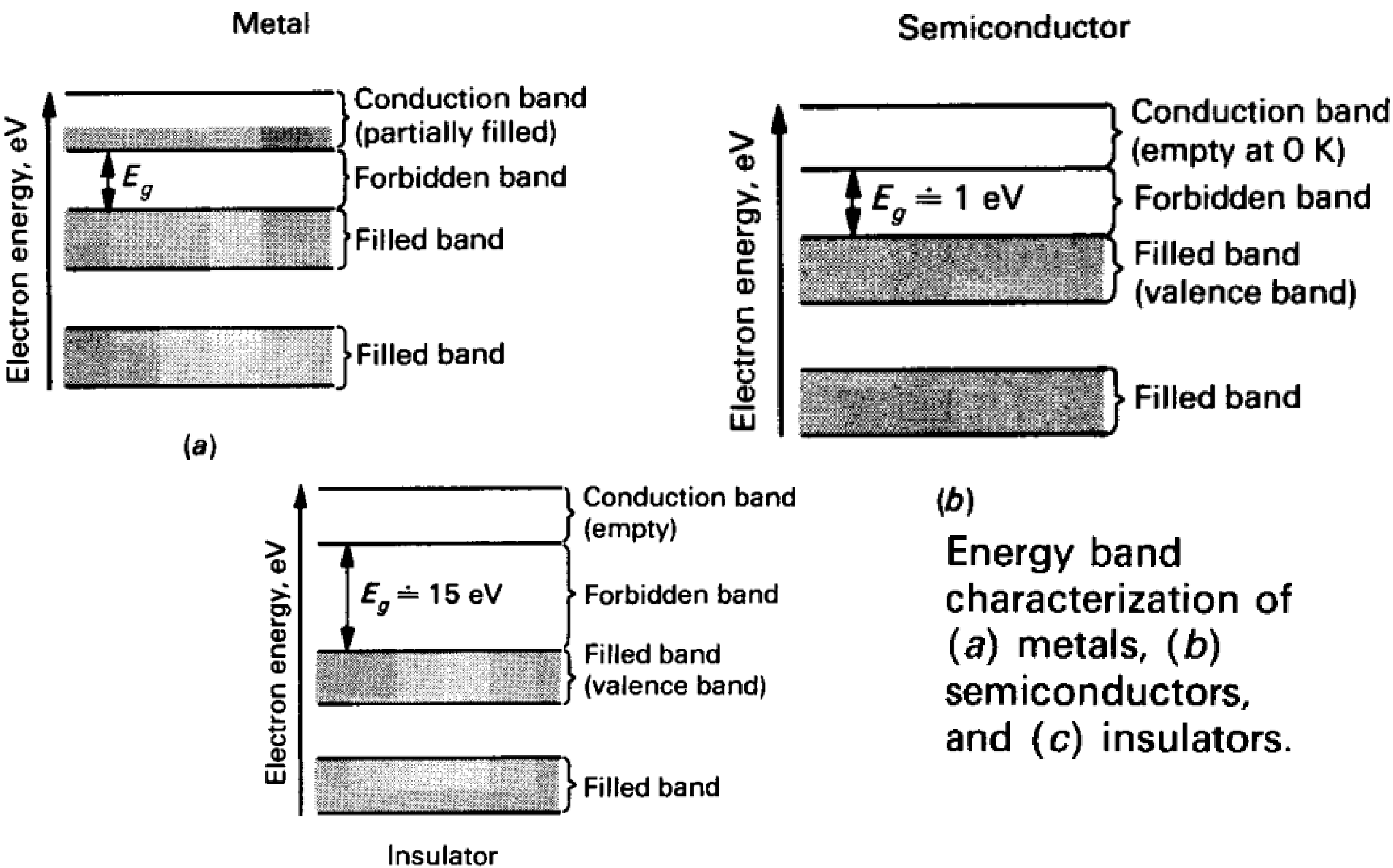
Semiconductor: Si

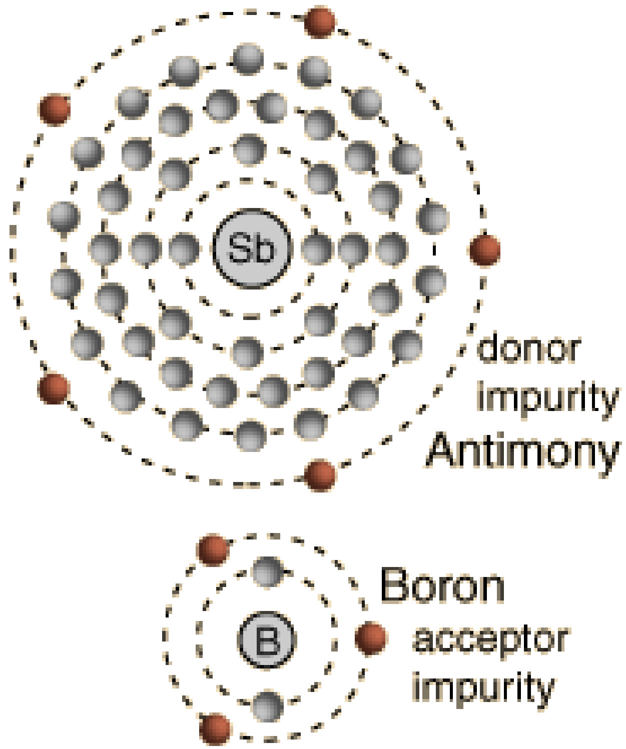


Energy band characterization of (*a*) metals, (*b*) semiconductors, and (*c*) insulators.

Semiconductor

Antimony
Arsenic
Phosphorous

Boron
Aluminum
Gallium

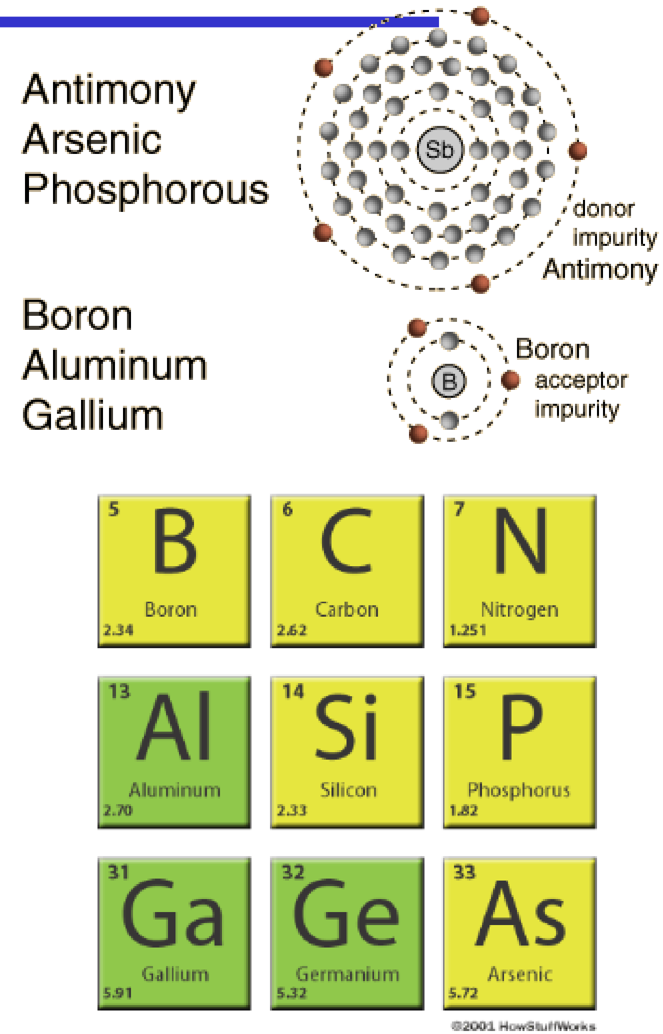


N-type and P-type Semiconductors

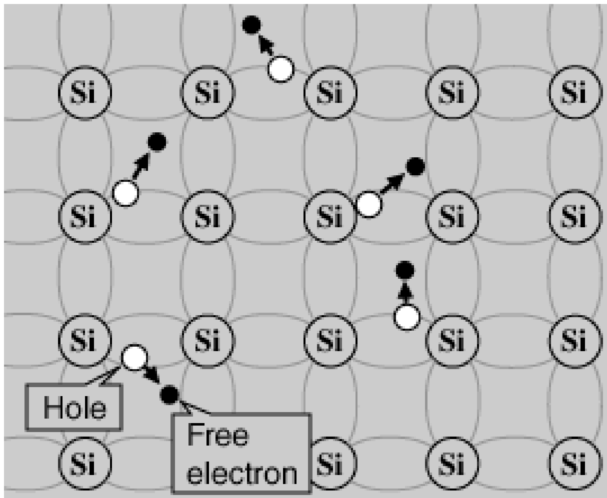
There are two types of impurities:

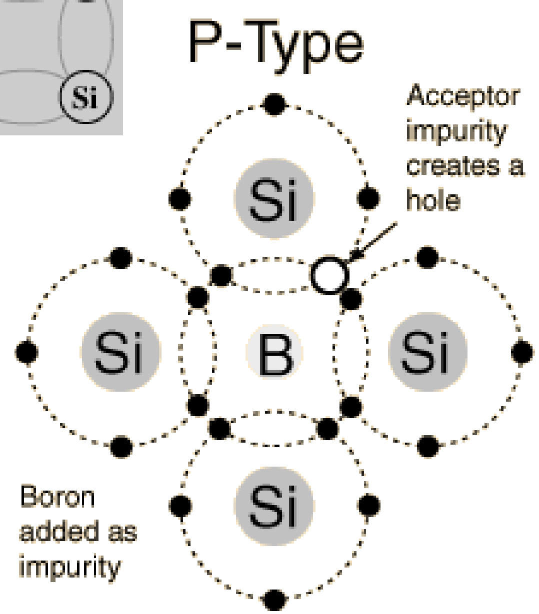
N-type - In N-type doping, **phosphorus** or arsenic is added to the silicon in small quantities. Phosphorus and arsenic each have five outer electrons, so they're out of place when they get into the silicon lattice. The fifth electron has nothing to bond to, so it's free to move around. It takes only a very small quantity of the impurity to create enough free electrons to allow an electric current to flow through the silicon. N-type silicon is a good conductor. Electrons have a negative charge, hence the name N-type.

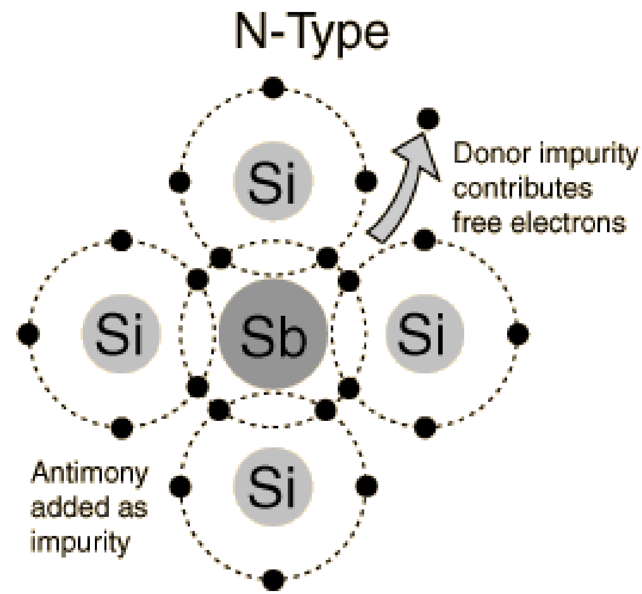
P-type - In P-type doping, boron or gallium is the dopant. Boron and gallium each have only three outer electrons. When mixed into the silicon lattice, they form "holes" in the lattice where a silicon electron has nothing to bond to. The absence of an electron creates the effect of a positive charge, hence the name P-type. Holes can conduct current. A hole happily accepts an electron from a neighbor, moving the hole over a space. P-type silicon is a good conductor.



N-type and P-type Semiconductors



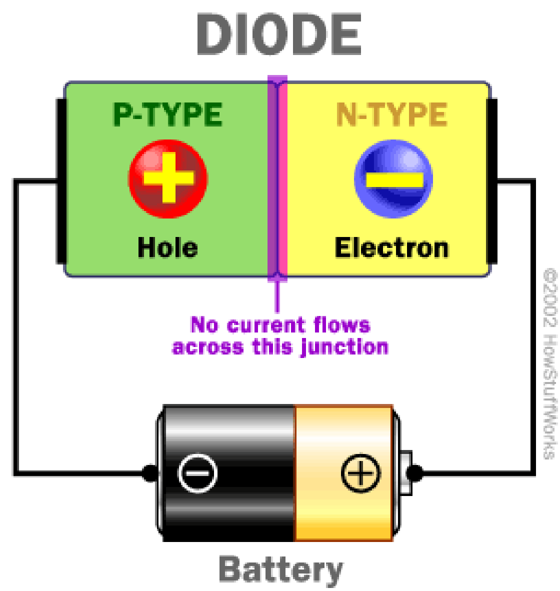


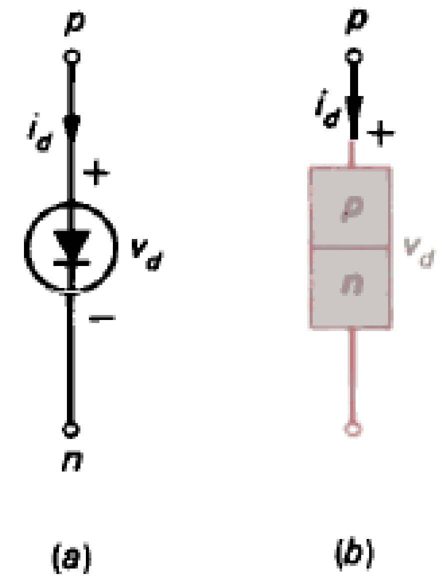


Semiconductor device-diode

A diode is the simplest possible semiconductor device. A diodeallows current to flow in one direction but not the other. You may have seen turnstiles at a stadium or a subway station that let people go through in only one direction. A diode is a one-way turnstile for electrons.

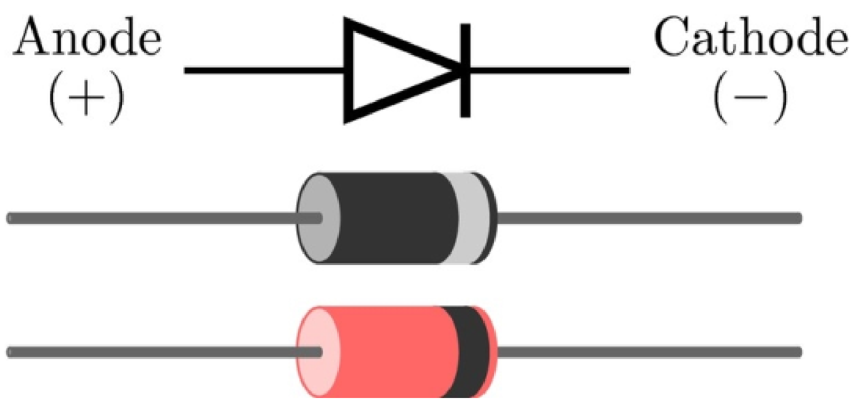
When you put N-type and P-type silicon together as shown in this diagram, you get a very interesting phenomenon that gives a diode its unique properties.



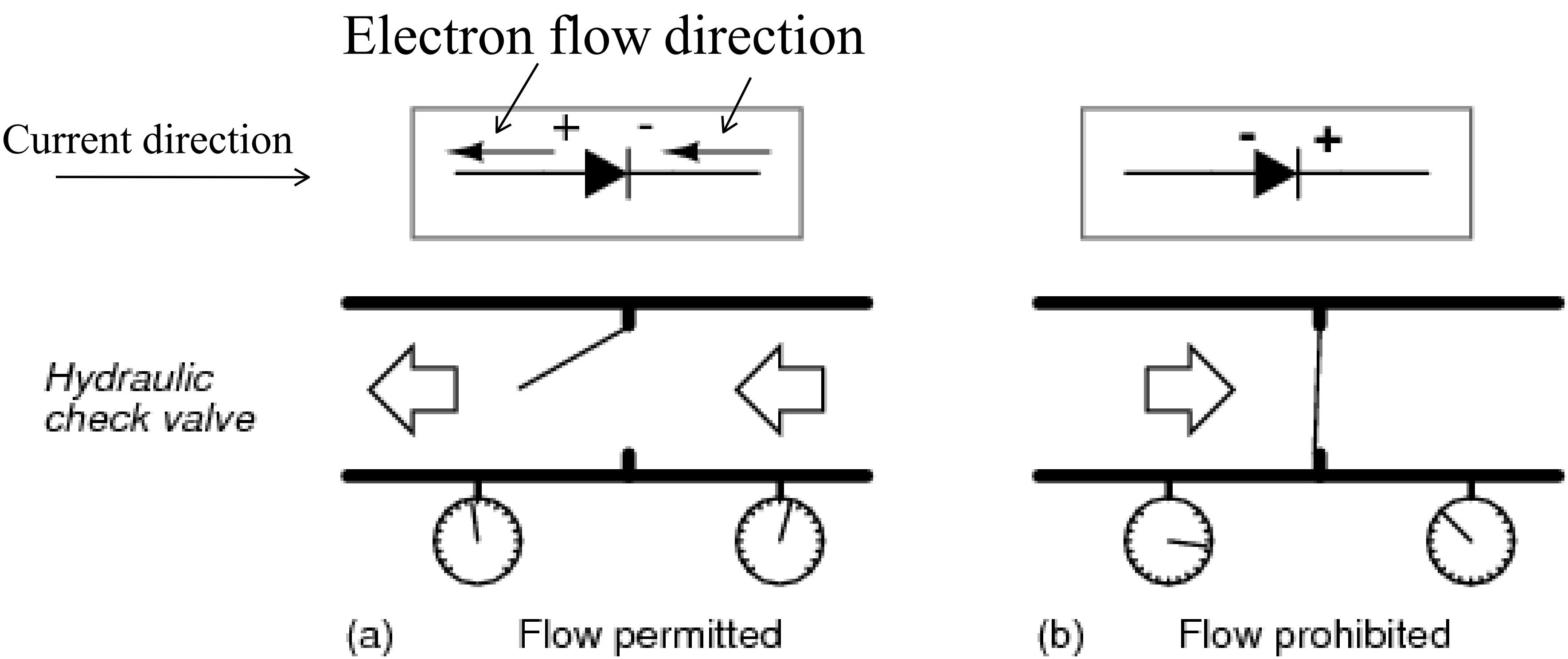


The semiconductor diode: (a) circuit symbol; (b) physical construction.

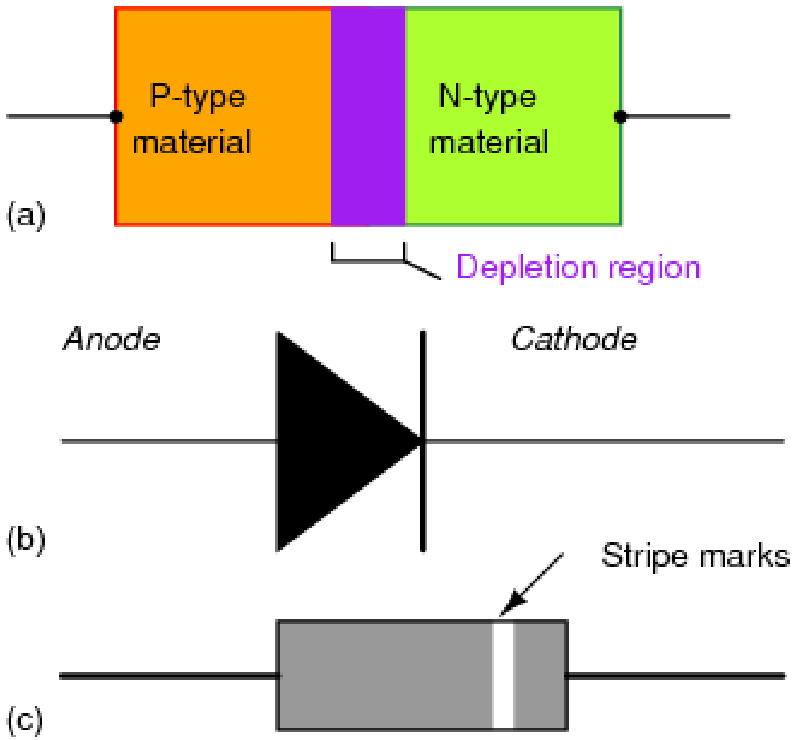
Diodes



Diode


Electron flow direction
Current direction
+
-
-
+
Hydraulic check valve
(a) Flow permitted
(b) Flow prohibited

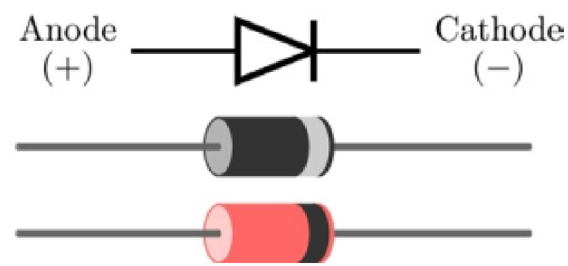
Diode depletion region



P-N junction representation

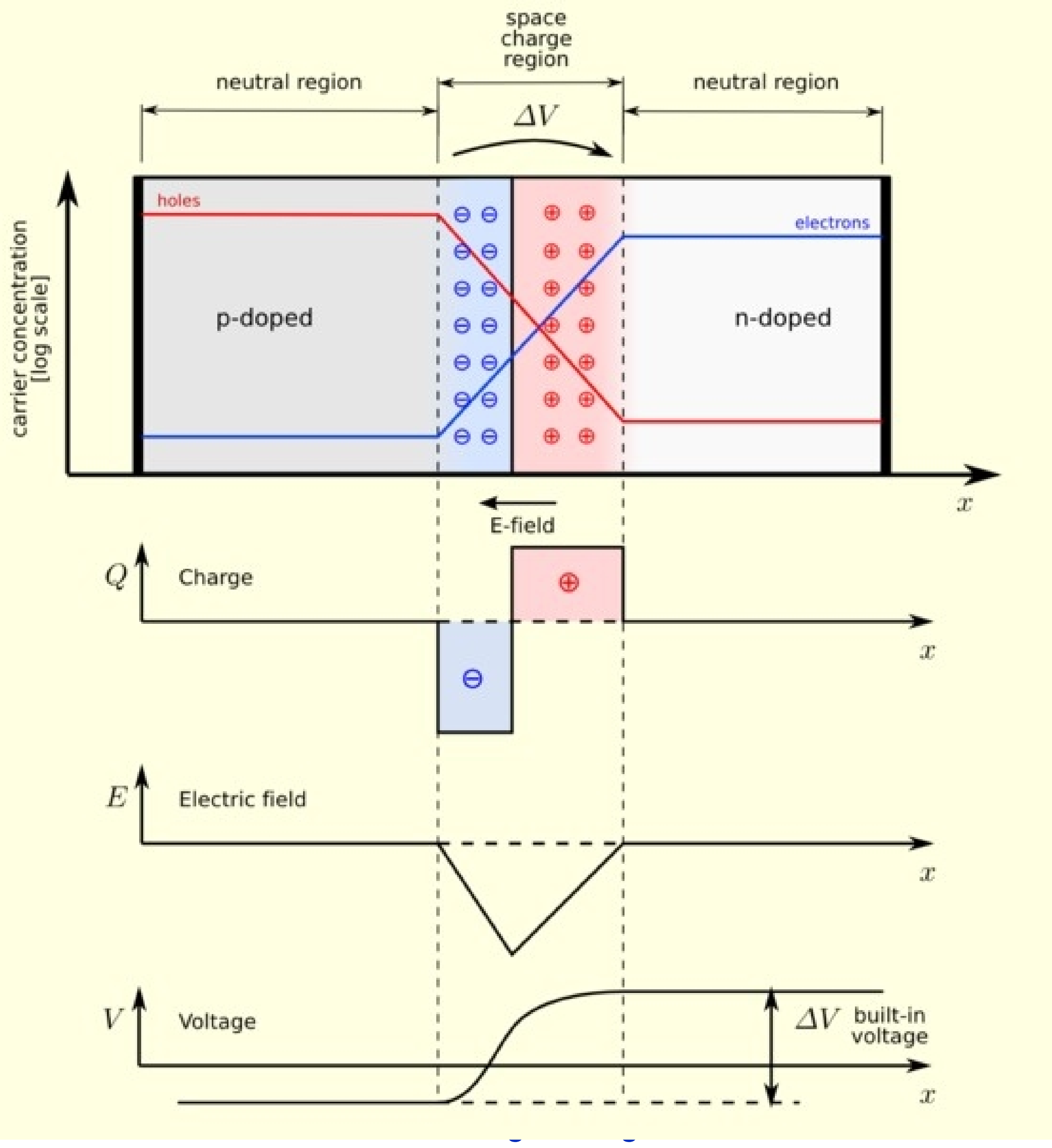
Schematic symbol

Real component appearance

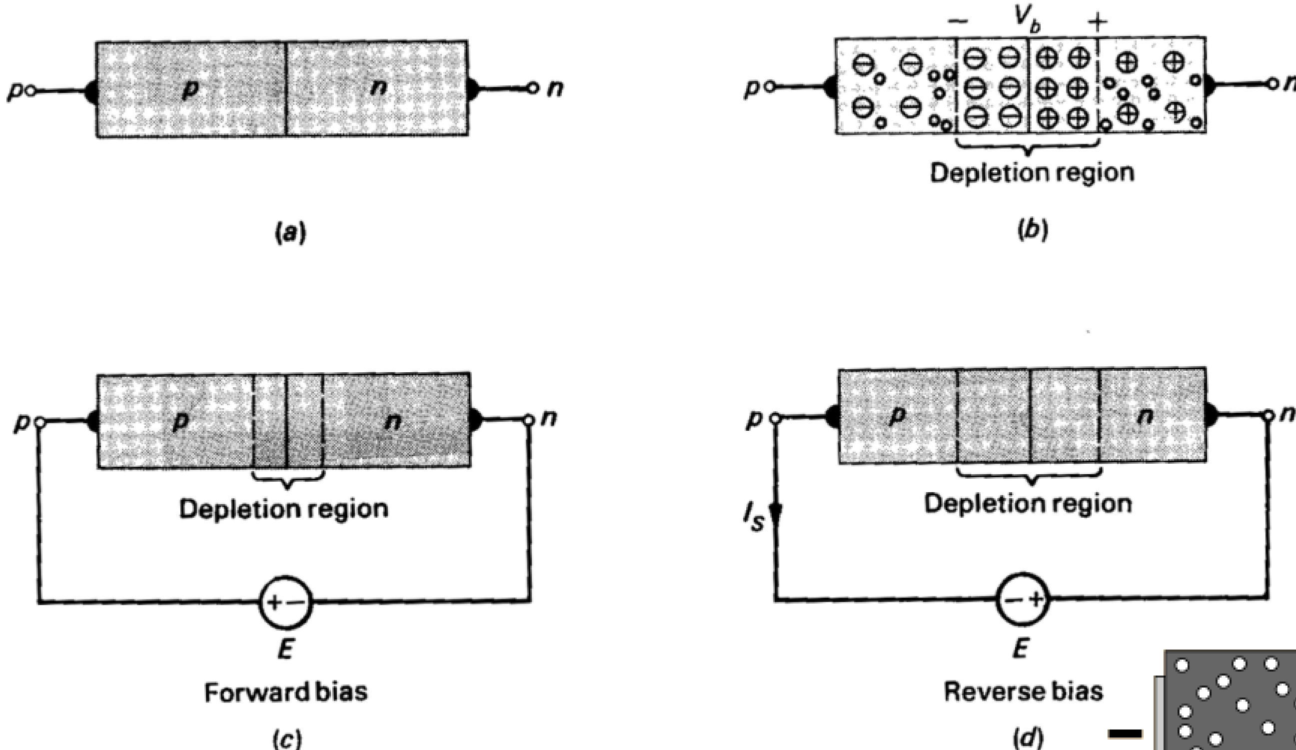


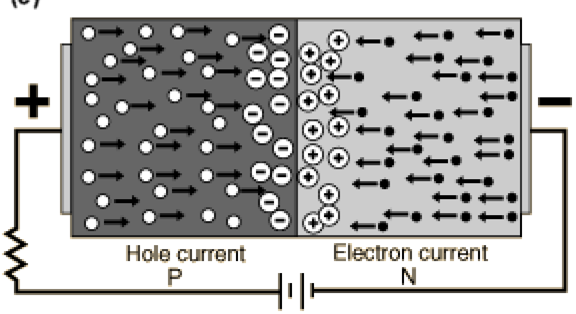
pn junction

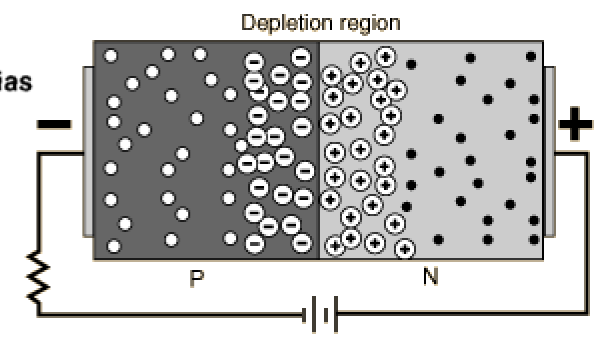
◆ **PN Junction**



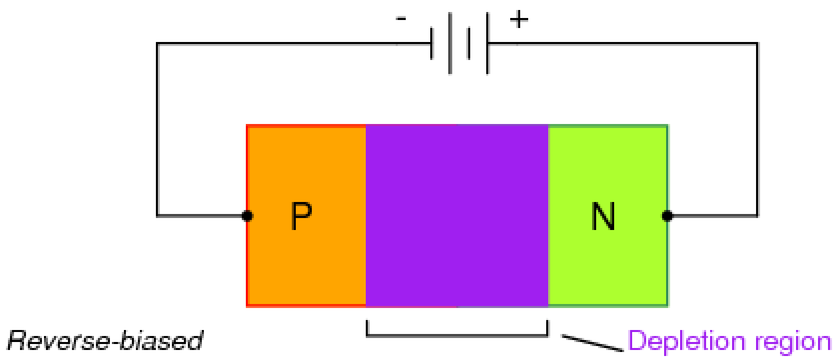
Diode depletion region







Diode forward and reverse bias

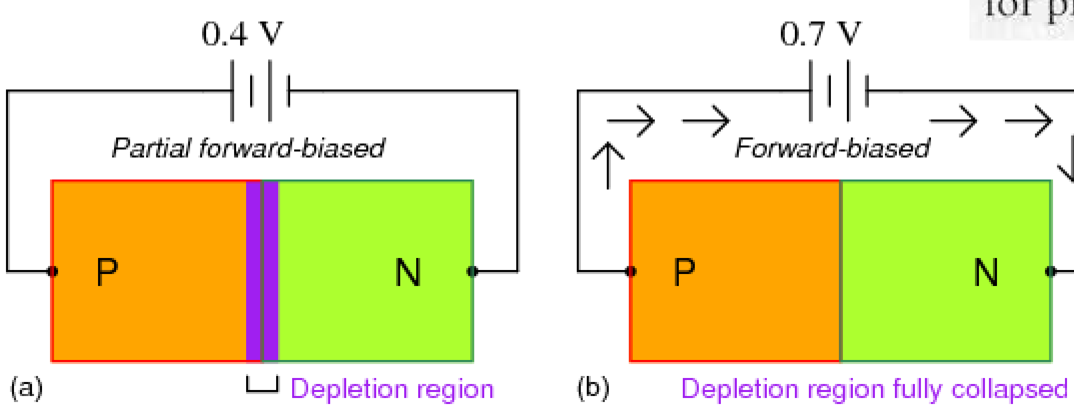


Shockley diode equation

$$i_d = I_S(e^{qv_d/(\eta kT)} - 1)$$

($\eta = 1$ for Ge and $\eta = 2$ for Si)

for practical purposes as unity ($\eta \doteq 1$).



Shockley diode equation

$$I_D = I_S\,(e^{qV_D/NkT} - 1)$$

Shockley diode equation

Where,

I_D = Diode current in amps

I_S = Saturation current in amps (typically 1 x 10^{-12} amps)

e = Euler's constant (~ 2.718281828)

q = charge of electron (1.6 x 10^{-19} coulombs)

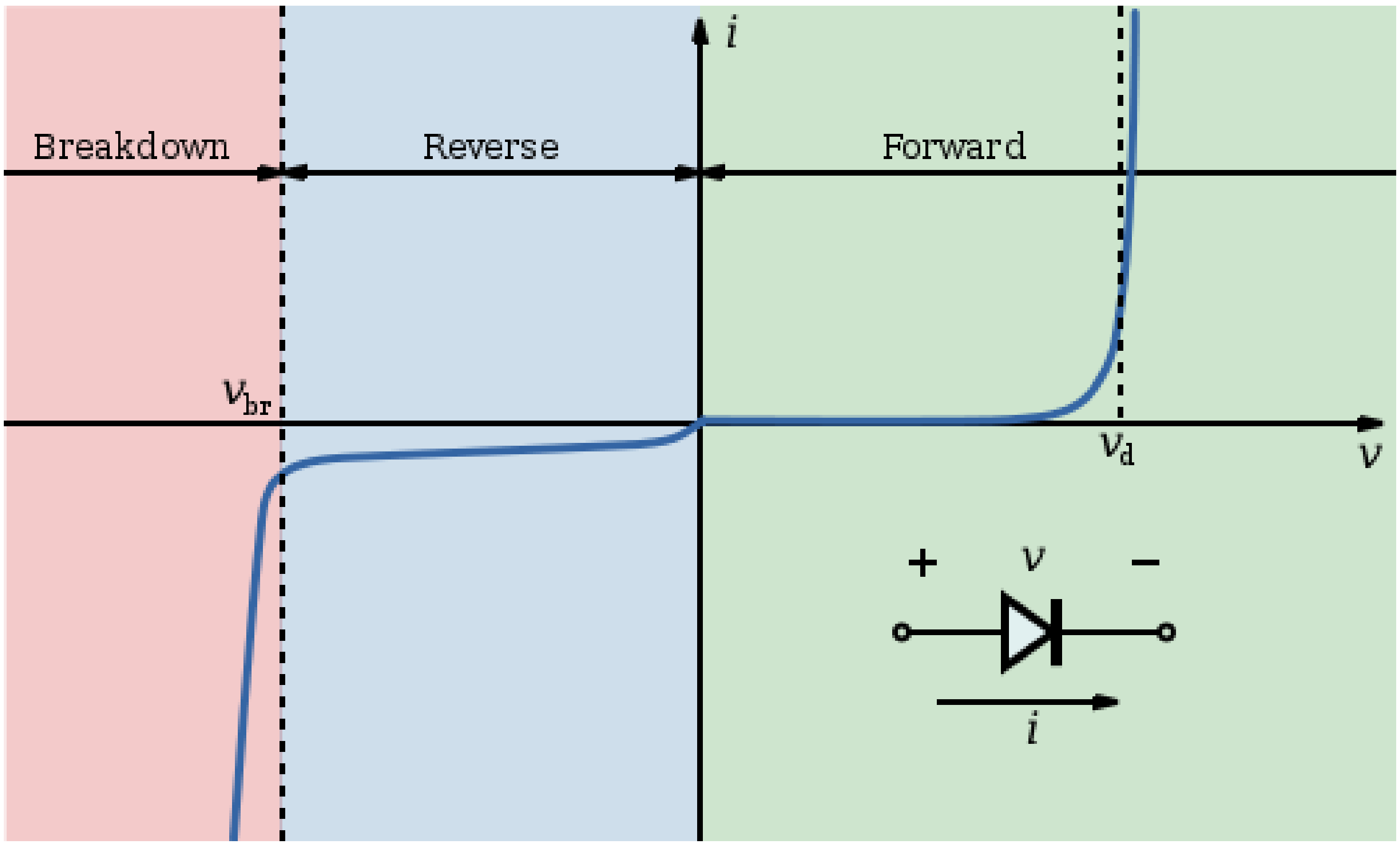
V_D = Voltage applied across diode in volts

N = "Nonideality" or "emission" coefficient (typically between 1 and 2)

k = Boltzmann's constant (1.38 x 10^{-23})

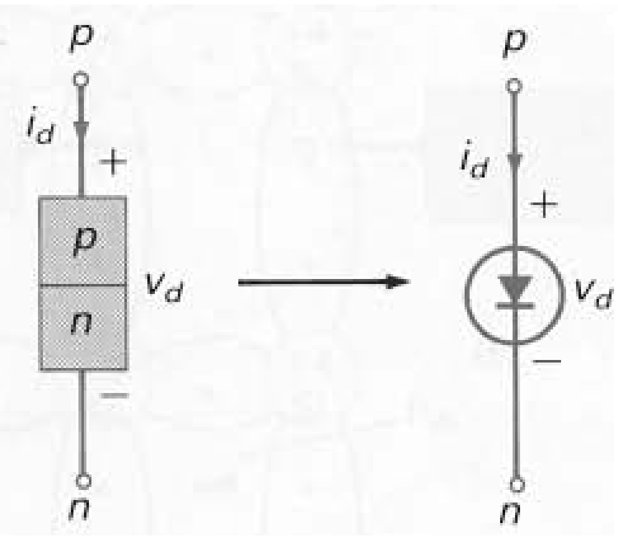
T = Junction temperature in Kelvins

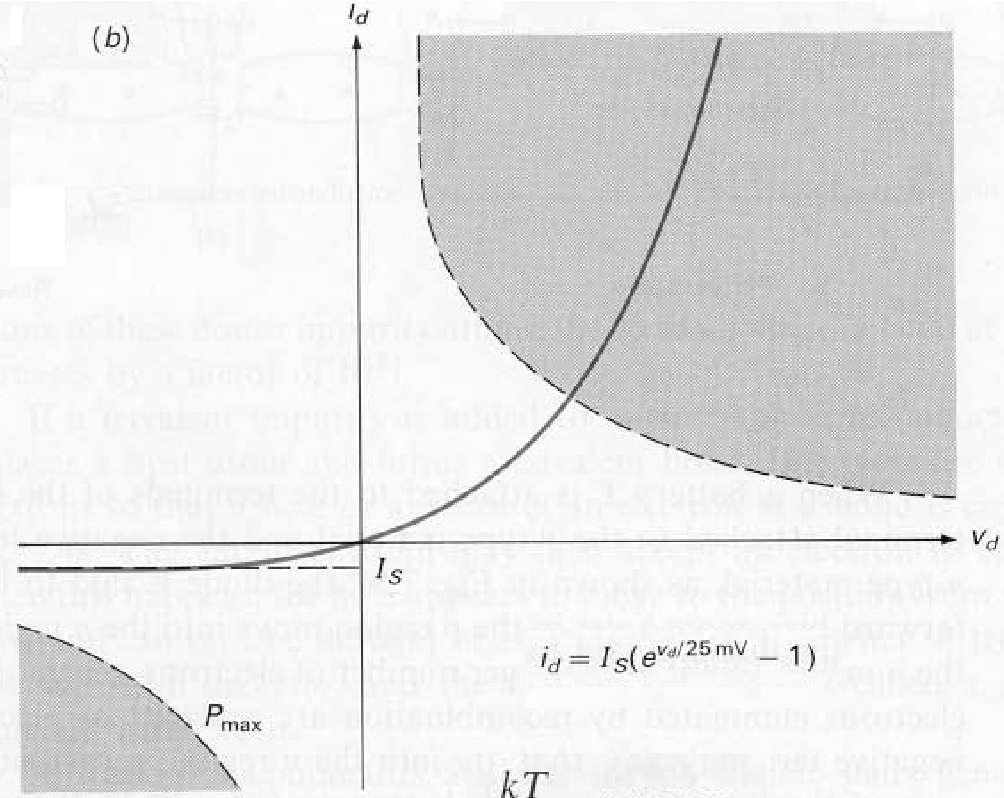
Diode current and voltage



Diode Characteristic

FIGURE
The terminal characterization of a semiconductor diode:
(a) circuit symbol;
(b) device characteristic;



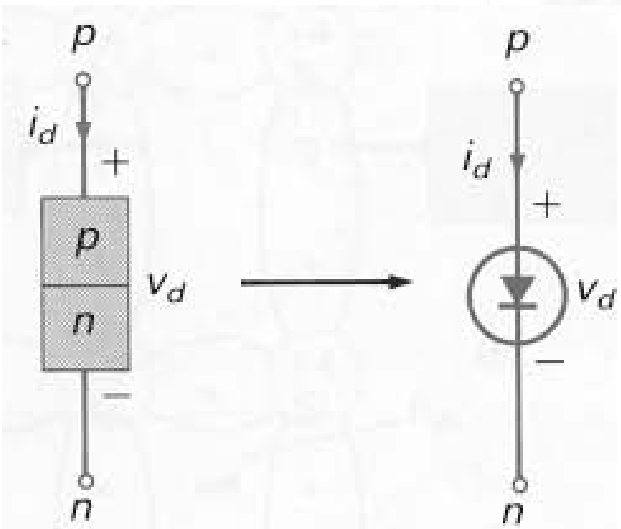


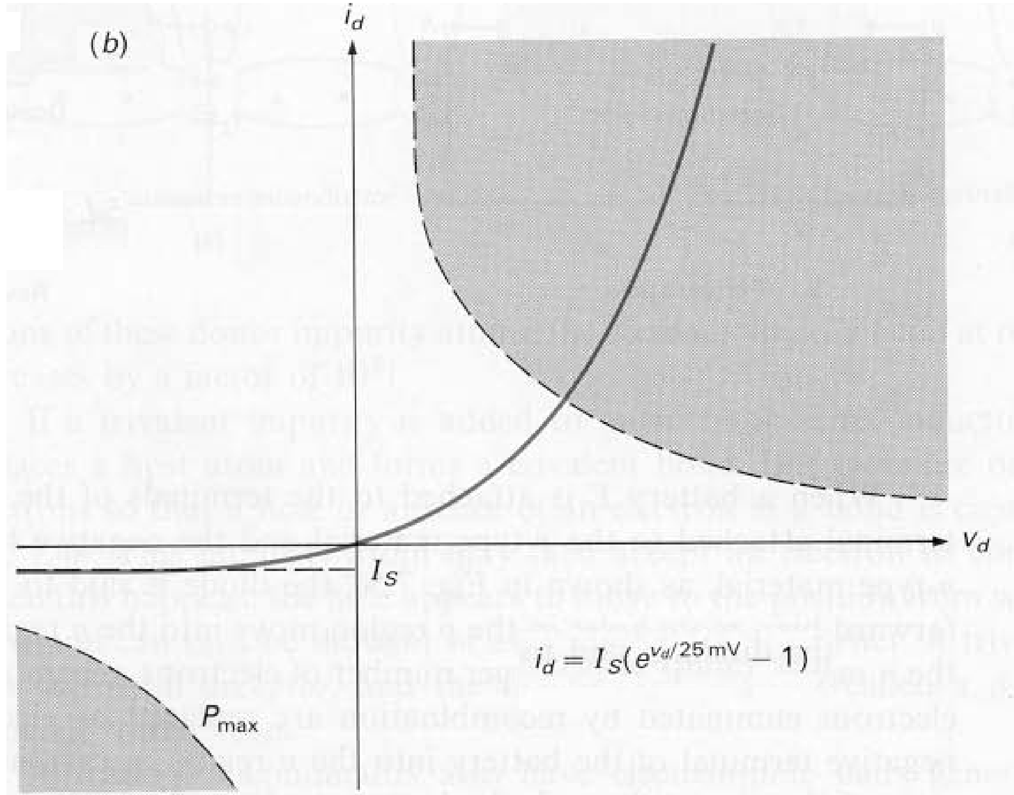
$$\frac{kT}{q} = 0.025\ \mathrm{V}$$

$$= 25\ \mathrm{mV}$$

Diode Characteristic

FIGURE
The terminal characterization of a semiconductor diode:
(a) circuit symbol;
(b) device characteristic;

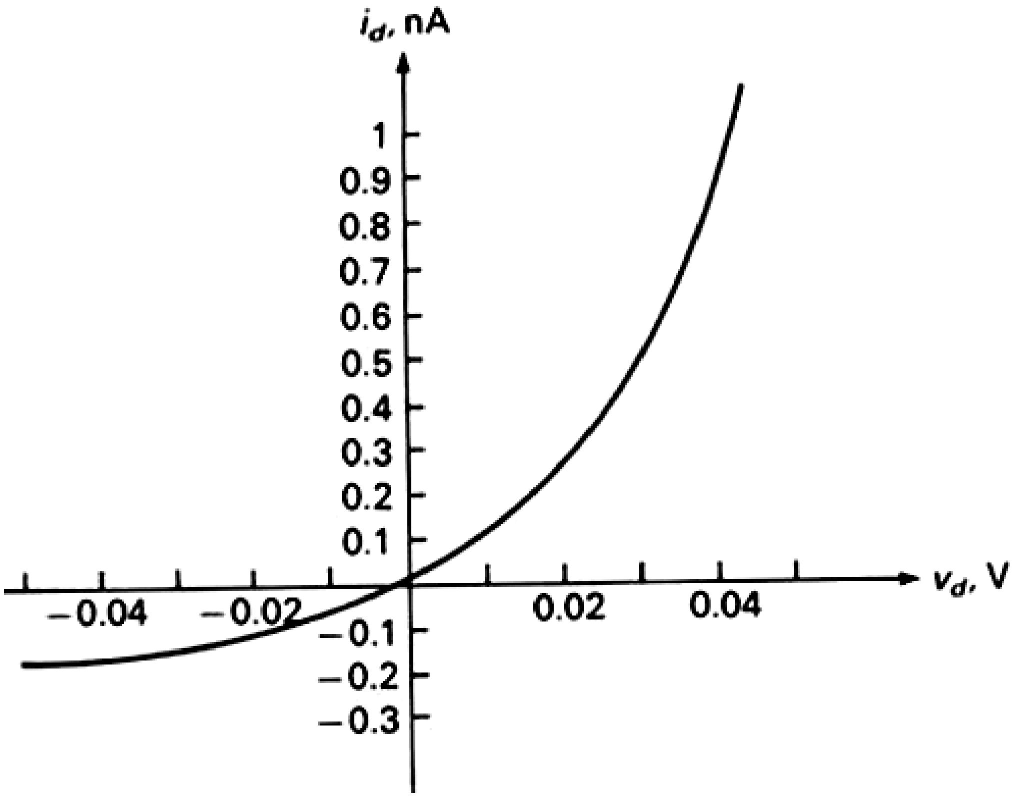


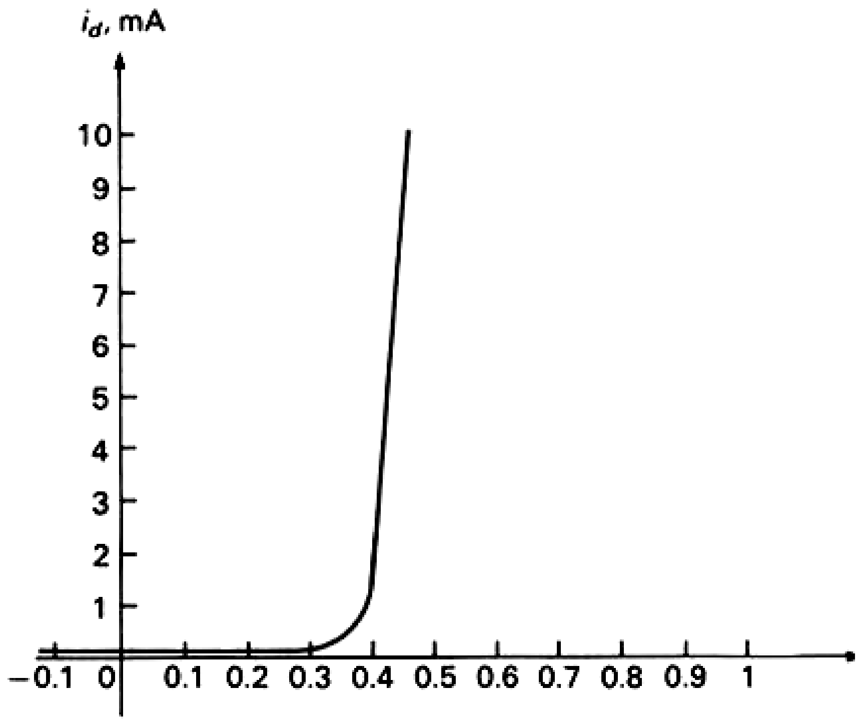


$$i_d = I_S(e^{v_d/25\,\text{mV}} - 1)$$

$$i_d \approx I_S e^{v_d/25\,\text{mV}} \qquad v_d \gg 25\,\text{mV}$$

Diode Characteristic at different scale





Diode Characteristic at different scale