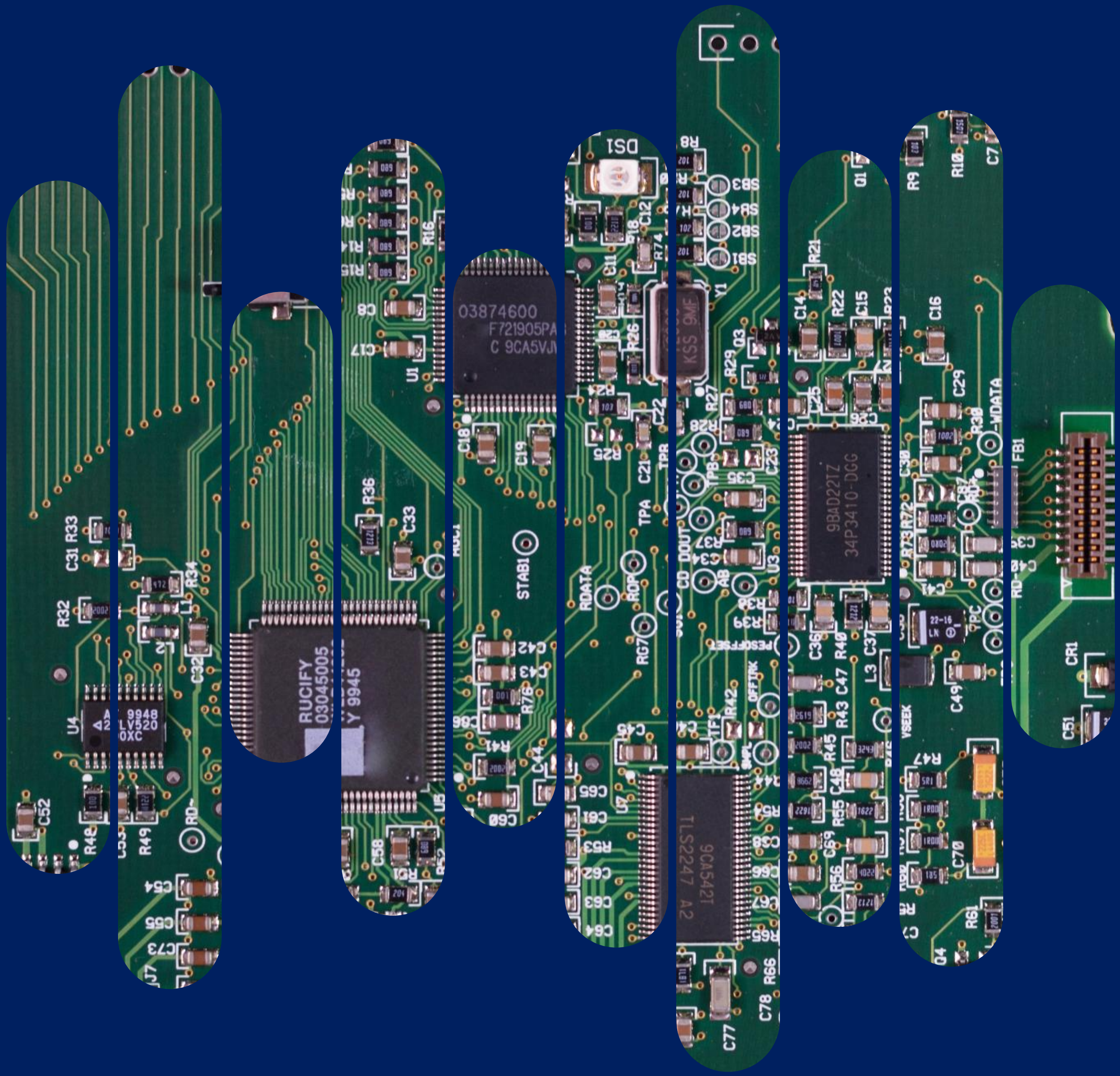
Electronic Devices



CHAPTER 1

Semiconductor Diode

Syllabus

1.1 Review of insulator, semiconductor and conductors

1.2 Conduction in semiconductors

1.3 Theory of pn junction

1.4 Forward and reverse biasing of diode

1.5 Diode as a nonlinear device

1.6 Ideal and piecewise linear model of diode

1.7 The effects of temperature in VI characteristics curves

1.8 Junction capacitances and its effects

1.9 Diode switching times

1.10 Junction breakdown

1.11 Construction, characteristics and application of Zener diode, Schottky diode

1.1 Review of insulator, semiconductor and conductors

Energy Bands in Solids

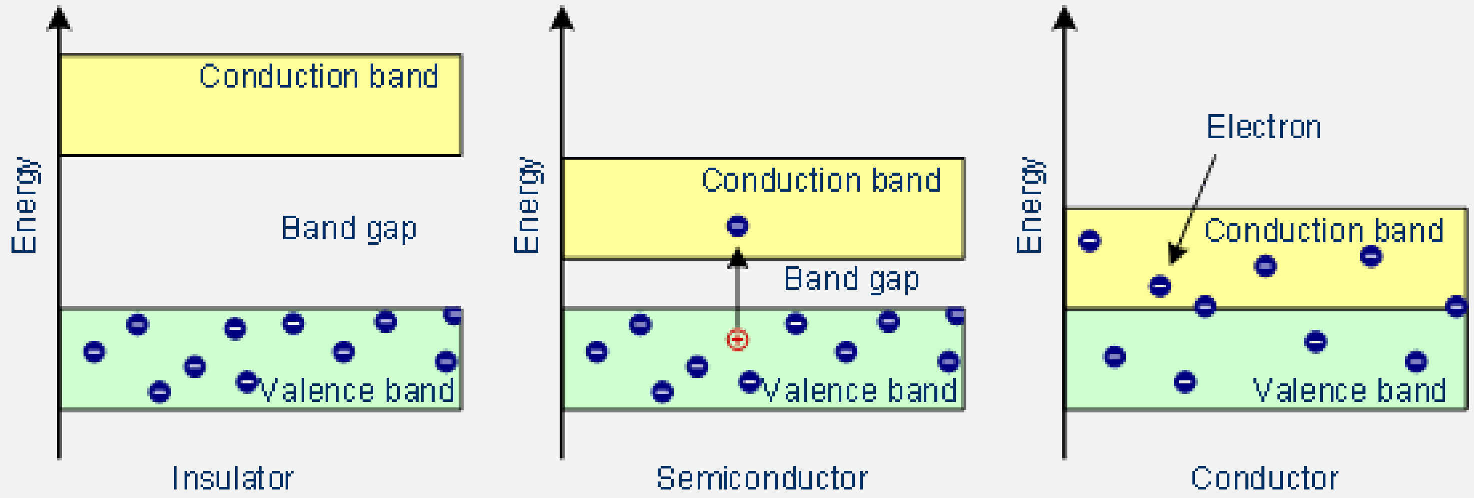
In solid materials, electron energy levels form bands of allowed energies, separated by forbidden bands.

Valence band: Outermost (highest) band filled with electrons (completely filled)
Conduction band: Next highest band to valence band (empty or partly filled)
Gap: Energy difference between valence and conduction bands (width of forbidden band)

- Electrons in a completely filled band cannot move, since all states occupied (Pauli principle).
- Only way to move would be to 'jump' into next higher band – needs energy.
- Electrons in partly filled band can move, since there are free states to move to

1.1 Review of insulator, semiconductor and conductors

Band structure

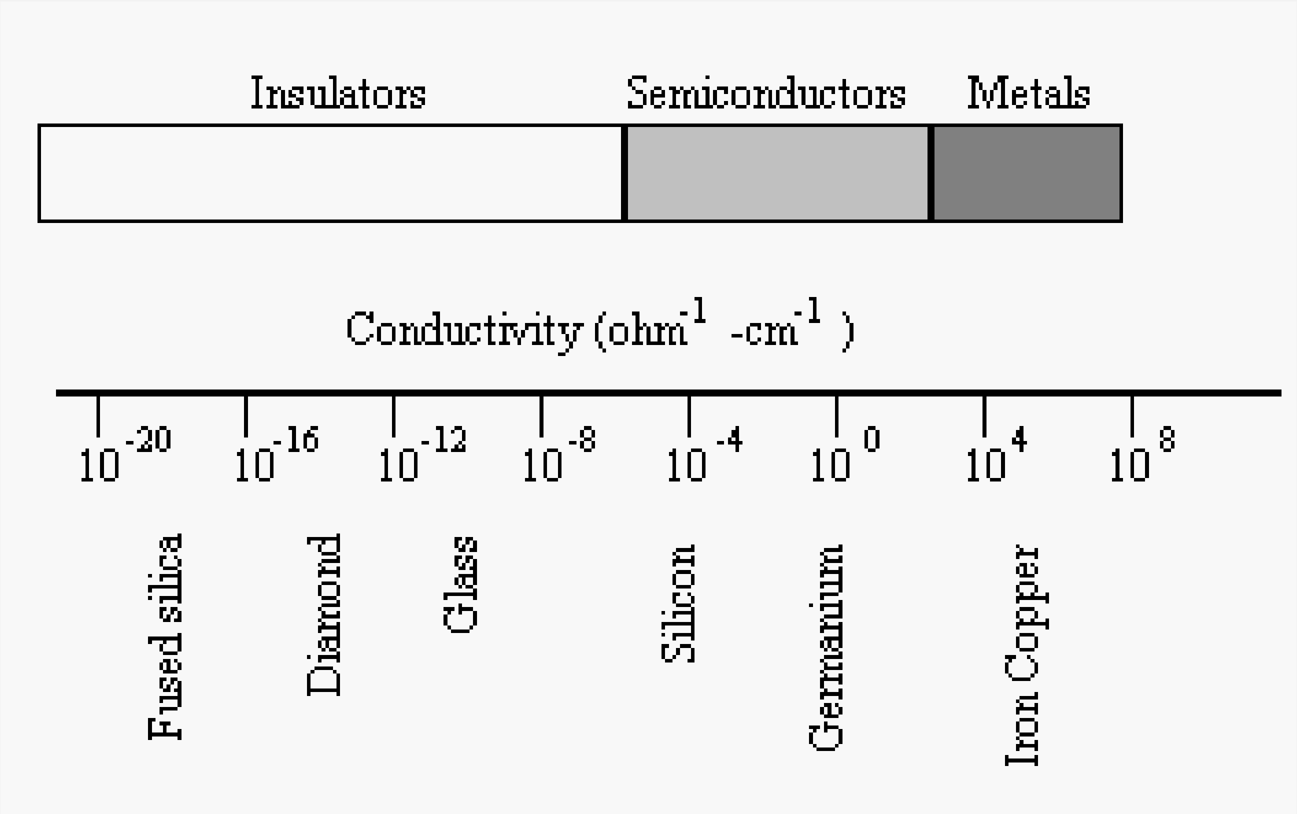


- Conductor: The valence and conduction bands overlap, so practically the energy gap is zero.
- Semiconductor: The energy gap between valance band and conduction band is very narrow, about 0.1 to 1 eV.
- Insulator: The energy gap between valence band and conduction band is very wide, about 3 to 6 eV.

1.2 Conduction in semiconductors

Conductivity

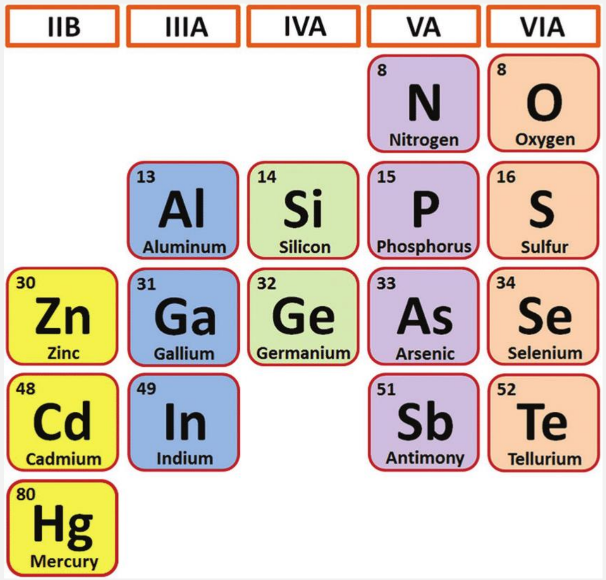
- The semiconductors fall somewhere midway between conductors and insulators
- Semiconductors have special electronic properties which allow them to be insulating or conducting depending on their composition.



1.2 Conduction in semiconductors

Semiconductors

- The energy gap is very small, and very little energy is needed to transfer electrons from the valance band into the conduction band.
- Even the thermal energy at room temperature is enough.
- By raising the temperature, more and more electrons will be transferred to the conduction band.
- The process results in an increase in conductivity with increase in temperature
- Examples are: germanium and silicon

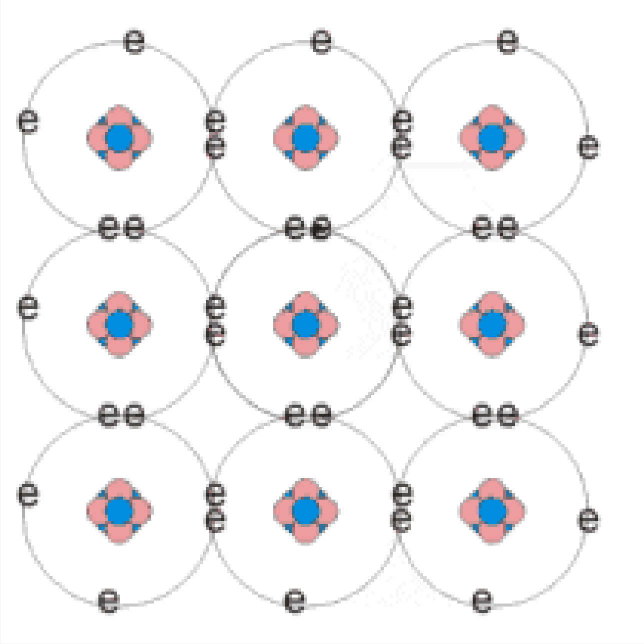


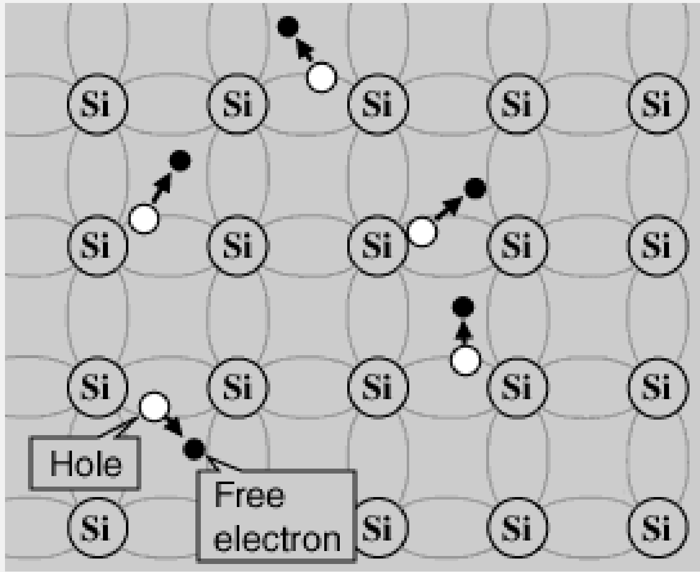
- Intrinsic or pure semiconductor
- Extrinsic or impure semiconductor
  1. P-type
  2. N-type

1.2 Conduction in semiconductors

Intrinsic Semiconductor

- A silicon crystal is different from an insulator.
- Four electrons of outermost orbit of silicon combine with other four silicon atoms.
- At any temperature above absolute zero temperature, there is finite probability that an electron in the lattice will be knocked loose from its position.
- The electron in the lattice knocked loose from its position leaves behind an electron deficiency called a hole.





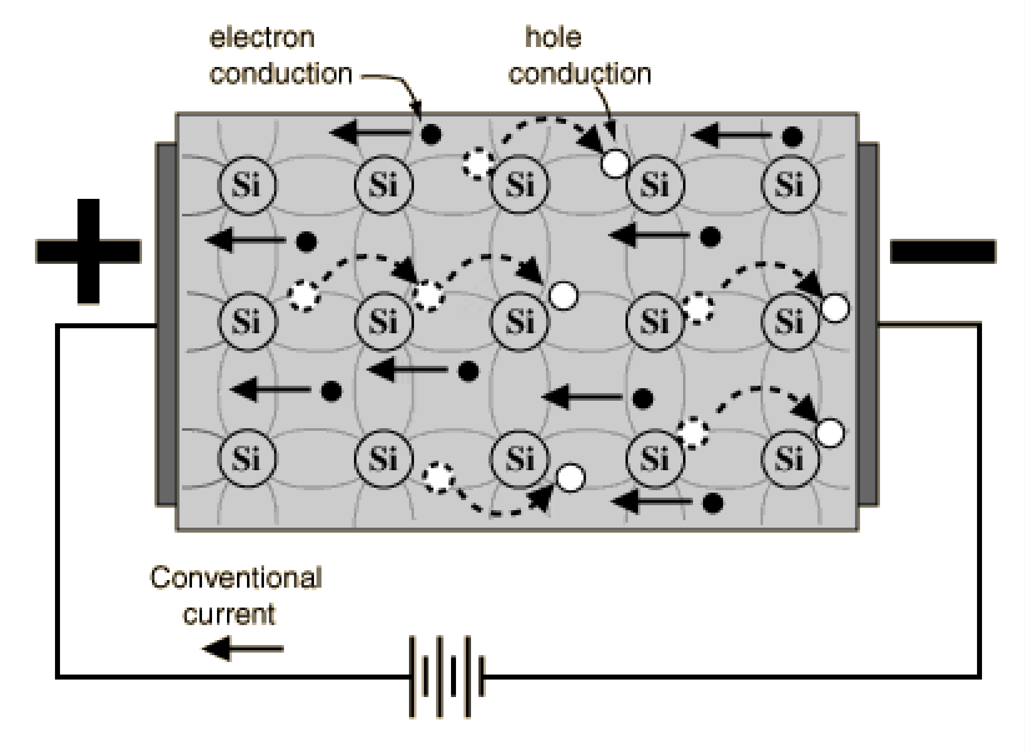
1.2 Conduction in semiconductors

Intrinsic Semiconductor

- If a voltage is applied, then both the electron and the hole can contribute to a small current flow.
- Current density of semiconductor is given by,

$$J_x = \sigma E_x = e(n\mu_e + p\mu_h)E_x$$

- Where, σ is conductivity
- E_x is electrical field
- μ_e and μ_h are electron mobility and hole mobility



1.3 Theory of PN junction

PN junction diode is a device that is formed by joining p-type semiconductor with n-type semiconductor and separated by thin junction is called PN junction.

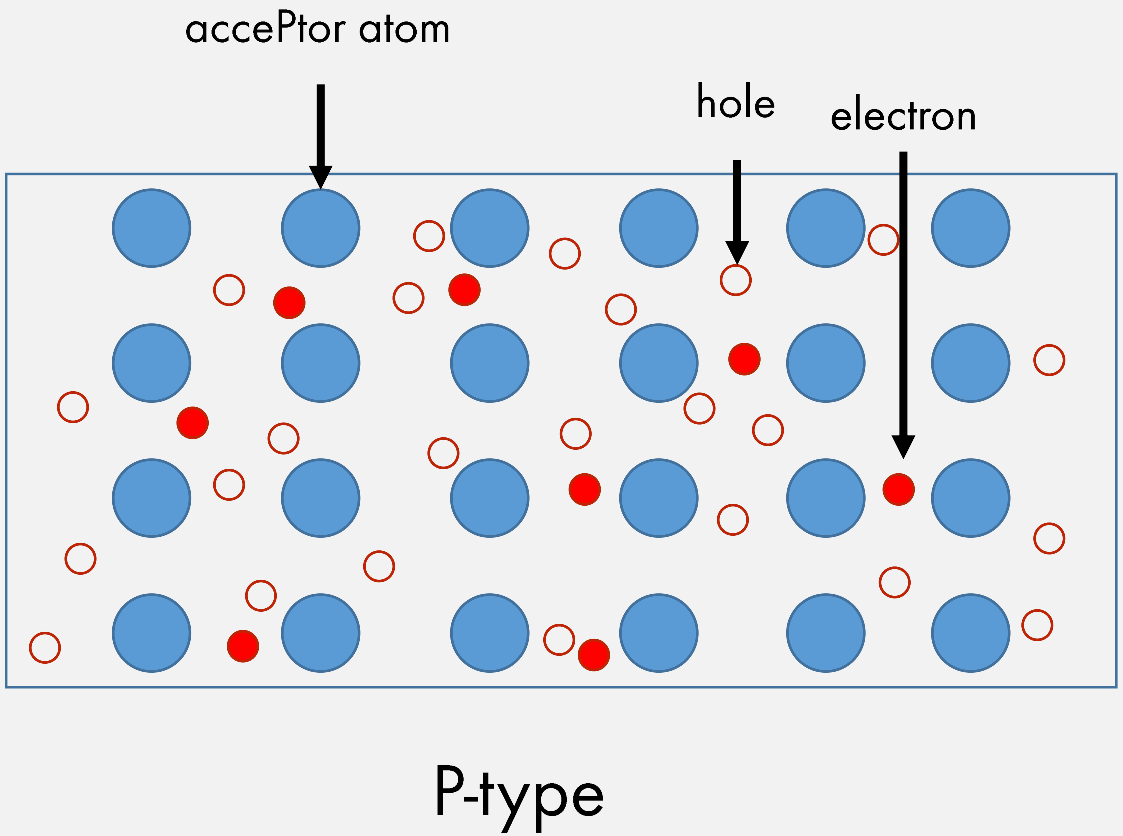
P-type semiconductor

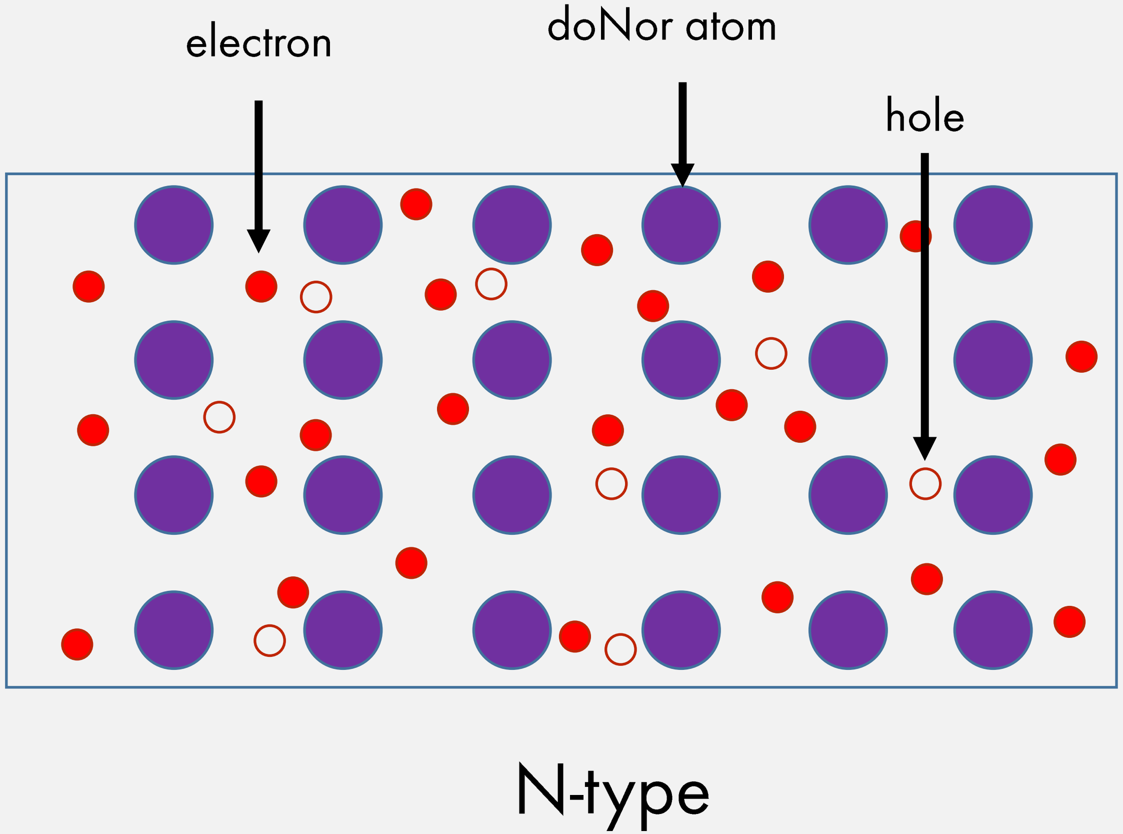
When intrinsic semiconductor is doped with trivalent impurity such as aluminum, gallium, Indium, boron
Majority charge carriers are holes
Trivalent impurities are called accePtor.

N-type semiconductor

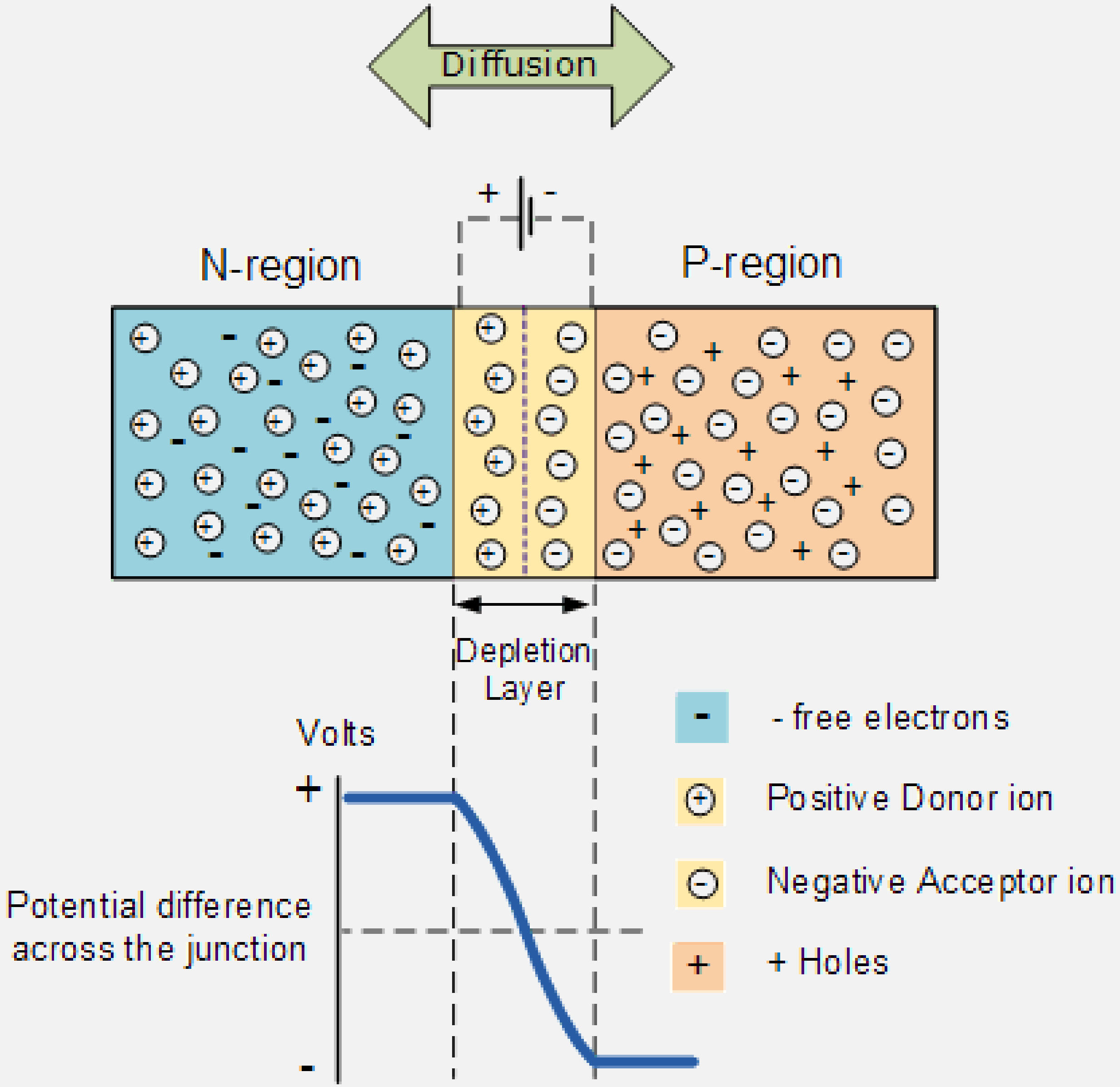
When intrinsic semiconductor is doped with pentavalent impurity such as phosphorus, arsenic
Majority charge carriers are electrons
Pentavalent impurities are called doNor

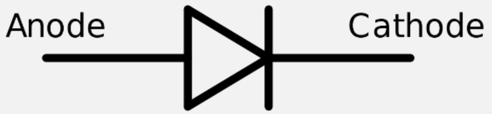
1.3 Theory of PN junction





1.3 Theory of PN junction





1.3 Theory of PN junction

$$Current\ in\ diode\ (I_D) = \ I_s(e^{V/\eta V_T} - 1)$$

$I_s = Reverse\ saturation\ current,$ doubles with every 10^0C

$$V = Applied\ Voltage$$

$$\eta = ideality\ factor, (1 \leq \eta \geq 2)$$

$V_T = Thermal\ Voltage$ which is 26mV at 25^0C

The reverse saturation current of diode is 5nA at 25^0C. Find reverse saturation current at 125^0C

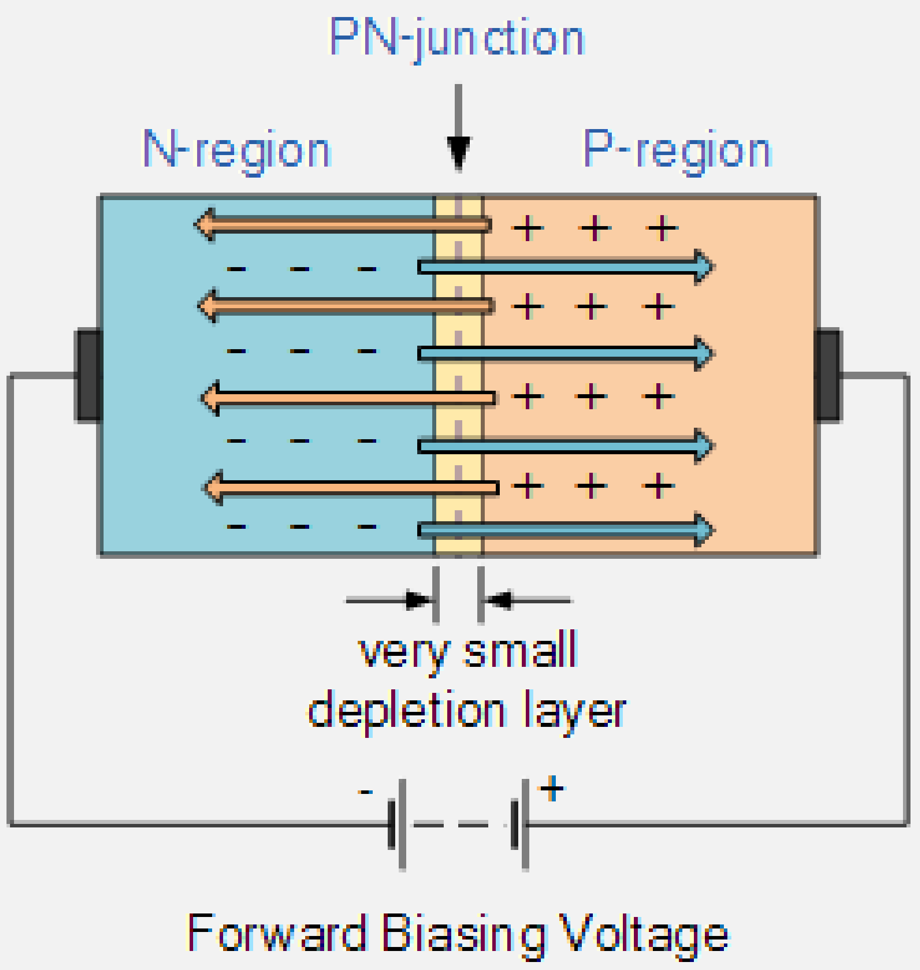
The reverse saturation current of diode is 2nA at 25^0C. At what temperature the current be 512nA?

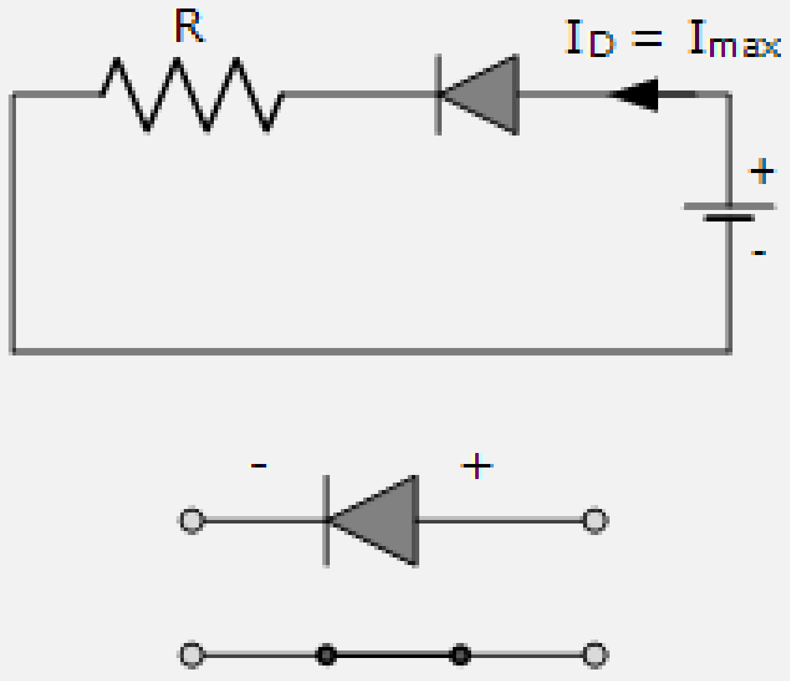
PN junction diode can work as insulator?

What happens to potential barrier when reverse biased?

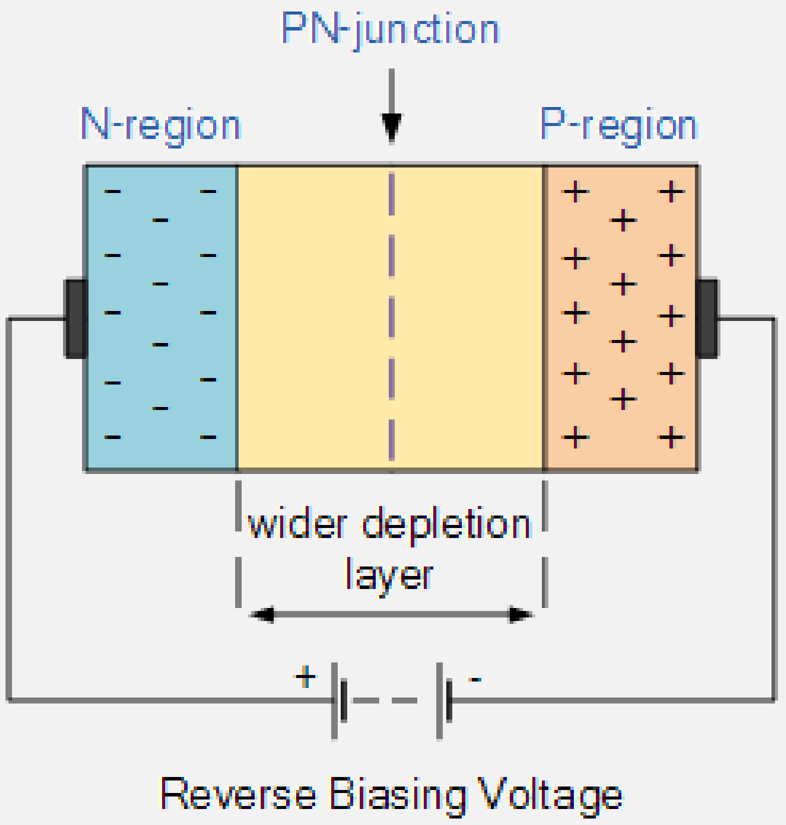
How is the electrical resistance of depletion layer?

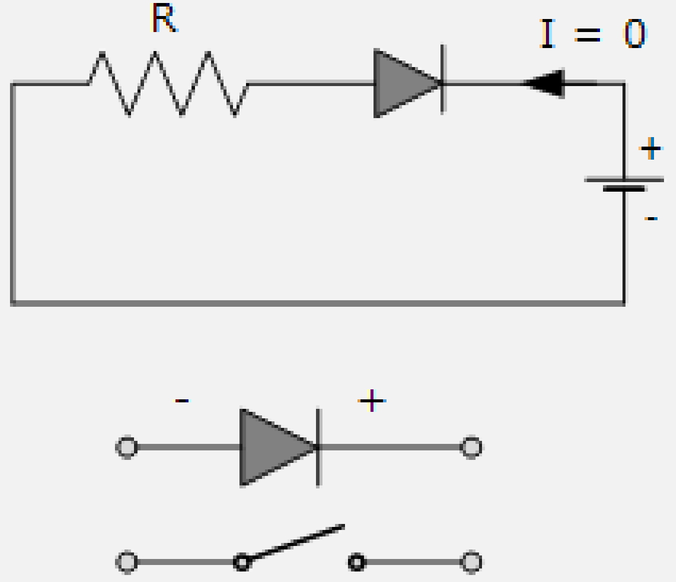
1.4 Forward and Reverse biasing of diode



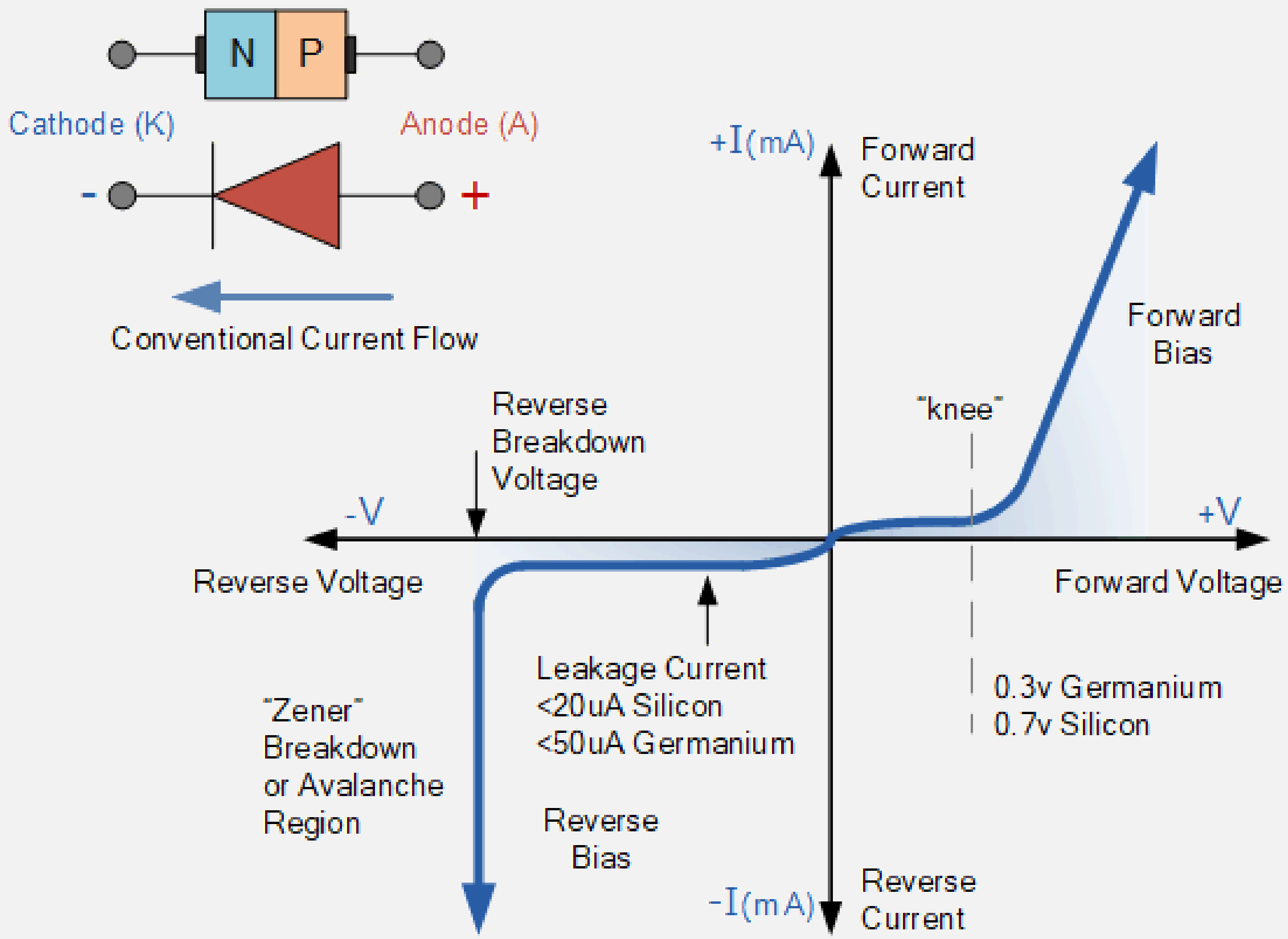


1.4 Forward and Reverse biasing of diode





1.5 Diode as a non-linear device

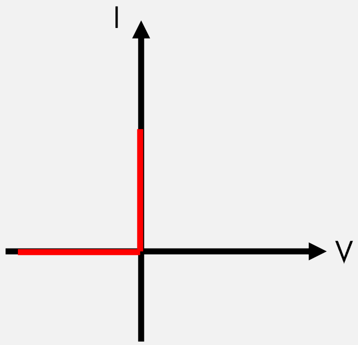


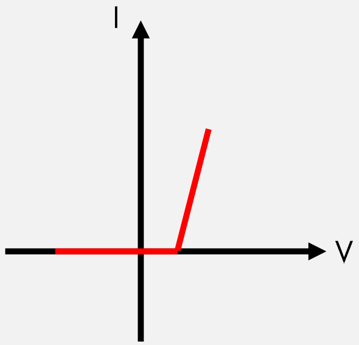
What happens when the concentration of doped molecules are different in p-type and n-type semiconductor?

What happens when forward biased diode is suddenly reverse biased?

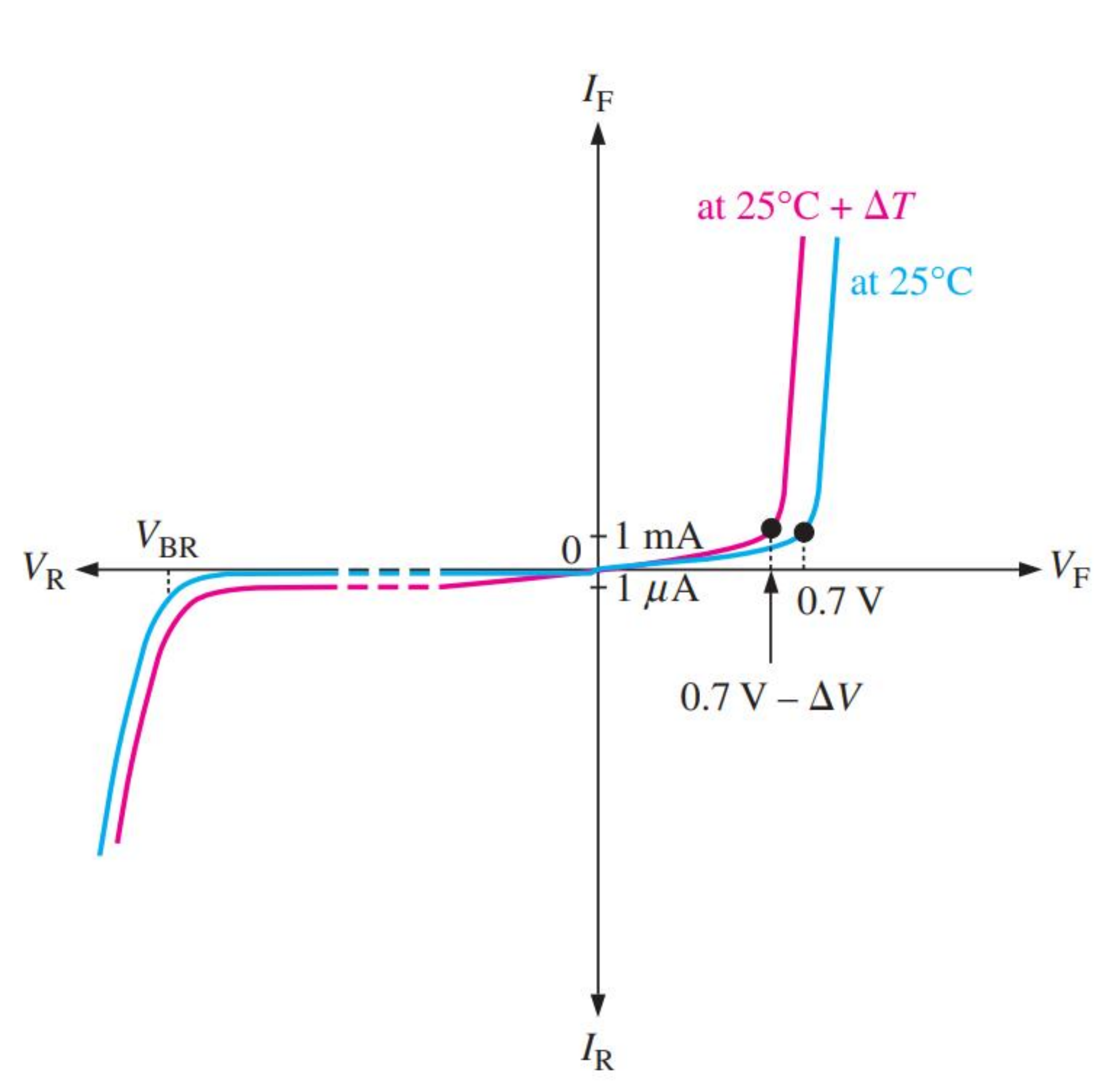
What is the peak reverse voltage of a diode?

1.5 Ideal and piecewise linear model of diode





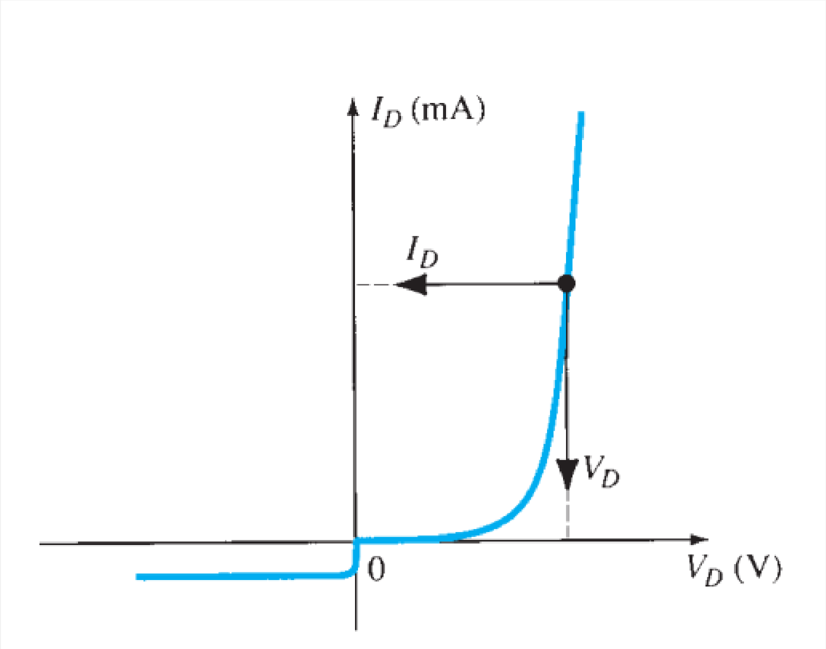
1.6 Effects of temperature in VI characteristic curves

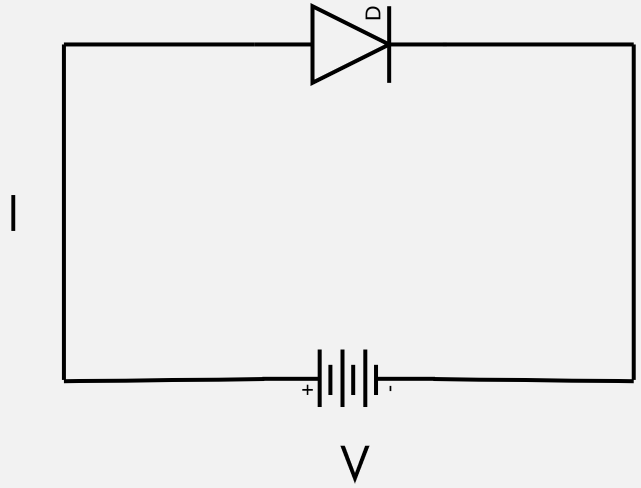


1.8 Junction capacitances and its effects

Diode Resistance

Static Resistance (DC resistance)



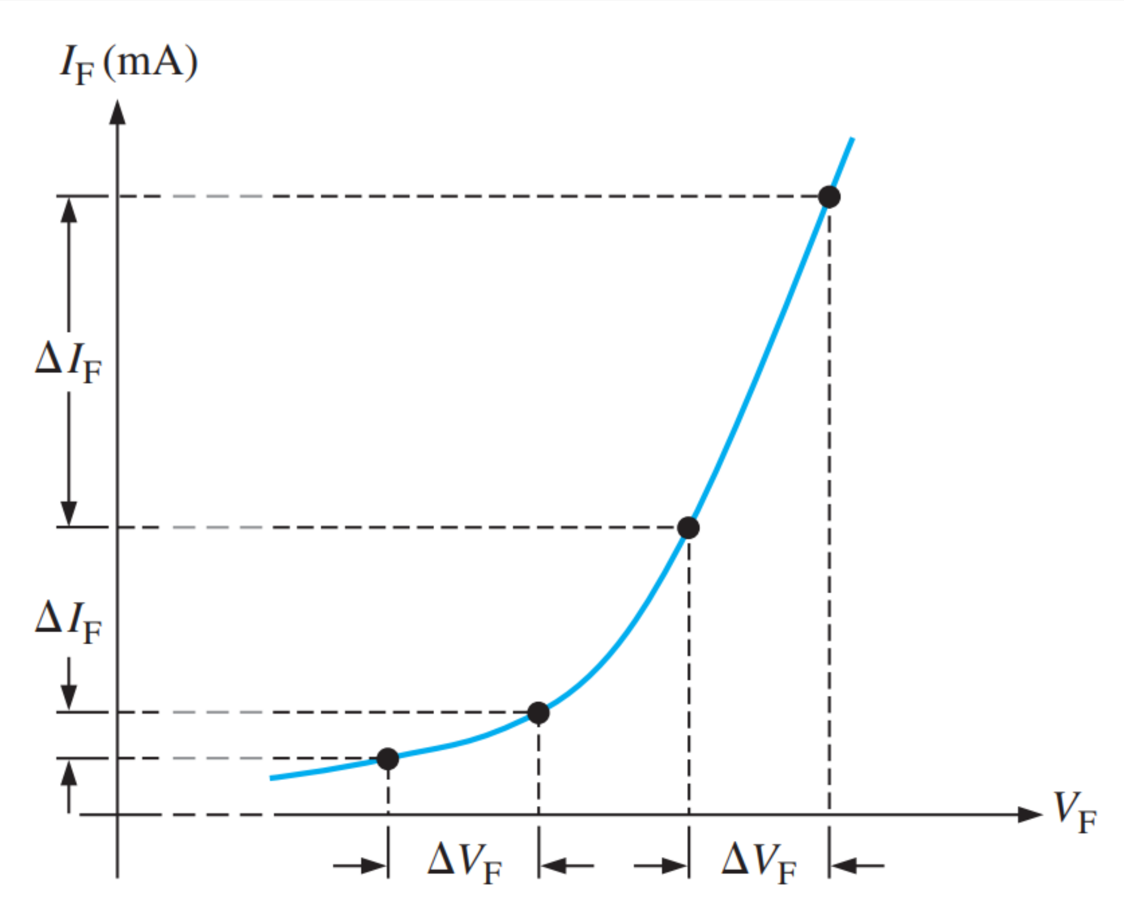


$$R_{DC} = \frac{V_D}{I_D}$$

1.8 Junction capacitances and its effects

Diode Resistance

Dynamic Resistance (AC resistance)



$$r_{ac} = \frac{\Delta V_F}{\Delta I_F}$$

$$I = I_s(e^{V/\eta V_T} - 1)$$

$$\frac{dI}{dV} = I_s \times \frac{1}{\eta V_T} \times e^{V/\eta V_T}$$

$$\frac{dI}{dV} = \frac{I}{\eta V_T} \qquad \frac{dV}{dI} = \frac{\eta V_T}{I}$$

1.8 Junction capacitances and its effects

Diode Capacitance

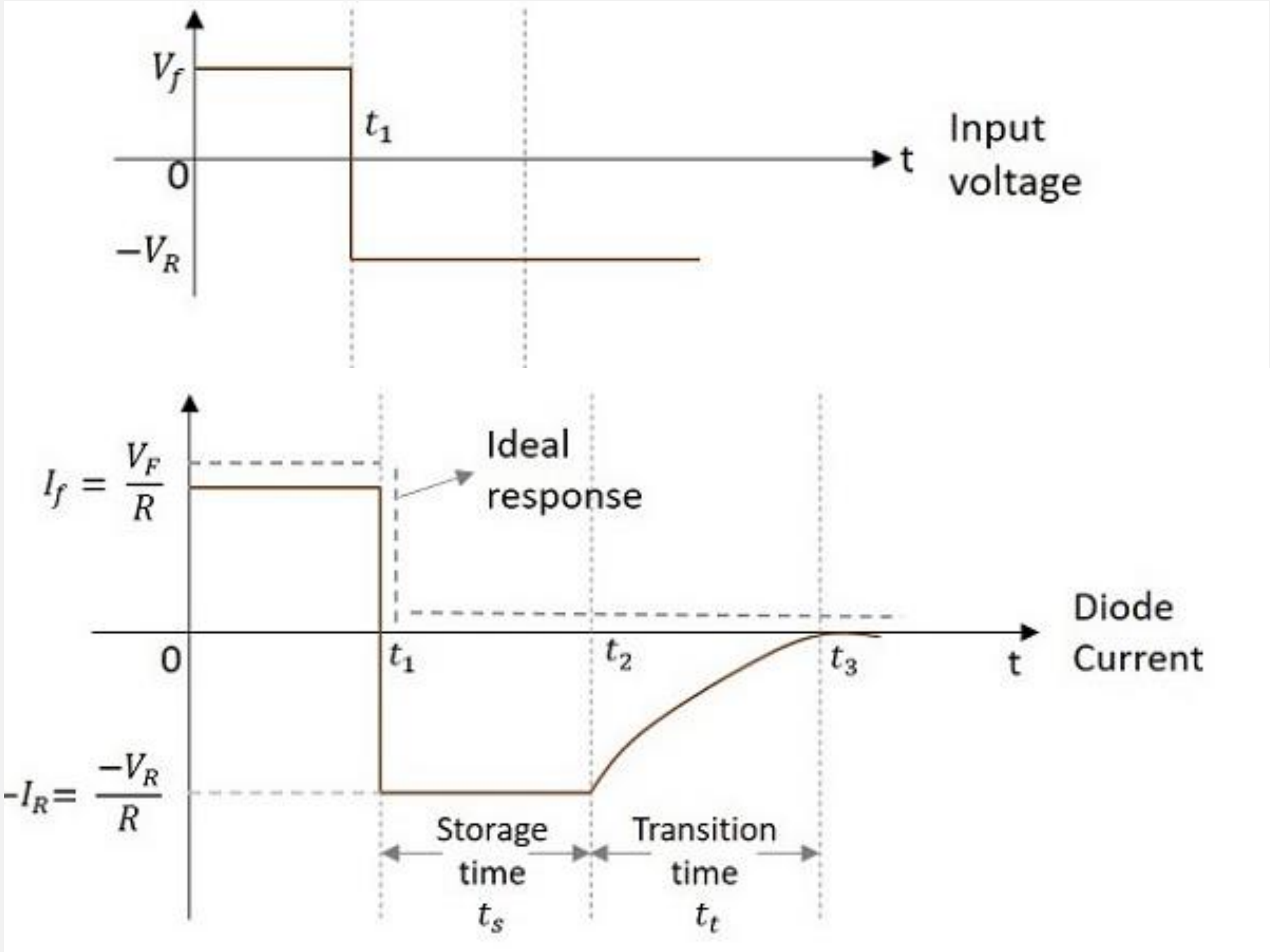
Transition Capacitance

A reverse biased p-n junction diode also stores electric charge at the depletion region. The ability of a material to store electric charge is called capacitance. Thus, there exists a capacitance at the depletion region known as transition capacitance.

Diffusion Capacitance

A large number of charge carriers, which try to move into another region will be accumulated near the depletion region before they recombine with the majority carriers. As a result, a large amount of charge is stored at both sides of the depletion region.

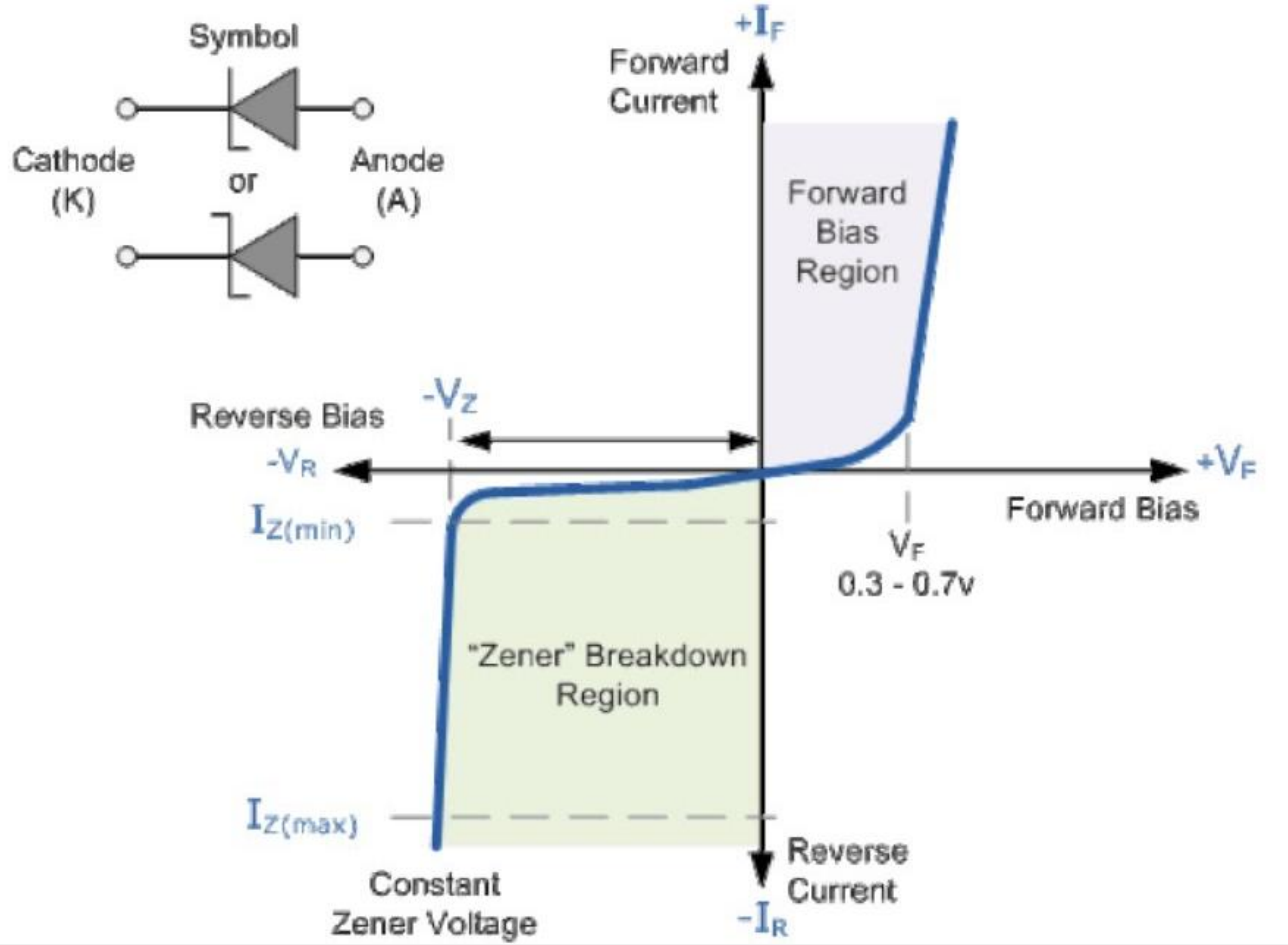
1.9 Diode switching times



1.10 Junction breakdown

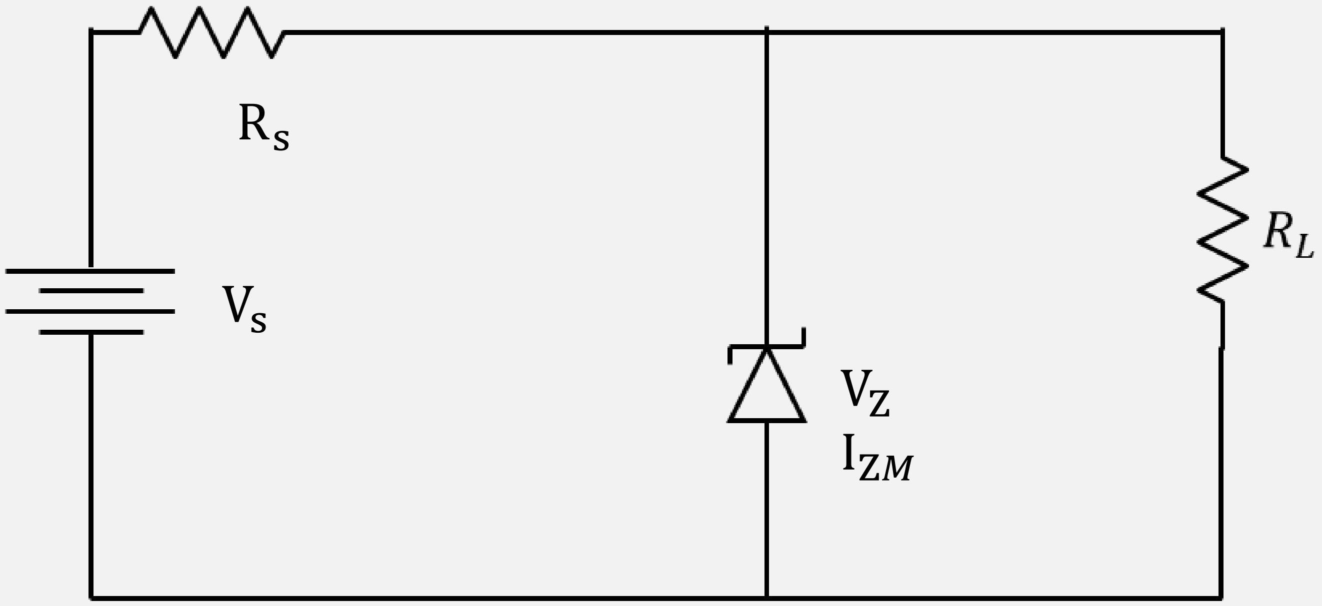
Avalanche Breakdown	Zener Breakdown
Junction with wide depletion widths	Junction with narrow depletion width
Higher reverse voltages is required	Needs to rupture covalent bond
Above 6V breakdown voltage is required	Zener effect is also possible below 6V

1.11 Zener diode



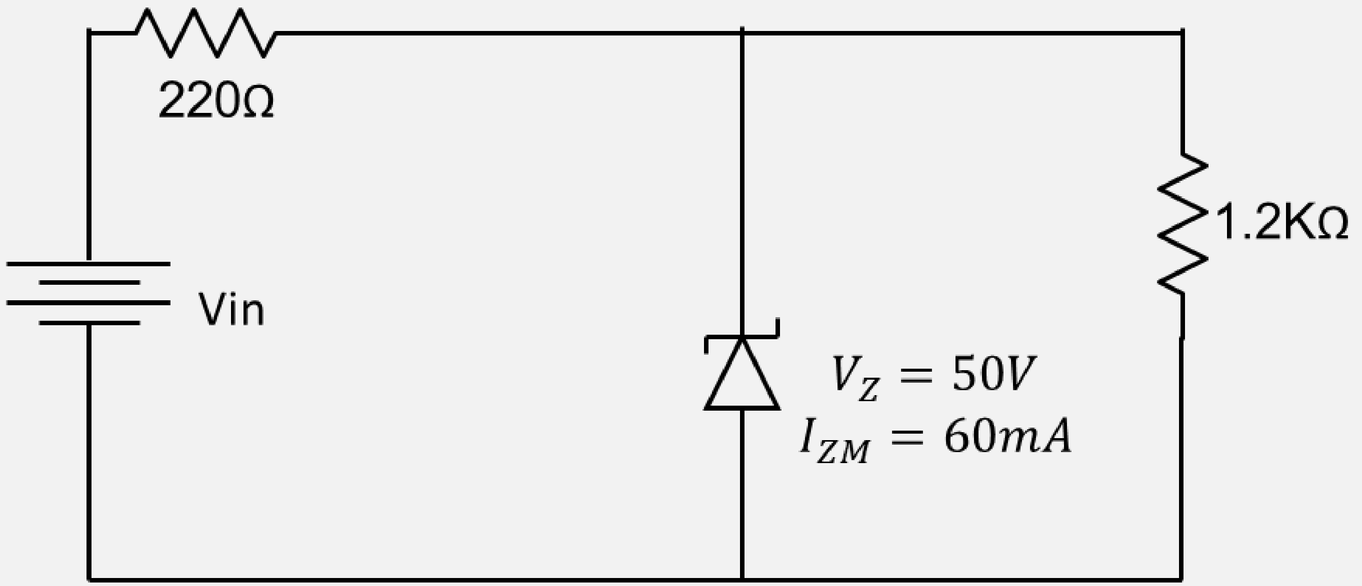
1.11 Zener diode

$$V = \frac{R_L}{R_L + R_S} \times V_S \qquad I = \frac{V_s - V_Z}{R_S} \qquad I_L = \frac{V_L}{R_L}$$



1.11 Zener diode

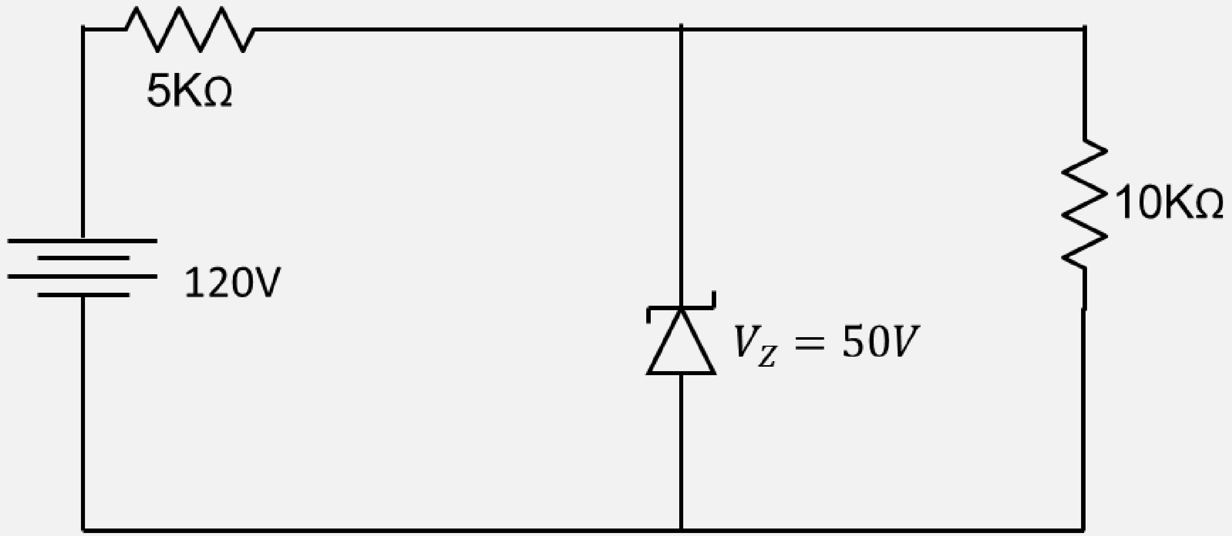
Determine the range of values of Vin that will maintain the Zener diode in the ON state. Also find the maximum power that can be dissipated to the diode.



1.11 Zener diode

For the circuit shown in figure below find

- The output voltage
- Voltage drop across series resistance
- Current through Zener diode



Solution:

Let's assume there is no diode

$V = \frac{10}{10+5} \times 120 = 80V$

Since, V=80V the diode is on.

Therefore, output voltage is 50V.

Voltage across series resistance = 120-50 = 70V

Current across series resistance = $70 \div 5000 = 1.4mA$

Current across load resistance = $50 \div 10000 = 0.5mA$

Current across Zener diode = $1.4 - 0.5 = 0.9mA$

1.11 Zener diode

Design a Zener diode voltage regulator circuit that has output voltage of 10V and 100mA current output.

Available circuit elements:
Resistors of 1K and 500ohms
Zener diode of rating 5V/200mA
Wires
Output of power supply is 1A at 30VDC

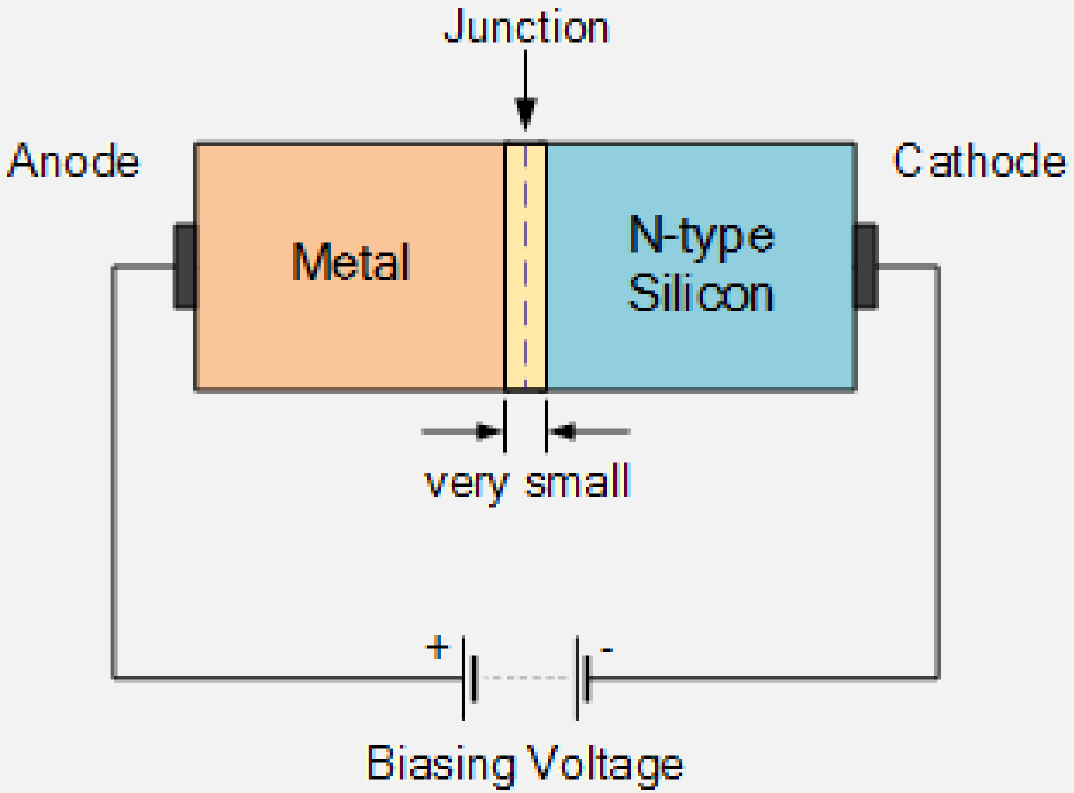
1.11 Zener diode

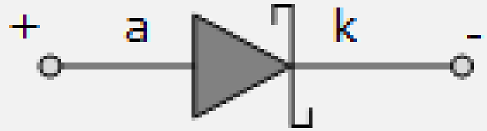
Design a Zener diode voltage regulator circuit that has output voltage of 10V and 150mA current output.

Available circuit elements:
Resistors of 100ohms and 200ohms
Zener diode of rating 5V/150mA
Wires
Output of power supply is 1A at 30VDC

1.12 Schottky Diode

Schottky diode offers fast switching action and has a low forward voltage drop.





Symbol