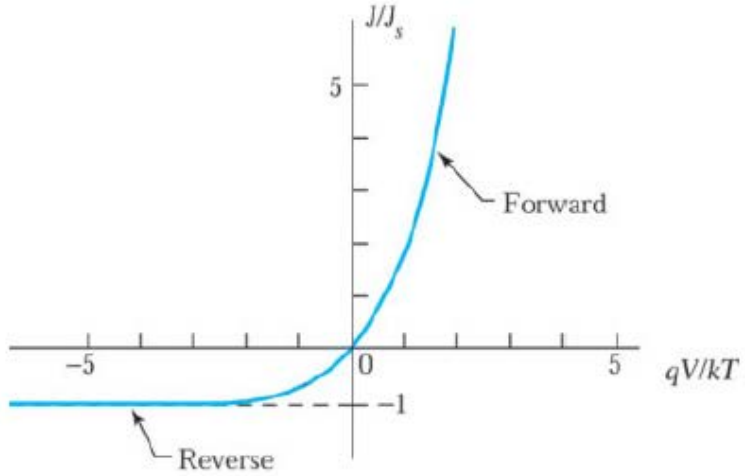
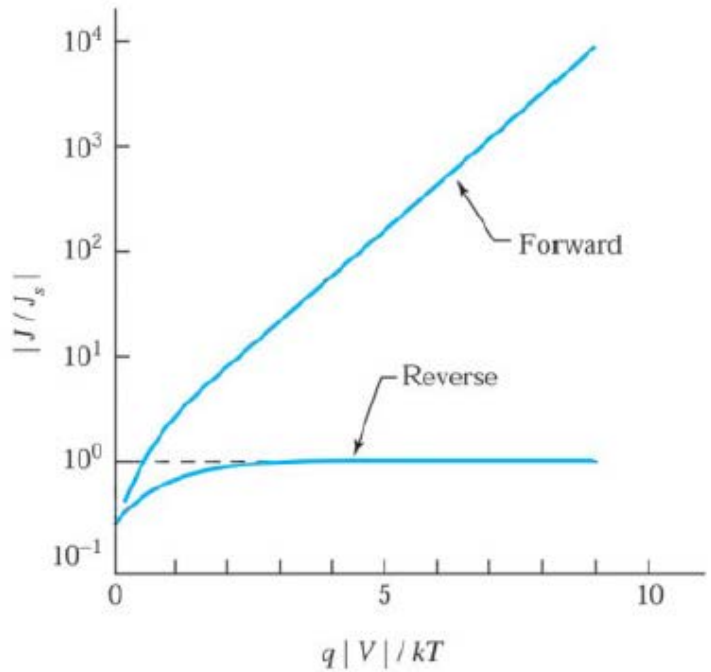


Fig. 15 **Injected minority carrier distribution and electron and hole currents. (*a*) Forward bias. (*b*) Reverse bias. The figure illustrates idealized currents. In practical devices, the currents are not constant across the space charge layer.**



(a)



(b)

Fig. 16 **Ideal current-voltage characteristics. (*a*) Cartesian plot. (*b*) Semilog plot.**

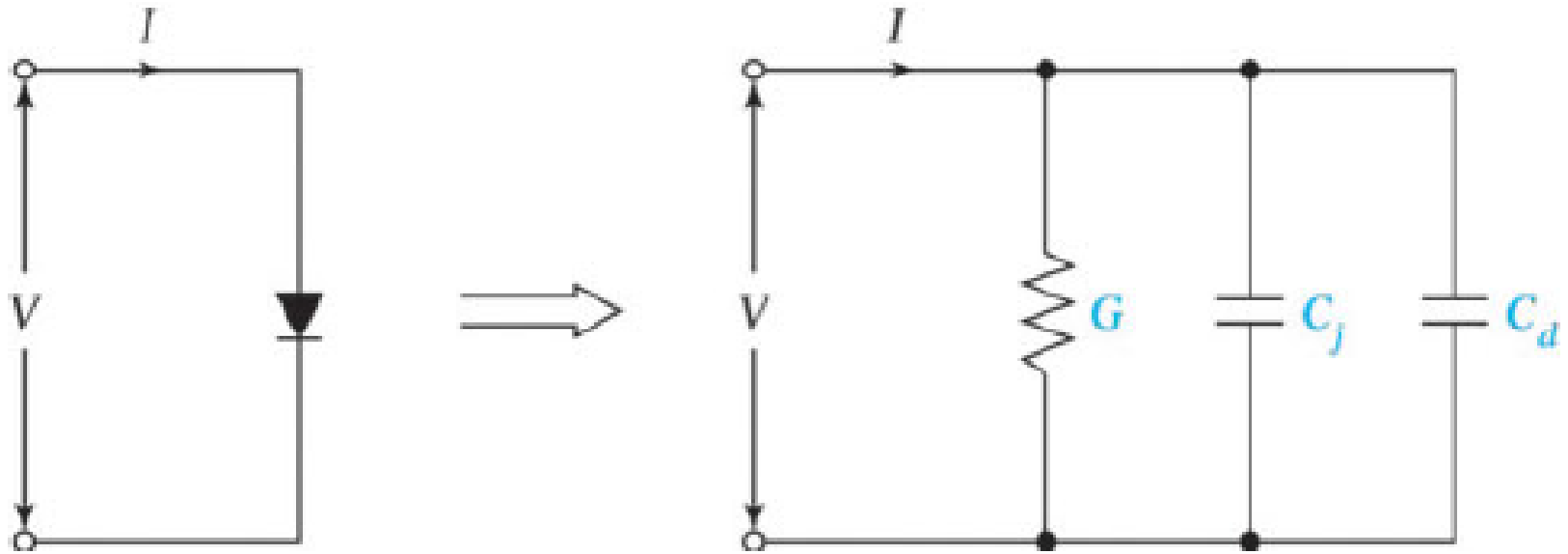


Fig. 19 **Small-signal equivalent circuit of a *p–n* junction.**