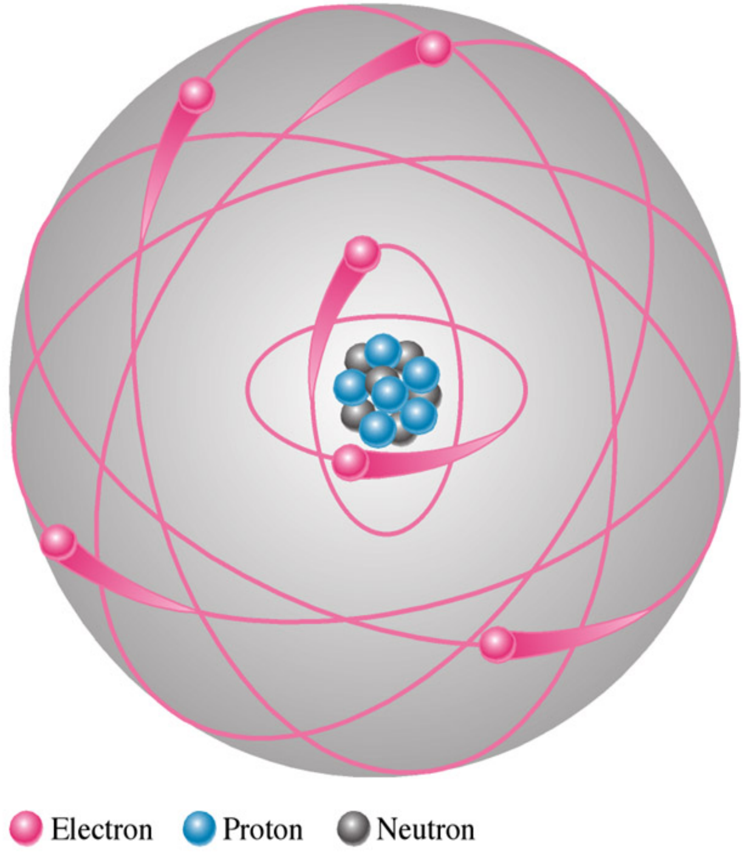
INTRODUCTION TO SEMICONDUCTOR PHYSICS

OBJECTIVES

- ➢Discuss the basic structure of atoms
- ➢Discuss properties of insulators, conductors, and semiconductors
- ➢Discuss covalent bonding
- ➢Describe the properties of both p and n type materials
- ➢Discuss both forward and reverse biasing of a p-n junction
- ➢Discuss basic operation of a diode

L1 SEC-A
RUTHERFORD MODEL OF AN ATOM



CONDUCTORS, INSULATORS, AND SEMICONDUCTORS

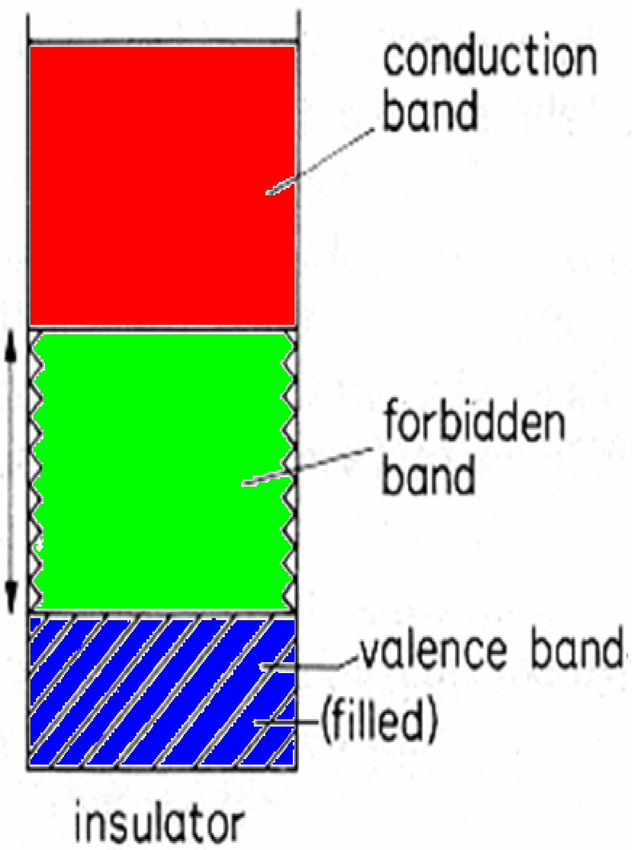
Elements

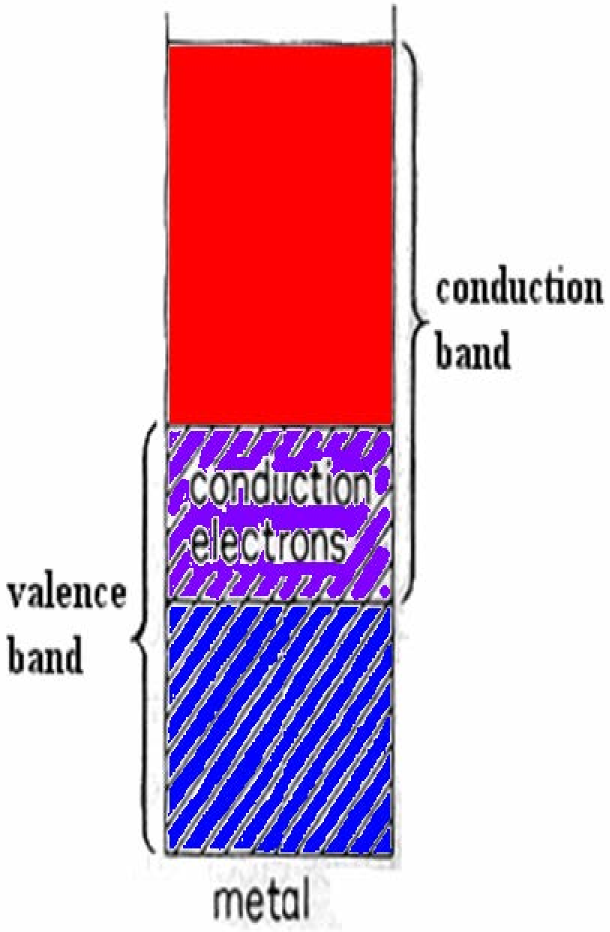
- Elements in the periodic table are grouped by the number of electrons in their valence shell (most outer shell).
  - Conductors – Valence shell is mostly empty (1 electron)
  - Insulators – Valence shell is mostly full
  - Semiconductors – Valence shell is half full.

(Or is it half empty?)

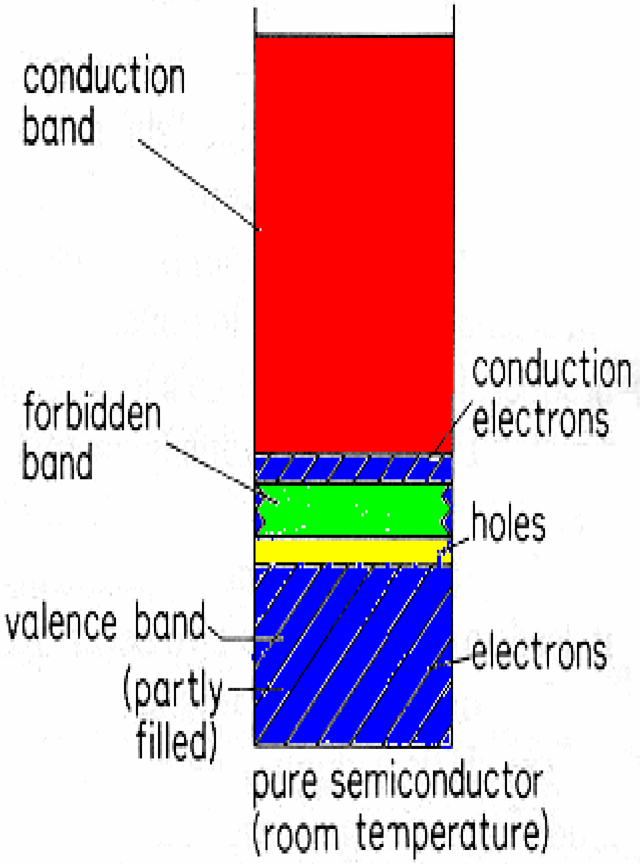
ENERGY BANDS

L3 SEC-A
ENERGY BANDS IN INSULATORS & CONDUCTORS





CONTD……ENERGY BANDS IN SEMICONDUCTORS



Forbidden band small for semiconductors.

Less energy required for electron to move from valence to conduction band.

L4 SEC A

Insulators

- Elements that have a large energy band gap of 3 to 6 eV are insulators because at room temperature, essentially no free electrons exist.
- Note: an eV is an electron volt. It is the amount of energy an electron will gain if it accelerated through a 1 volt potential

Conductors

Elements that have a small energy band gap are conductors.

- These elements have a large number of free electrons at room temperature because the electrons need very little energy to escape from their covalent bonds.

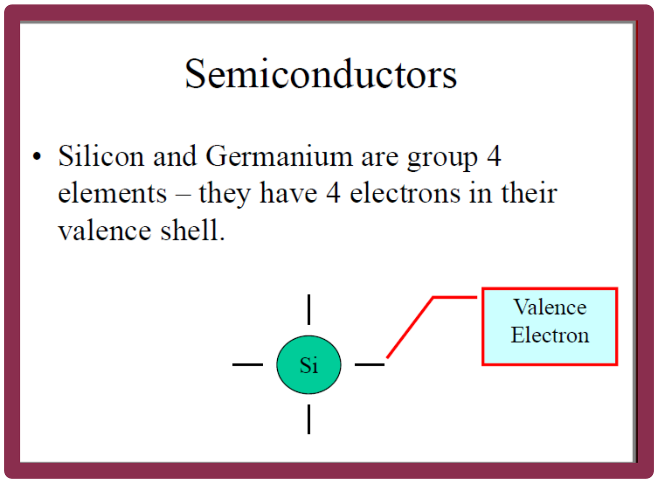
SEMICONDUCTORS

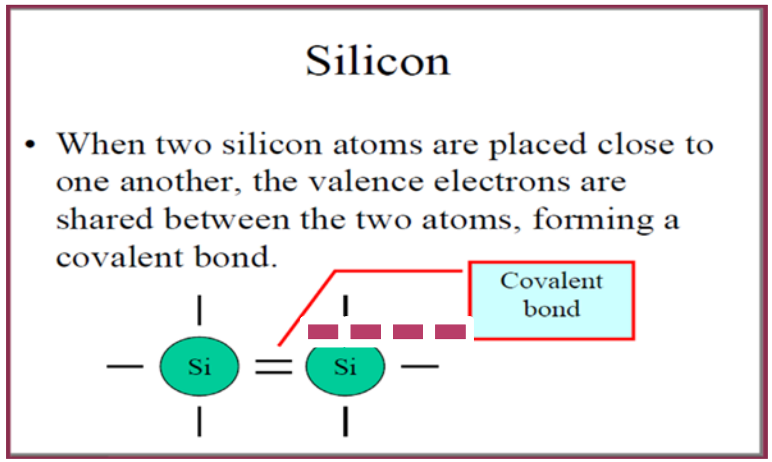
Semiconductors are materials whose electrical conductivities are higher than those of insulators but lower that those of conductors.

- Silicon, Germanium, Gallium, Arsenide, Indium, Antimony and cadmium sulphide are some commonly used semiconductors.

- Semiconductors have negative temperature coefficients of resistance, i.e. as temperature increases resistivity decreases.

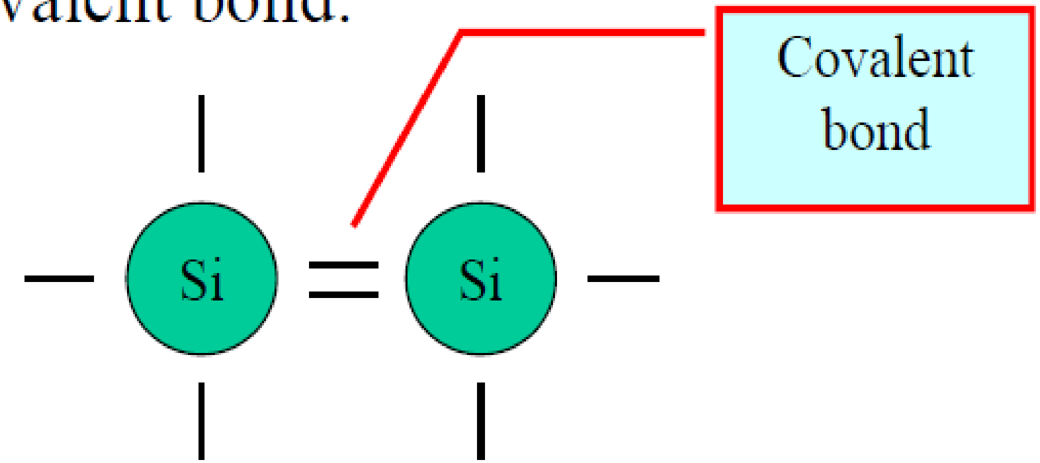
CONTD… EXAMPLE





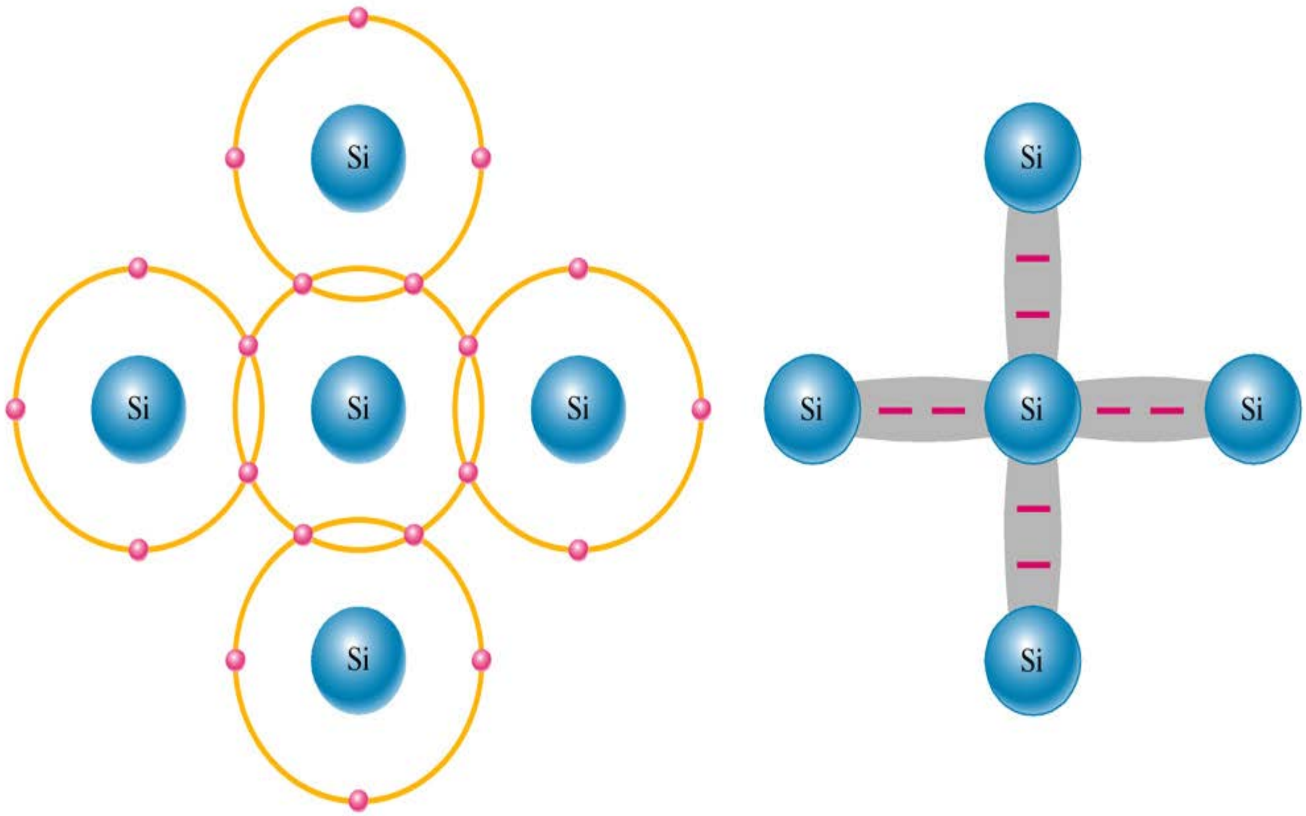
Silicon

- When two silicon atoms are placed close to one another, the valence electrons are shared between the two atoms, forming a covalent bond.



COVALENT BONDING

Covalent bonding is a bonding of two or more atoms by the interaction of their valence electrons.



Semiconductors

- Semiconductors have a band gap energy of about 1 eV
  - Silicon = 1.1 eV
  - GaAs = 1.4 eV
  - Ge = 0.66 eV

Empty States

- An electron that has sufficient energy and is adjacent to an empty state may move into the empty state, leaving an empty state behind.

DRIFT AND DIFFUSION CURRENT

- DRIFT CURRENT : Due to external electric field, the electrons are accelerated in one particular direction. They travel at a speed equal to drift speed.the movement of current will give rise to current which ius known as drift current.

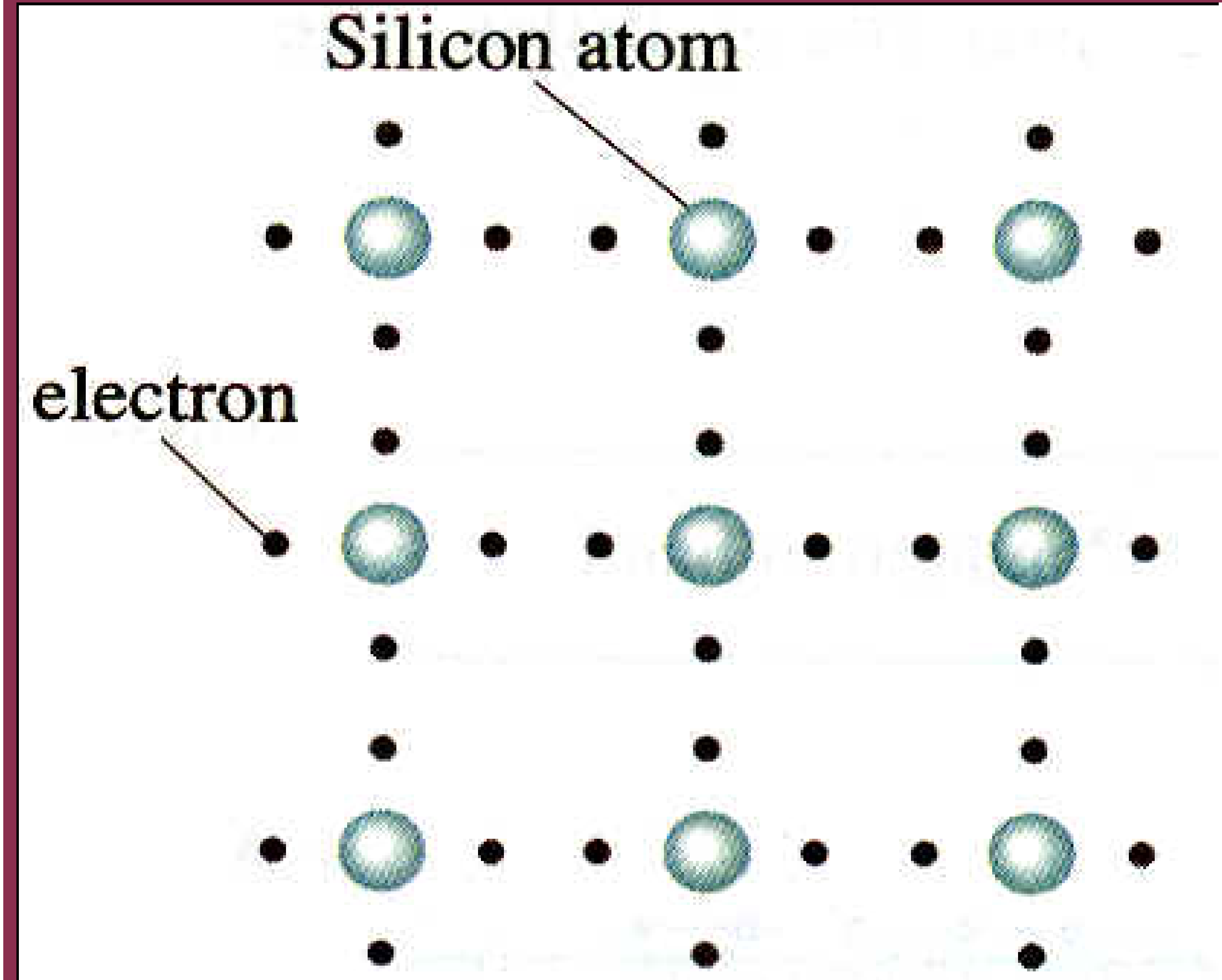
- DIFFUSION CURRENT : Due to non-uniform concentration of particles charge carriers move from high concentration to low concentration. transport of charges is coz of current.

TYPES OF SEMICONDUCTORS

- INTRINSIC SEMICONDUCTORS (PURE)
- EXTRINSIC SEMICONDUCTORS (IMPURE)

Intrinsic Semi–conductor

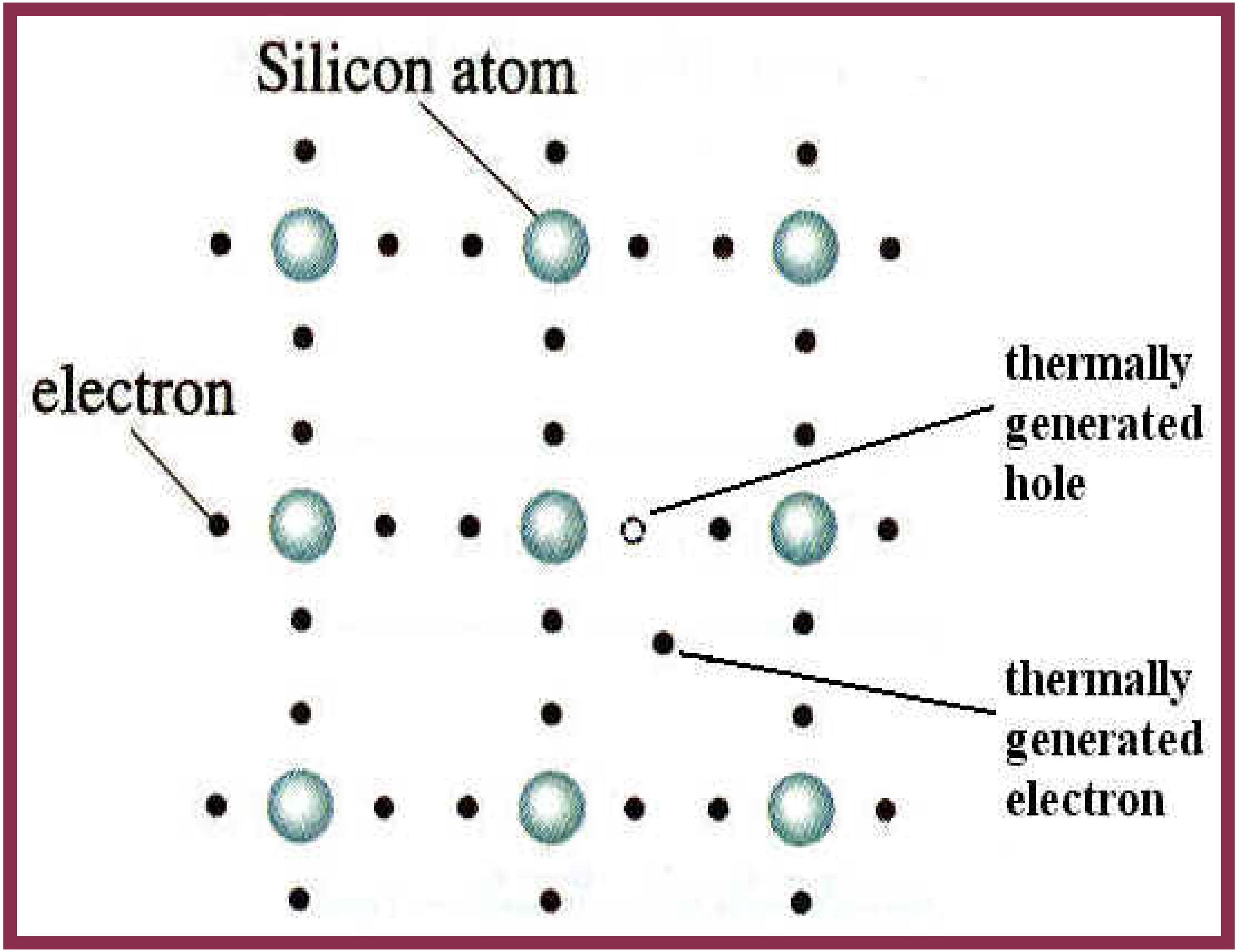
- Definition – An **intrinsic semiconductor** is a single crystal semiconductor with no other types of atoms in the crystal.
  - Pure silicon
  - Pure germanium
  - Pure gallium arsenide.


Silicon atom
electron

INTRINSIC SEMICONDUCTOR

At temperatures above zero Kelvin some of the valence electrons are able to break free from their bonds to become free conduction electrons.

Formation of Electron and hole pairs in intrinsic semiconductor



Extrinsic Semiconductors

- Since the concentrations of free electrons and holes is small in an intrinsic semiconductor, only small currents are possible.
- Impurities can be added to the semiconductor to increase the concentration of free electrons and holes.

DIFFERENCE BETWEEN INTRINSIC AND EXTRINSIC SEMICONDUCTOR

- PURE
- NO DOPING
- NO OTHER TYPE
- ELECTRONS=HOLES
- INSULATOR
- FERMI LEVEL AT THE CENTRE
- LESS APPLICATIONS
- REGULAR SHAPE
- NATURAL

- IMPURE
- DOPING
- TWO TYPES-n & p
- ELECTRONS≠ HOLES
- High CONDUCTIVITY
- NOT IN CENTRE
- FOR MANUFACTURING ELECTRONICS COMPONENTS
- IRREGULAR SHAPE
- MANMADE

DOPING

The electrical characteristics of Silicon and Germanium are improved by adding materials in a process called doping.

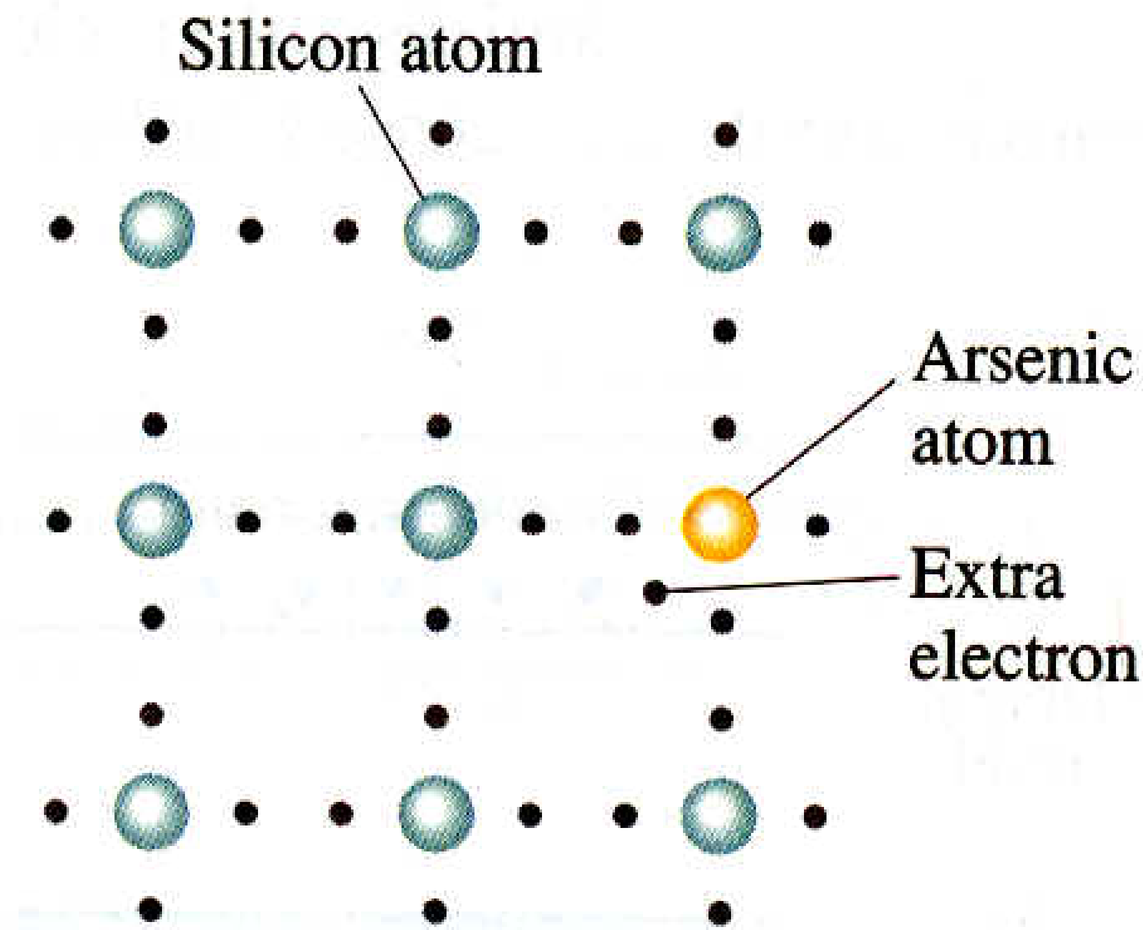
The additional materials are in two types:

- n-type or donor
- p-type or acceptor

N-TYPE EXTRINSIC SEMICONDUCTOR

Arsenic has 5 valence electrons, however, only 4 of them form part of covalent bonds. The 5th electron is then free to take part in conduction.

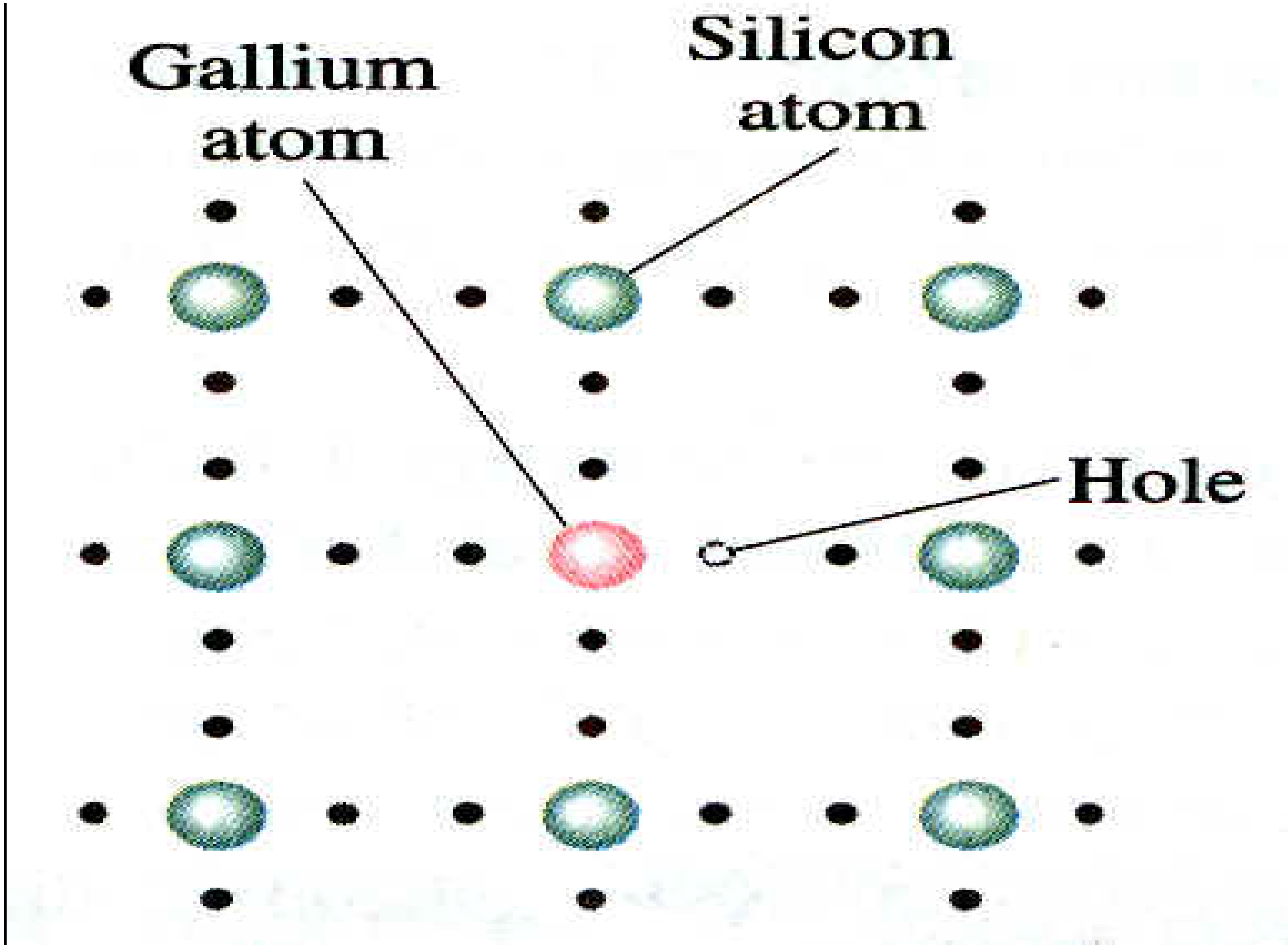
The electrons are said to be the majority carriers and the holes are said to be the minority carriers.


Silicon atom
Arsenic
atom
Extra
electron

P-TYPE EXTRINSIC SEMICONDUCTOR

Gallium has 3 valence electrons, however, there are 4 covalent bonds to fill. The 4^{th} bond therefore remains vacant producing a hole.

The holes are said to be the majority carriers and the electrons are said to be the minority carriers.

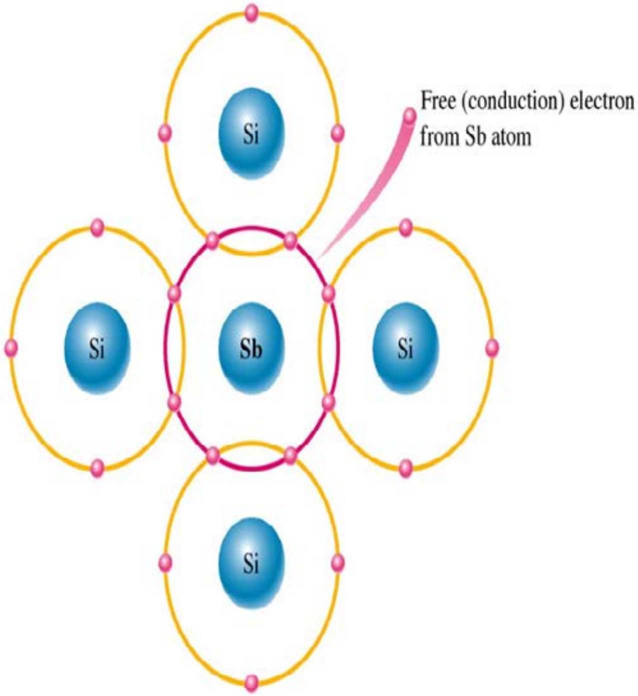


Gallium
atom
Silicon
atom
Hole

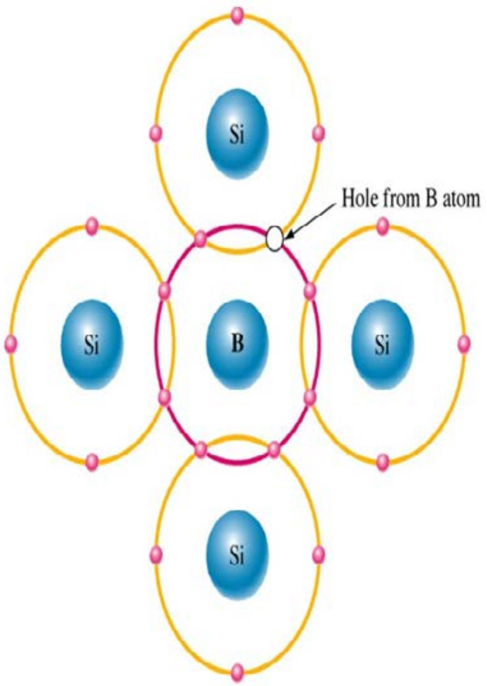
N-TYPE AND P-TYPE SEMICONDUCTORS

The process of creating N and P type materials is called doping.

N-type

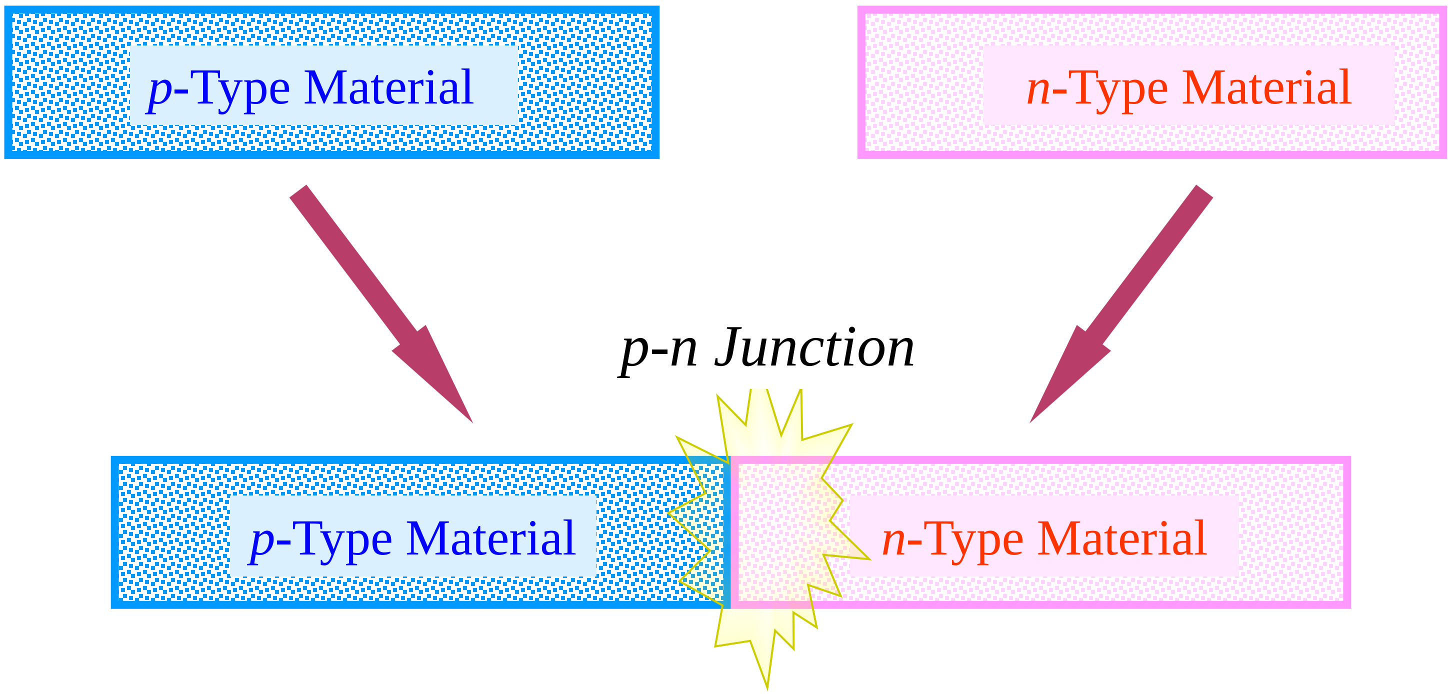


P-type



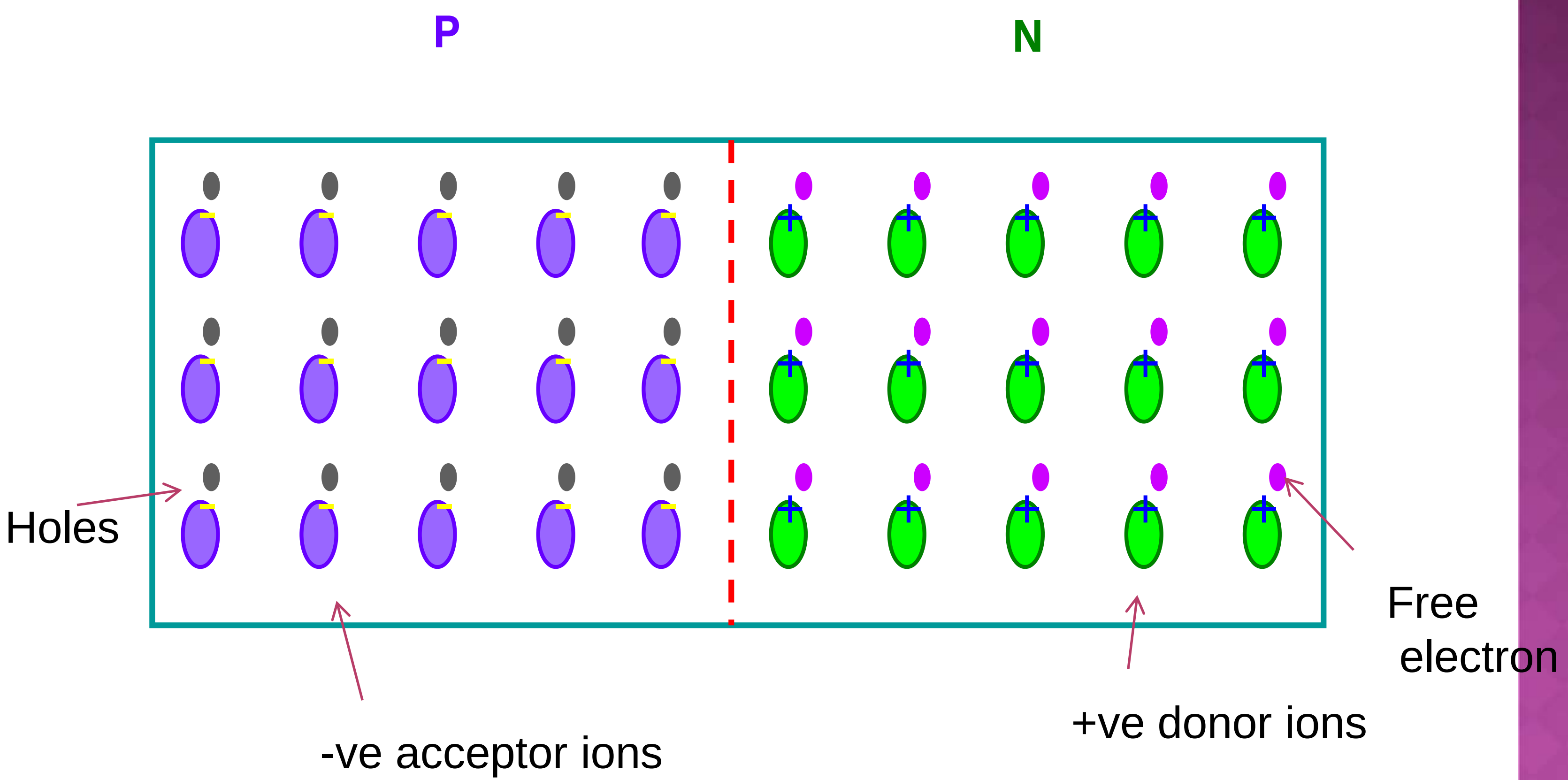
p-n Junction Diode

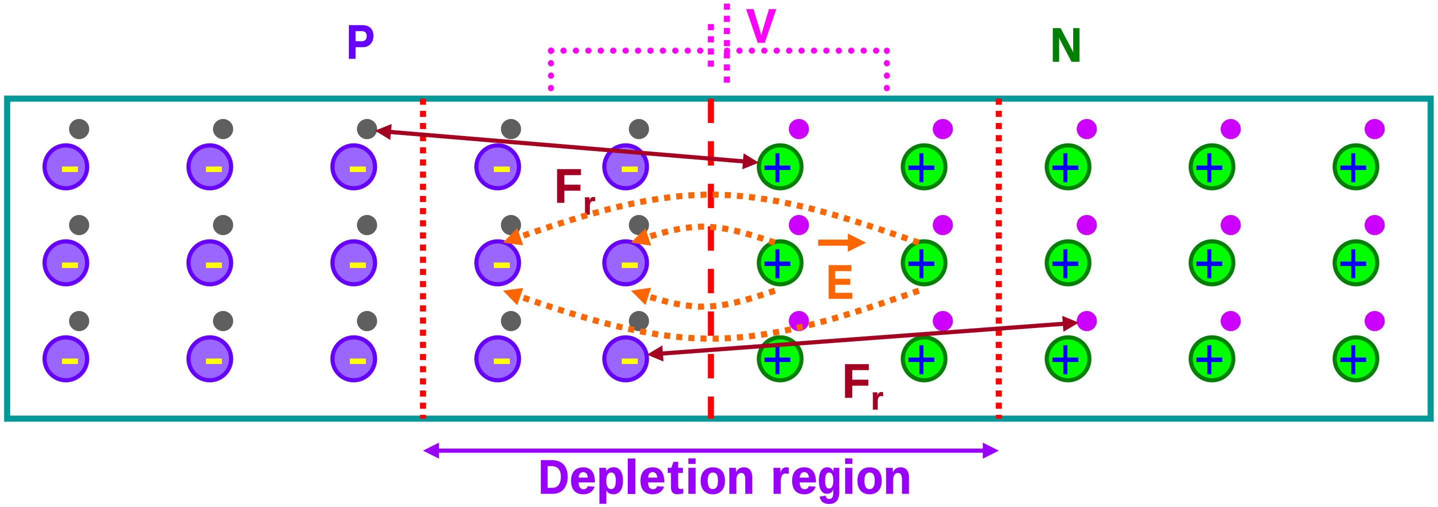
- p-n Junction



- A p-n junction diode is made by forming a p-type region of material directly next to a n-type region.

PN Junction Diode

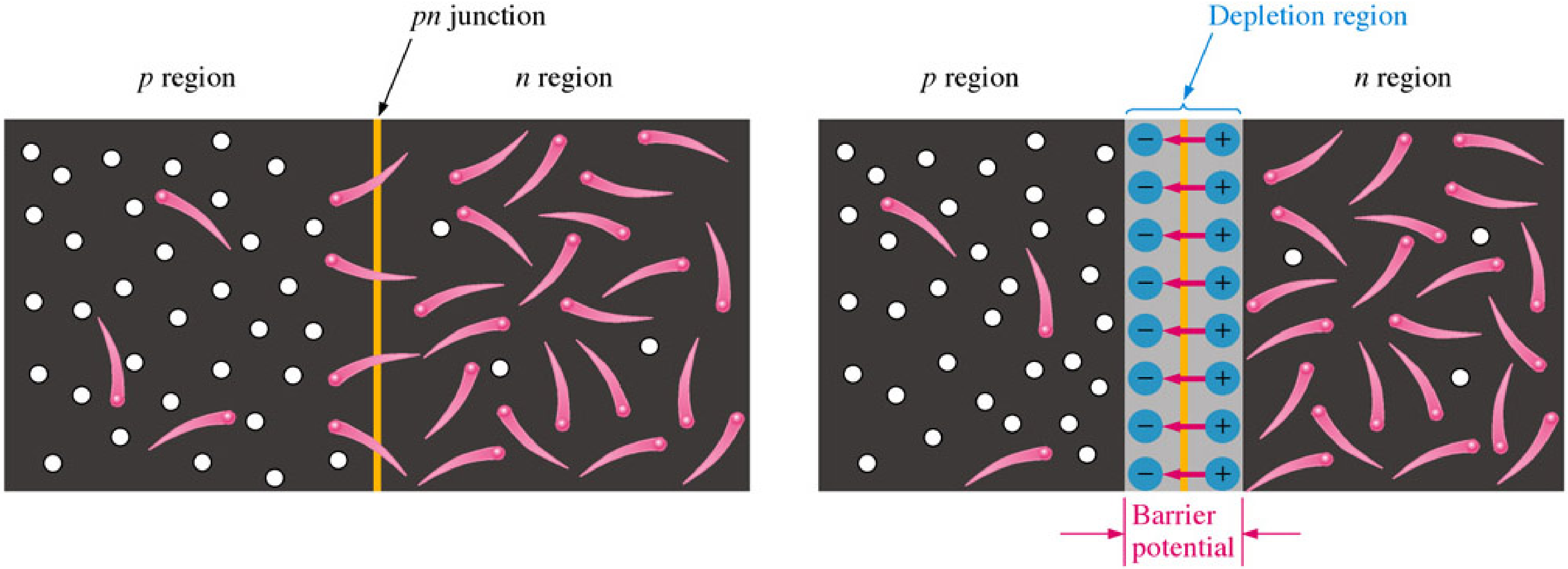




PN Junction Diode immediately after it is formed

THE DEPLETION REGION

p region **n region** **p region** **n region**



This creates the depletion region and has a barrier potential.

BARRIER POTENTIAL

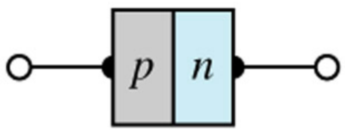
- Potential difference of the electric field in the depletion region
- The amount of energy required to move electron through the depletion region
- Silicon diode approximately 0.7 eV
- Germanium diode approximately 0.3eV

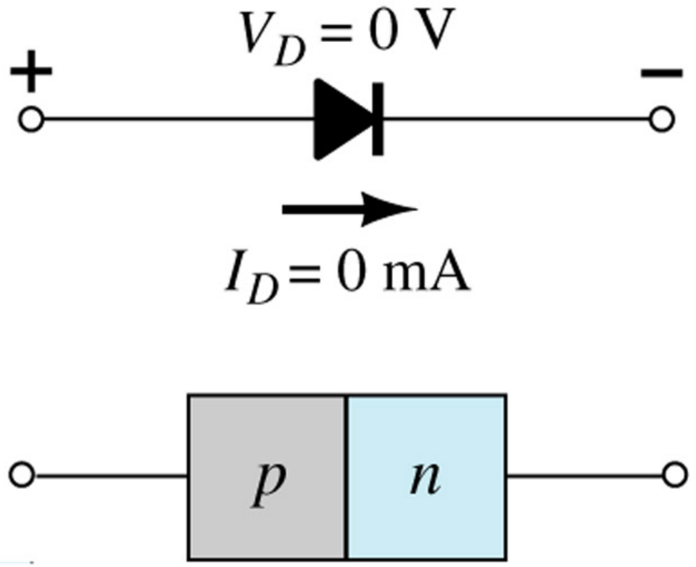
Operating Conditions

- No Bias
- Forward Bias
- Reverse Bias

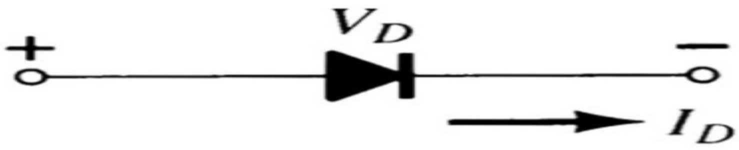
NO BIAS CONDITION

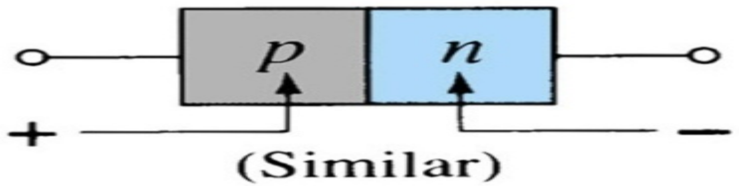
No external voltage is applied: V_D = 0V and no current is flowing I_D = 0A.

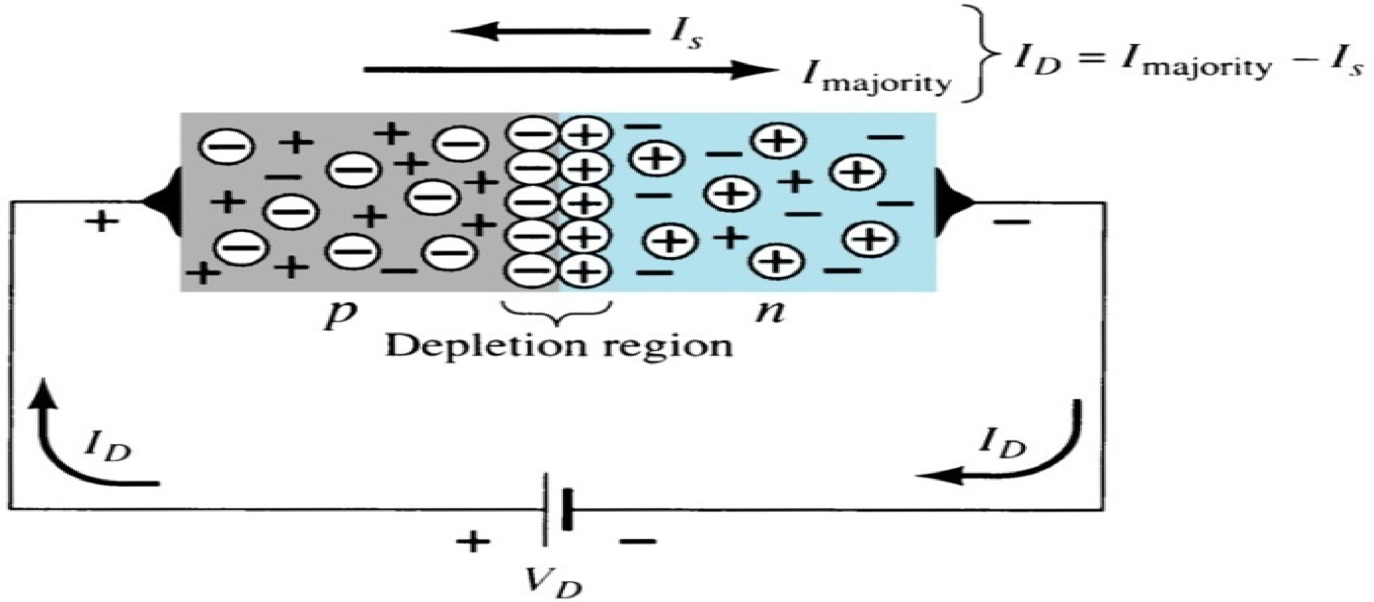




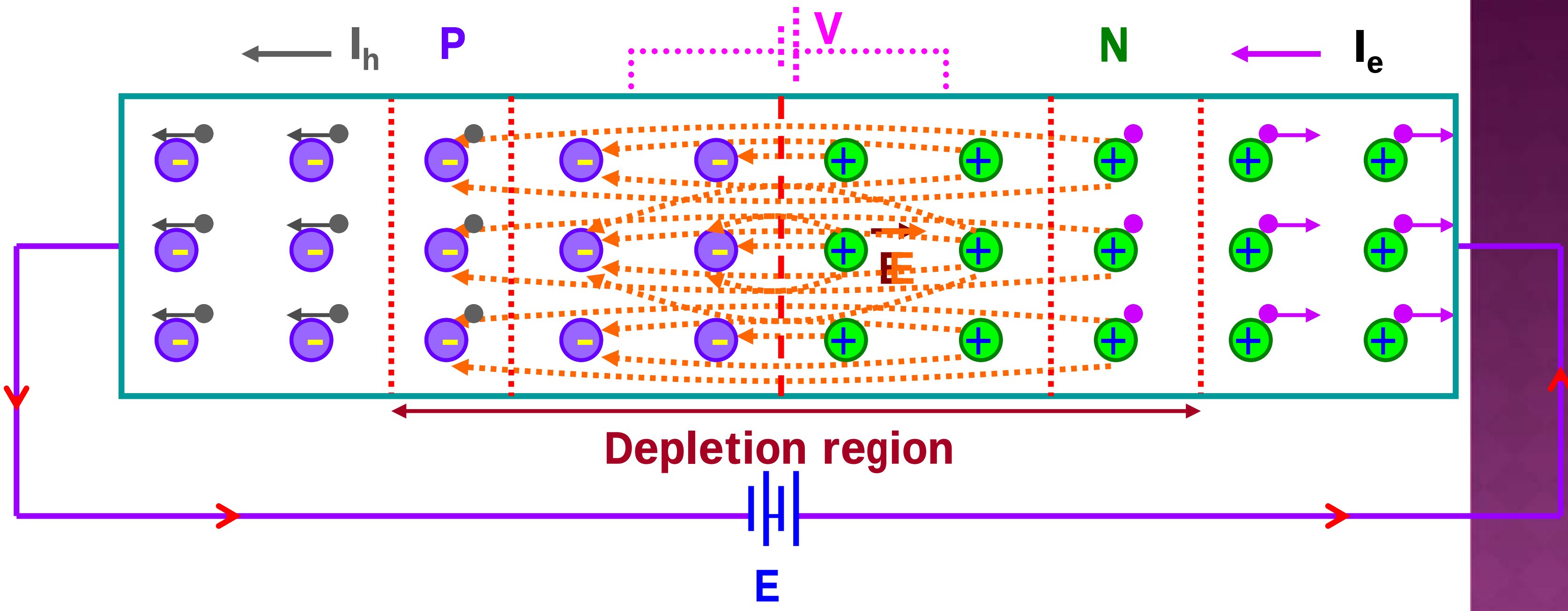
FORWARD BIAS CONDITION





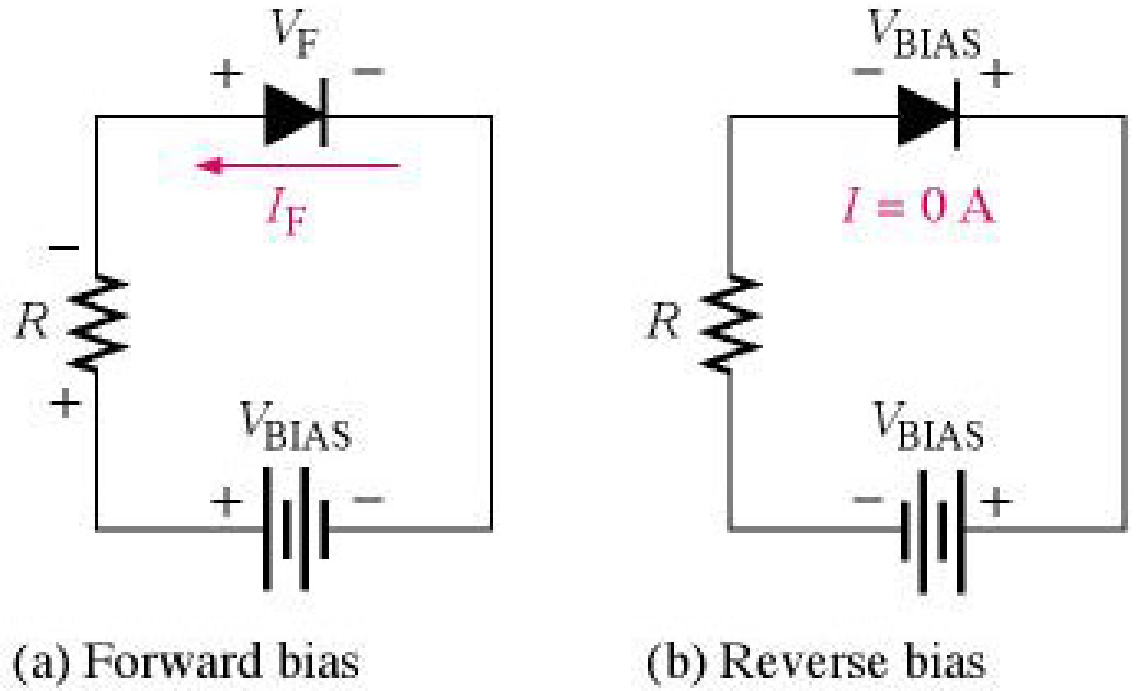


Reverse Bias:



When the negative terminal of the battery is connected to P-region and positive terminal is connected to N-region, then the PN junction diode is said to be reverse-biased.

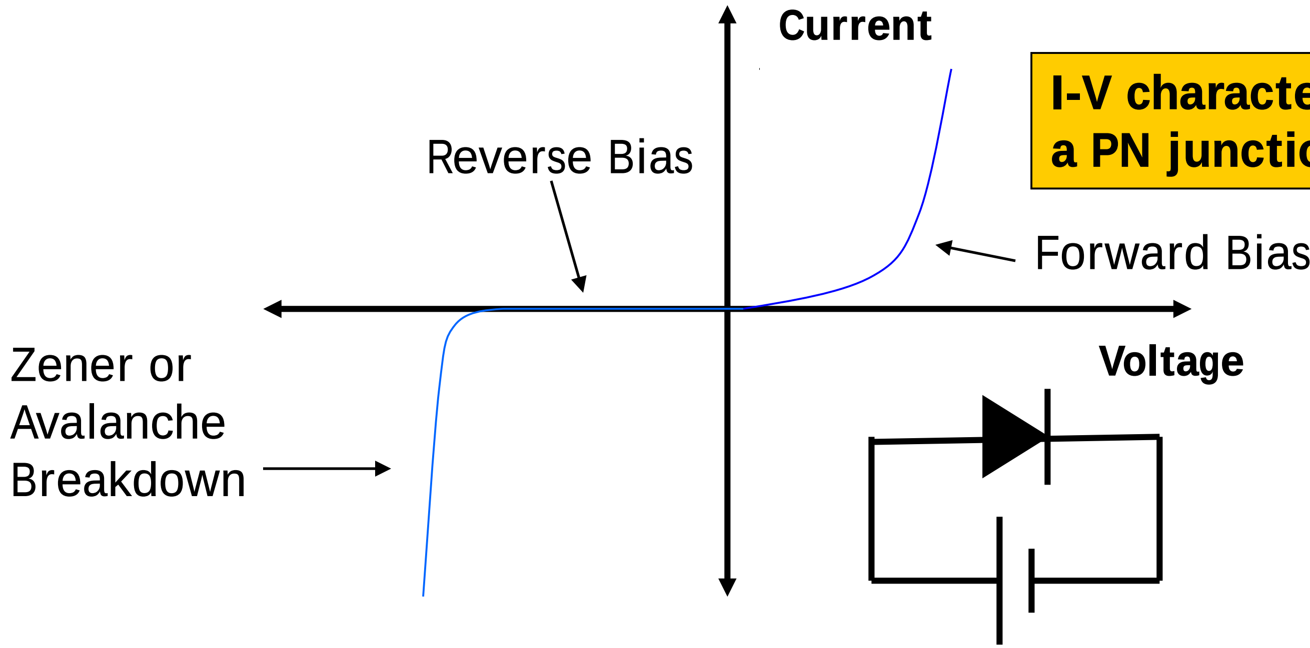
THE BASIC FUNCTION OF A DIODE IS TO RESTRICT CURRENT FLOW TO ONE DIRECTION.



Forward bias **Reverse Bias**

Current flows **No current flow**

WORKING OF A PN JUNCTION



I-V characteristic of a PN junction diode.

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IDEAL DIODES

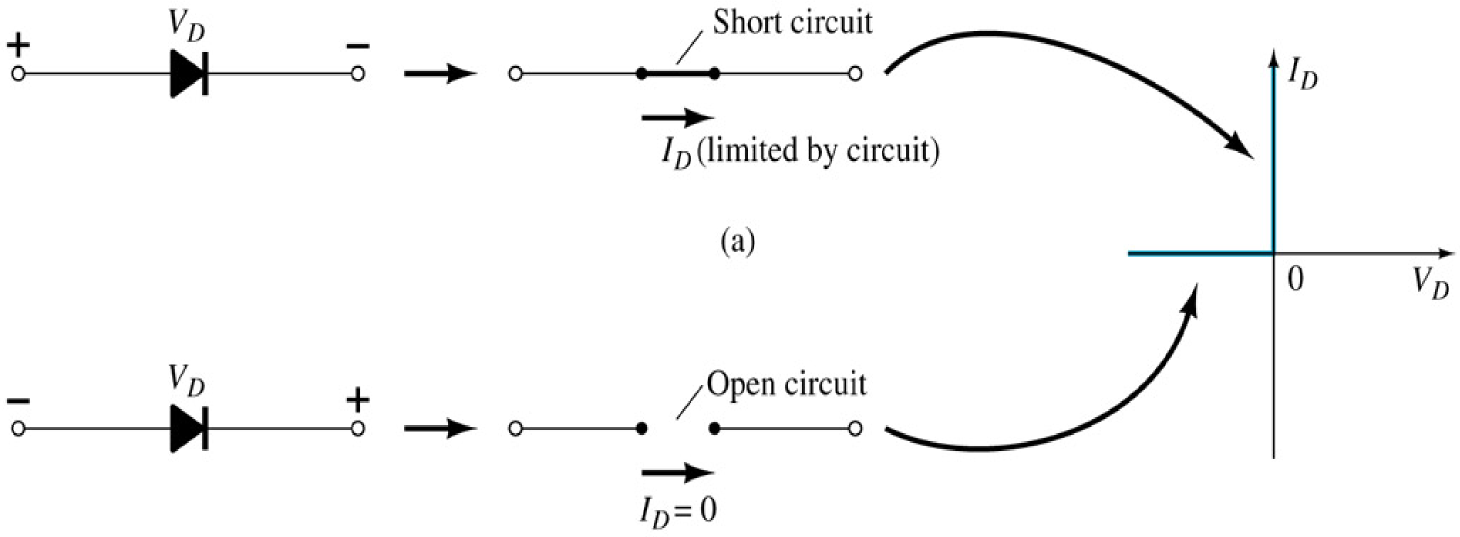
- In an ideal diode, current flow freely through the device when forward biased, having no resistance.

- In an ideal diode, there would be no voltage drop across it when forward biased. All of the source voltage would be dropped across circuit resistors.

- In an ideal diode, when reverse biased, it would have infinite resistance, causing zero current flow.

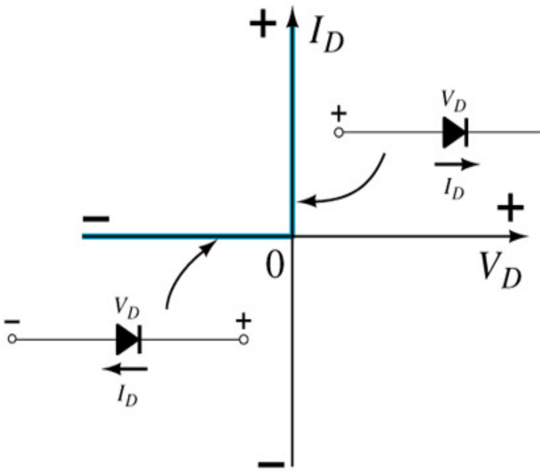
BASIC OPERATION

Ideally it ***conducts current in only one direction***



and acts like an ***open in the opposite direction***

CHARACTERISTICS OF AN IDEAL DIODE: CONDUCTION REGION



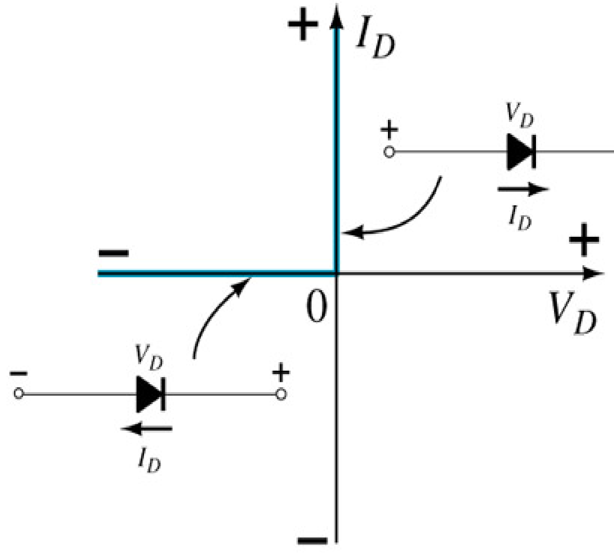
(b)

Look at the vertical line!

In the conduction region, ideally

- the voltage across the diode is 0V,
- the current is ∞,
- the forward resistance (R_F) is defined as $R_F = V_F/I_F$,
- the diode acts like a short.

CHARACTERISTICS OF AN IDEAL DIODE: NON-CONDUCTION REGION



(b)

Look at the horizontal line!

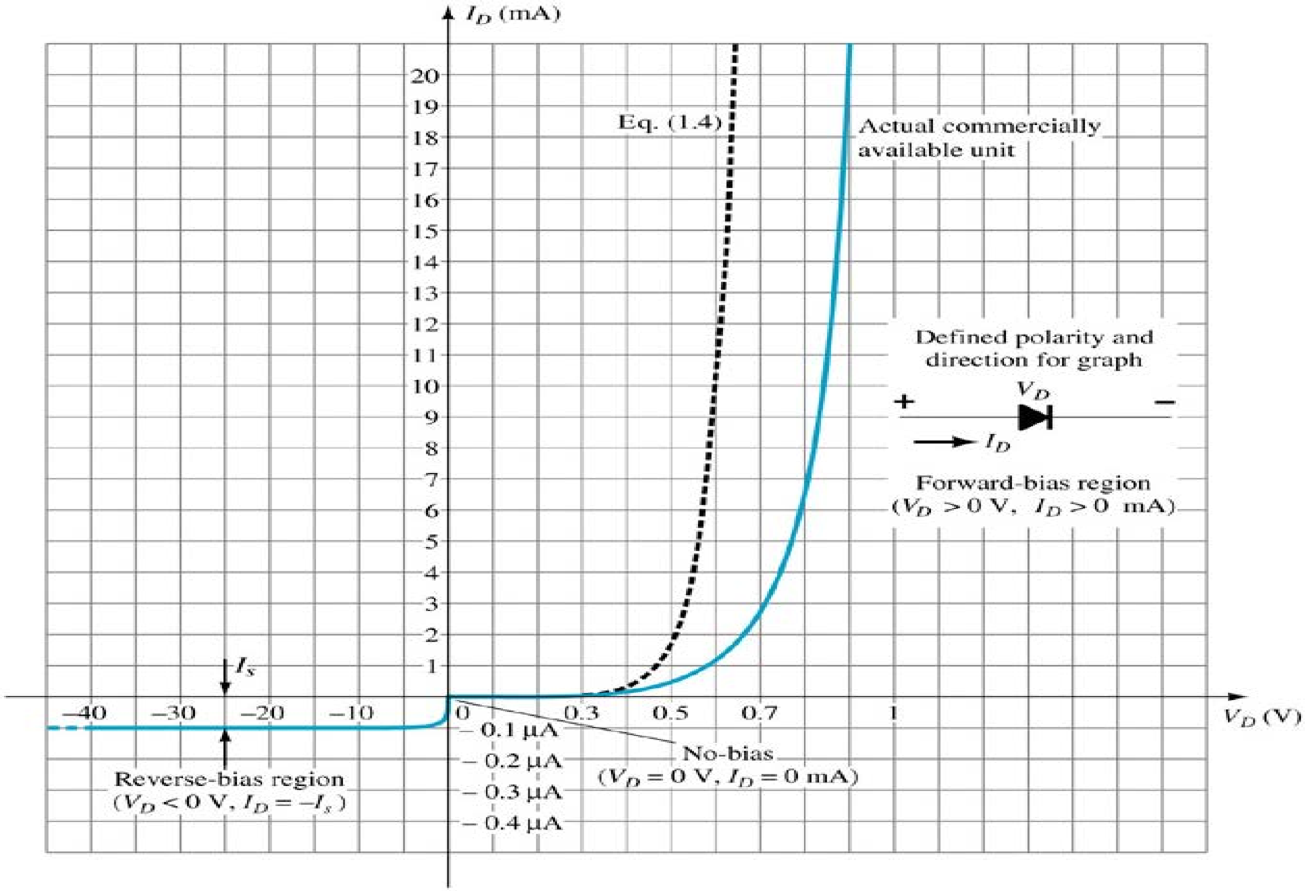
In the non-conduction region, ideally

- all of the voltage is across the diode,
- the current is 0A,
- the reverse resistance (R_R) is defined as $R_R = V_R/I_R$,
- the diode acts like open.

PRACTICAL DIODES

- A practical diode does offer some resistance to current flow when forward biased.
- Since there is some resistance, there will be some power dissipated when current flows through a forward biased diode. Therefore, there is a practical limit to the amount of current a diode can conduct without damage.
- A reverse biased diode has very high resistance.
- Excessive reverse bias can cause the diode to conduct.

ACTUAL DIODE CHARACTERISTICS



Note the regions for No Bias, Reverse Bias, and Forward Bias conditions. Look closely at the scale for each of these conditions!

Ideal diode characteristics

	Forward bias	Reverse Bias
Equivalent switch state	ON	OFF
Device resistance	Zero	Infinite
Device current	A-to-K current determined by external resistance and voltage	Zero
A-to-K voltage	Zero	Equal to the applied voltage

BREAKDOWN REGION

- Avalanche effect
- Zener effect
- Avalanche effect: $\uparrow$ reverse voltage $\uparrow$ velocity of minority carriers $\uparrow$ kinetic energy $\rightarrow$ K.E to the valence electron $\rightarrow$ valence electrons break covalent bond $\rightarrow$ Electrons become free to move
- So large current flows
- Zener effect: p & n heavily doped $\rightarrow$ depletion region narrow $\rightarrow$ intrense electric field across depletion region $\rightarrow$ due to intense field valence electrons break covalent bond $\rightarrow$ Electrons become free to move
- So large current flows

TEMPERATURE EFFECTS

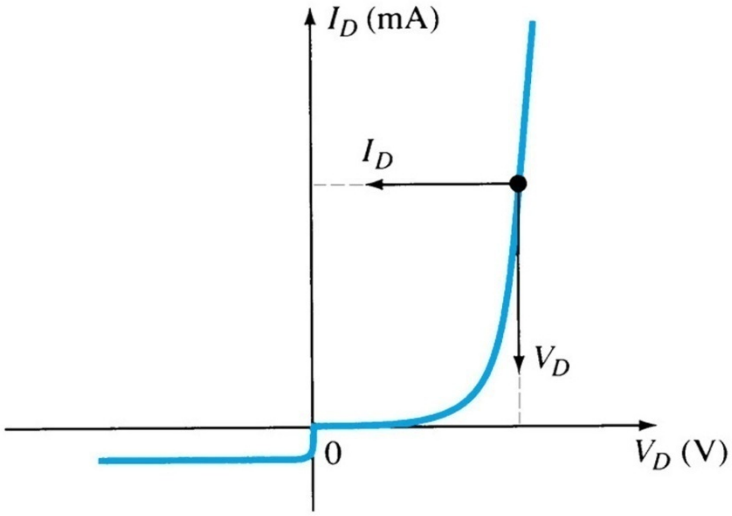
- As temperature increases it adds energy to the diode.
- It reduces the required Forward bias voltage in Forward Bias condition.
- It increases the amount of Reverse current in Reverse Bias condition.
- Germanium diodes are more sensitive to temperature variations than Silicon Diodes.

RESISTANCE LEVELS

Semiconductors act differently to DC and AC currents. There are 3 types of resistances.

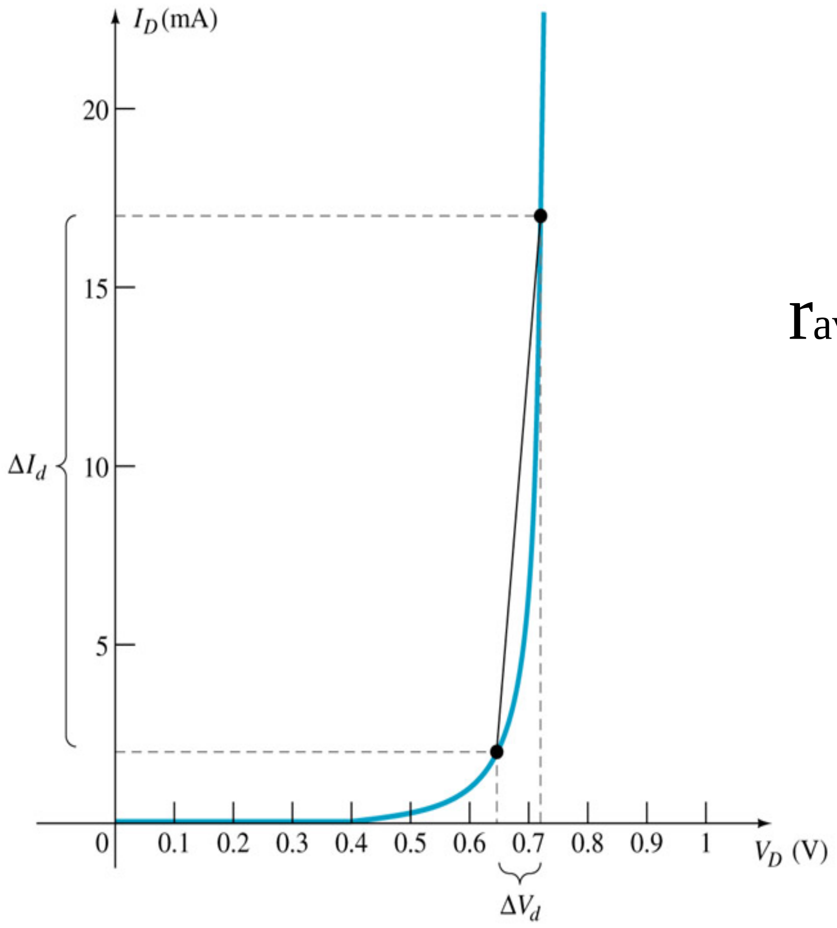
- DC or Static Resistance
- AC or Dynamic Resistance

DC OR STATIC RESISTANCE



$$R_D = V_D/I_D$$

AC OR DYNAMIC RESISTANCE



$$r_{av} = \frac{\Delta Vd}{\Delta Id} \text{(point to point)}$$

SUMMARY

- Diodes, transistors, and integrated circuits are all made of semiconductor material.
- P-materials are doped with trivalent impurities
- N-materials are doped with pentavalent impurities
- P and N type materials are joined together to form a PN junction.
- A diode is nothing more than a PN junction.
- At the junction a depletion region is formed. This creates barrier which requires approximately .3 V for a Germanium and .7 V for Silicon for conduction to take place.

CONTD…..

- A diode conducts when forward biased and does not conduct when reverse biased
- When reversed biased a diode can only withstand so much applied voltage. The voltage at which avalanche current occurs is called reverse breakdown voltage.
- There are two ways of analyzing a diode. These are ideal, practical, . Typically we use a practical diode model.