Analog Electronics

DIPLOMA WALLAH

EE/EEE

Jharkhand University Of Technology (JUT)

Unit 1 – Analog Electronics

1. Passive Components (Resistors, Inductors and Capacitors)

Introduction

In electronics, a *passive component* is a circuit element that **does not generate energy** (i.e., it can't amplify or produce power) but rather either **dissipates**, **stores**, or **controls** electrical energy. (Peerless Electronics Inc.)
The key passive components you'll often see are: resistors (R), inductors (L), and capacitors (C). (fromvinyltoplastic.com)
These make up much of the "back-bone" of analog (and digital) circuits — controlling currents, voltages, shaping signals, filtering, timing.

Resistor

Symbol, unit

- Symbol: Typically a zig-zag line (in many schematics) or a rectangle in some standards. (Basic Electronics Tutorials)
- Unit: Ohm (Ω). The resistance (R) is defined by Ohm's Law:
  [
  R = {V}/{I}
  ]
  where (V) is voltage across the resistor and (I) is current through it. (Basic Electronics Tutorials)
- Power dissipated: (P = I^2 \cdot R = V \cdot I). (You may need this in exam questions.)

Types / Classification

- By construction/material: carbon composition, metal film, wire-wound, SMD resistors.
- By functional type: fixed resistors (constant resistance) and variable resistors (potentiometers, rheostats) which allow adjustment.
- By behaviour: linear resistors (where $V \propto I$) versus non-linear ones (thermistors, etc).
- By packaging/size: e.g., through-hole vs surface-mount.

Identification & selection

- Identification: Through colour-code bands on classic resistors; numeric marking on SMD parts.
- Selection: When choosing a resistor consider the resistance value, tolerance (e.g., ±5 %), power rating (e.g., ¼ W, ½ W, etc), temperature coefficient (stability with temperature), noise, and frequency behaviour if high-frequency circuits.
- Also the resistor must be able to handle the expected current without overheating.

Applications

- Limiting current (for example, current through an LED).
- Dividing voltages (voltage divider circuits).
- Biasing of transistors or amplifiers.
- Feedback networks in amplifiers.
- In timing circuits (in conjunction with capacitors).
- Load resistors in many analog circuits.

Inductor

Symbol, unit

- Symbol: Usually a series of loops (coils) representing the winding.
- Unit: Henry (H). The fundamental relationship:
  [
  v(t) = L , .{di(t)}{dt}
  ]

where (L) is inductance, and the induced voltage (v(t)) is proportional to the rate of change of current. (Analog Devices)

- Inductors store energy in a magnetic field produced by current flow.

Types / Classification

- By core material: air-core, ferrite-core, iron-core. Each has different losses and frequency behaviours. (AnyPCBA)
- By construction: fixed inductors (coil with fixed number of turns) vs variable inductors (adjustable core or tap).
- Power vs signal inductors: large ones for power supplies, small ones for RF circuits.

Identification & selection

- Key properties: inductance value (in H, mH, µH), current rating (to avoid saturation), DC resistance (DCR) of the winding, self-resonant frequency (SRF), core losses (especially at high frequencies).
- Selection: based on frequency of operation, magnitude of current, required inductance, size/space constraints, plus the environment (temperature, whether EMI is important).

Applications

- In filters: LC filters for removing unwanted frequencies.
- In chokes: to block high-frequency noise and allow DC through.
- In tuning circuits: along with capacitors (LC tanks) for resonant circuits (radios, oscillators).
- In power electronics: energy storage in switching power supplies.
- In transformers (which are essentially coupled inductors).

Capacitor

Symbol, unit

- Symbol: Two parallel lines represent the plates; one line may be curved for a polarized capacitor.
- Unit: Farad (F). The capacitance (C) is defined by:
  [

C = .{Q}{V}
]
where (Q) is charge stored, (V) is voltage. And for changing voltage, the current is:
[
i(t) = C , .{dv(t)}{dt}
]
meaning a capacitor opposes changes in voltage. (Analog Devices)

- Capacitors store energy in an electric field between their plates.

Types / Classification

- By dielectric/material: ceramic, film (polyester/metal-film), aluminium electrolytic, tantalum electrolytic, etc.
- By function: fixed capacitors (set value) and variable capacitors (tuning).
- Polarised vs non-polarised: electrolytics are polarised (must observe correct polarity) whereas ceramics/films are not.
- By application: coupling/decoupling capacitors, timing capacitors, high-voltage capacitors, etc.

Identification & selection

- Identification: Marked with capacitance value (in µF, nF, pF), voltage rating (e.g., 50 V, 250 V), tolerance, sometimes temperature coefficient. For electrolytics also ESR (equivalent series resistance) and ripple current rating matter.
- Selection: Consider required capacitance, voltage rating (should exceed maximum circuit voltage), dielectric type (for stability, loss, temperature behaviour), size/physical mounting, ESR & ripple current if used in power circuits, frequency of operation (higher frequency needs low-ESR, low-inductance capacitors).

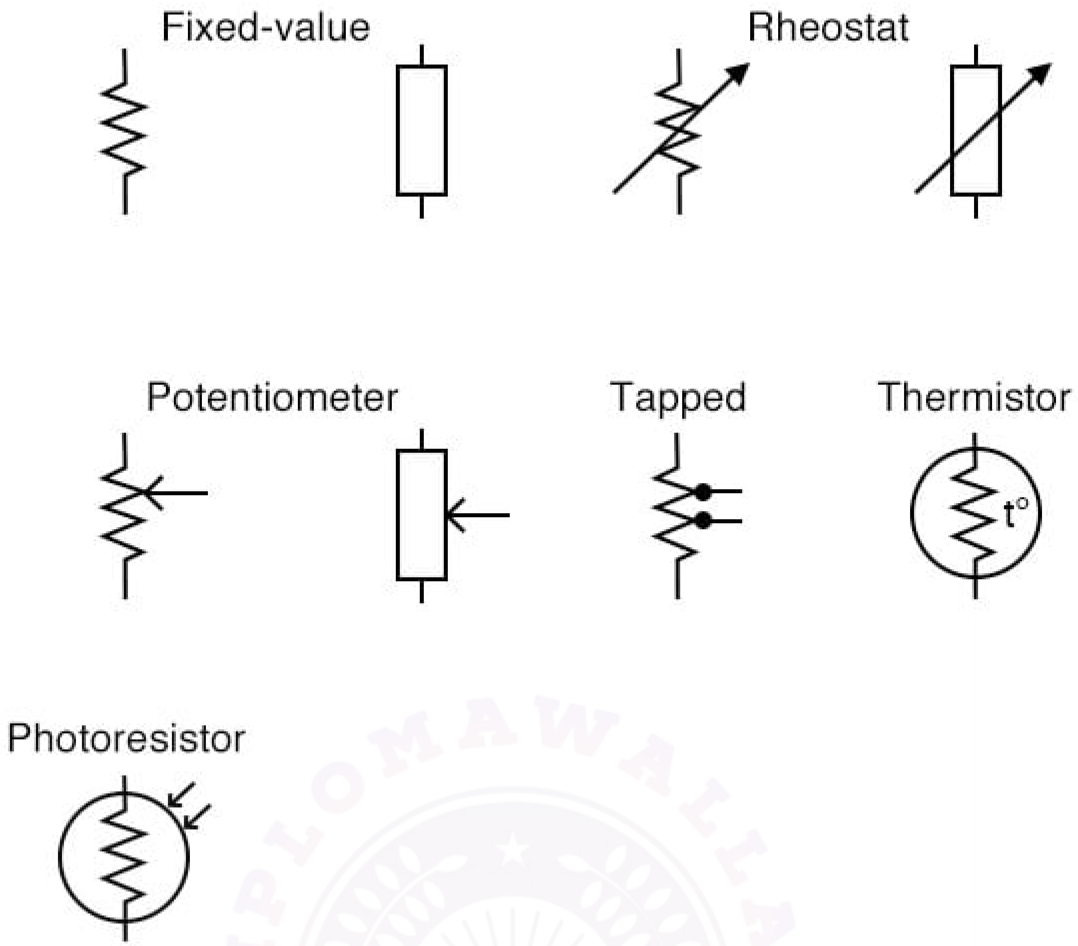
Applications

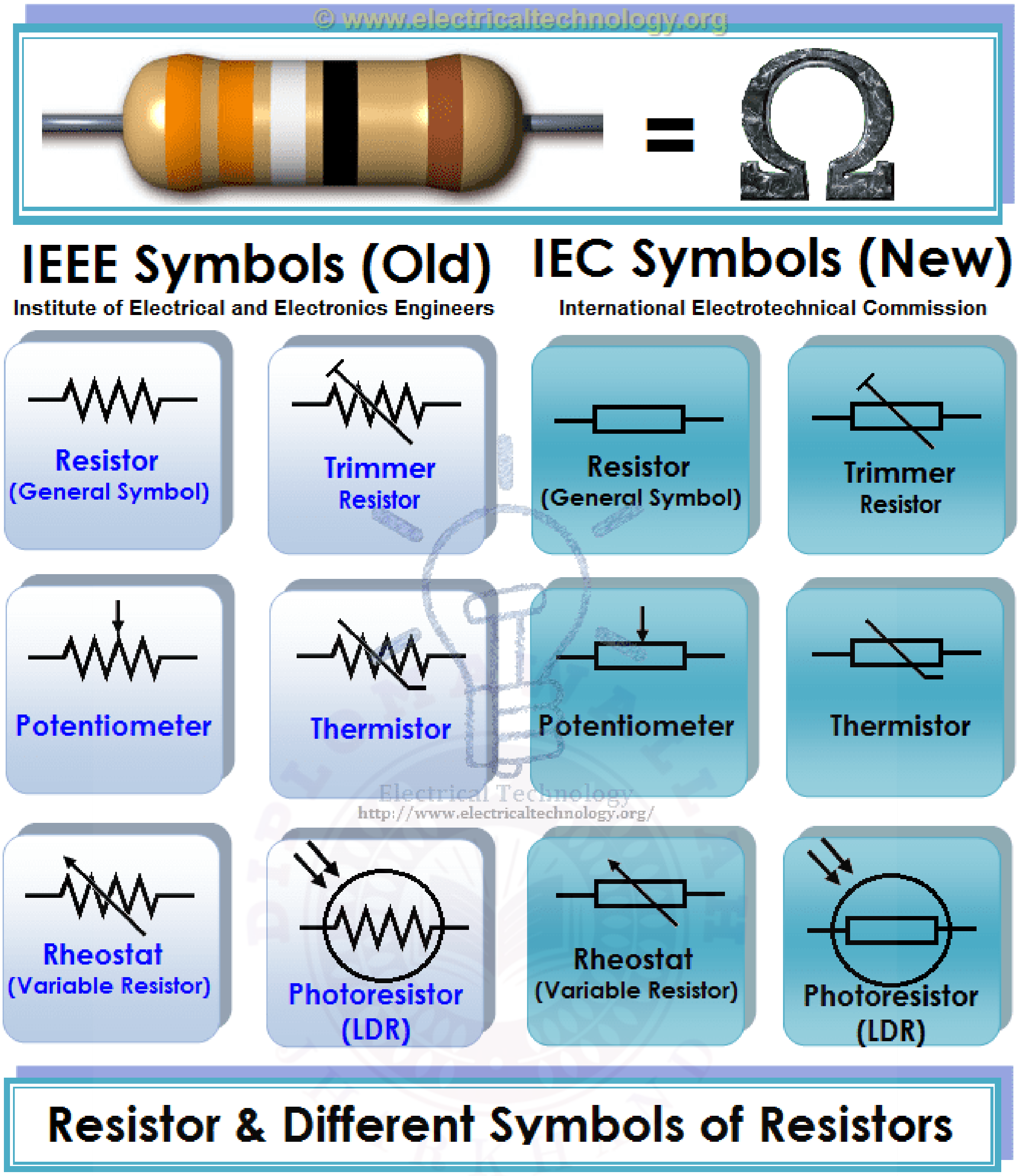
- Coupling/decoupling: capacitors block DC but pass AC (coupling) and smooth out fluctuations (decoupling) in power rails.
- Timing circuits: RC time constant circuits where capacitor charges/discharges through resistor to create delays.

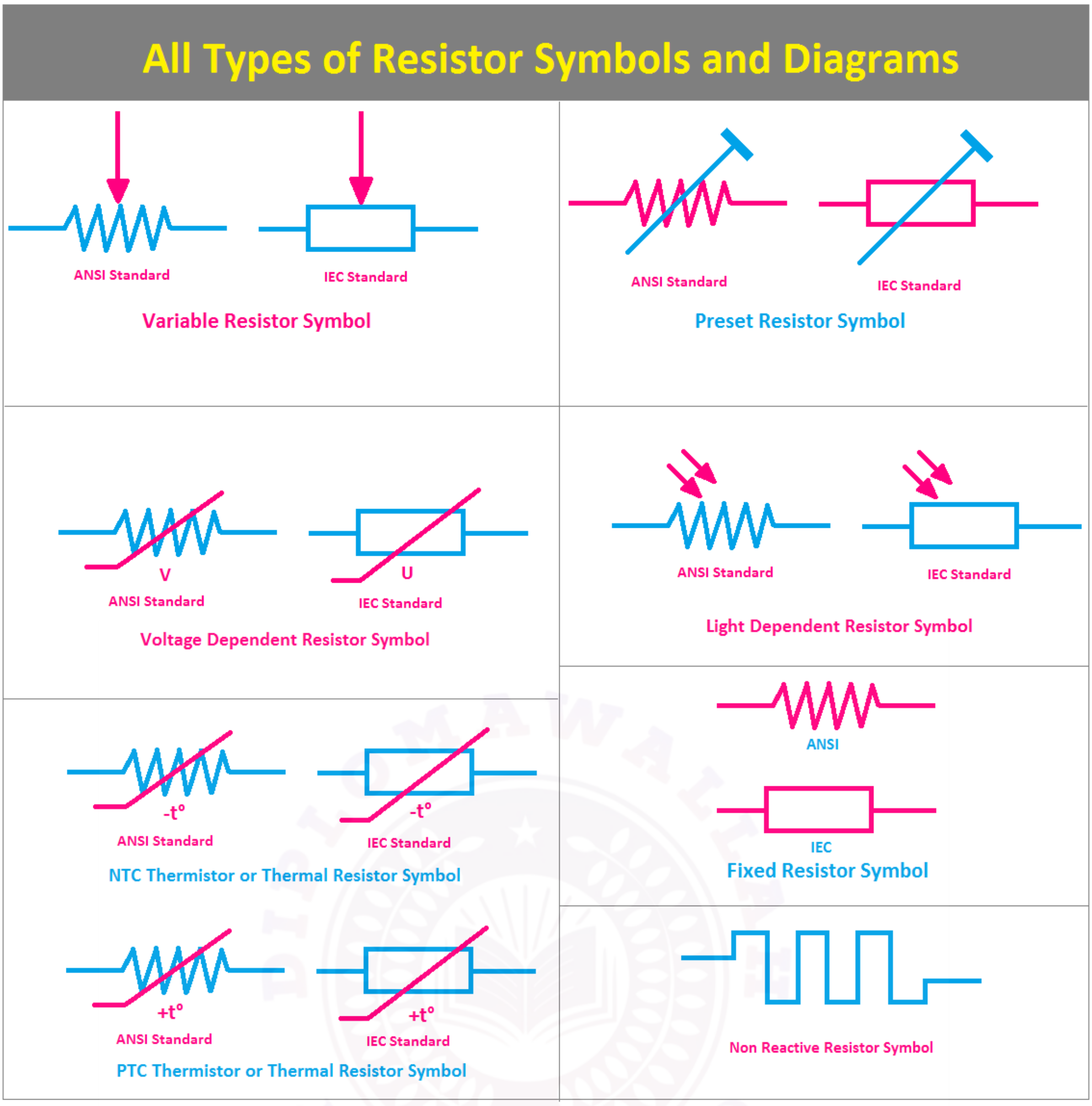
- Filtering: forming RC or LC filters to allow/block certain frequencies.
- Energy storage: in power electronics (e.g., smoothing in DC-link).
- Tuning: alongside inductors in LC circuits for resonance (radios, oscillators).

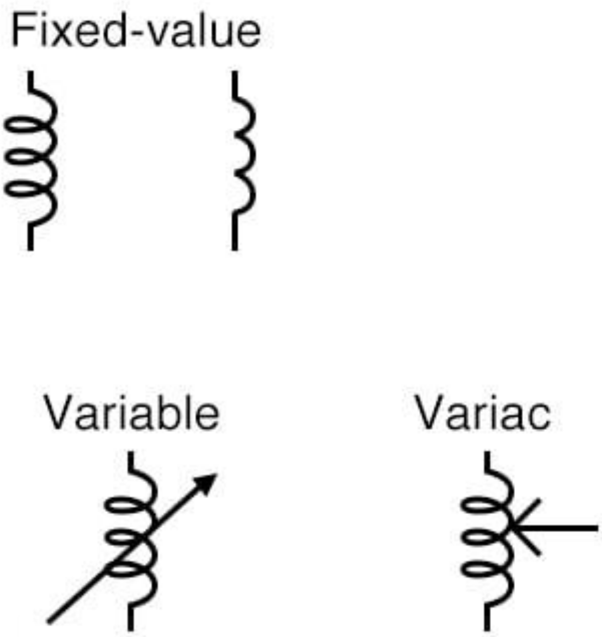
Summary of Passive Components

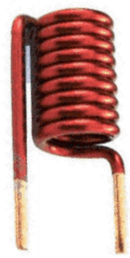
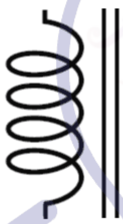
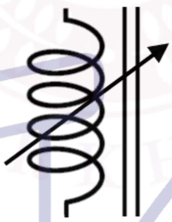
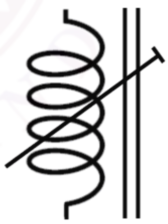
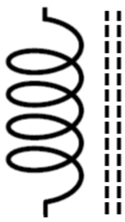
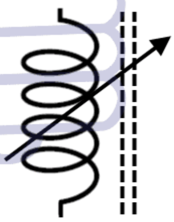
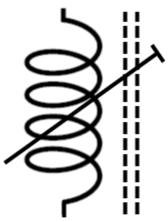
- Resistors: oppose current flow, dissipate energy as heat, unit Ω.
- Inductors: oppose changes in current, store magnetic energy, unit H.
- Capacitors: oppose changes in voltage, store electric energy, unit F.
- They all behave differently in DC and AC circuits (for example, capacitors block steady DC but allow AC; inductors allow steady DC but impede changing current). (Basic Electronics Tutorials)
- Selection of correct passive components is crucial in analog electronics design: wrong value or wrong type can lead to malfunction, noise, instability.

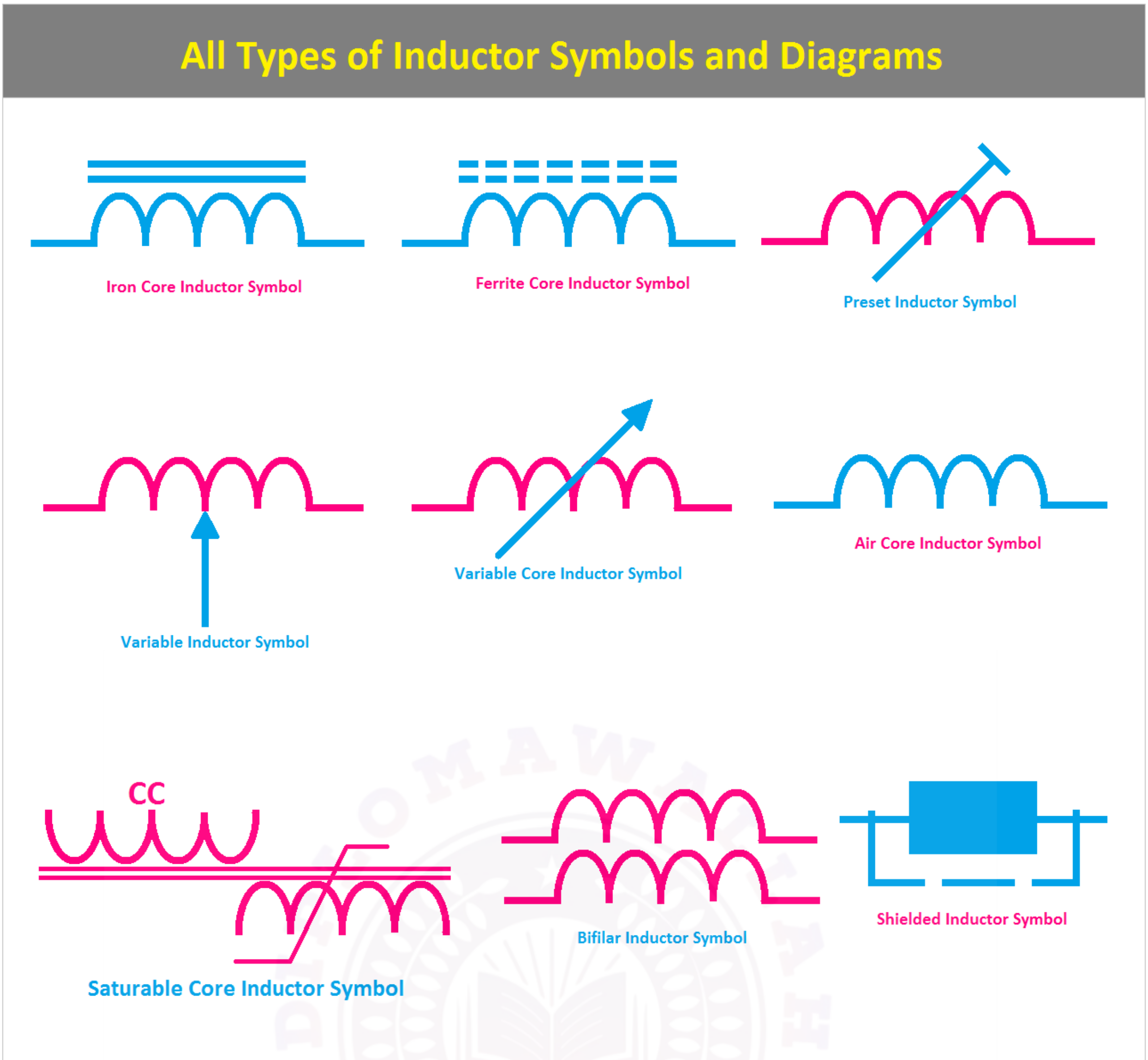

Fixed-value
Rheostat
Potentiometer
Tapped
Thermistor
t°
Photoresistor

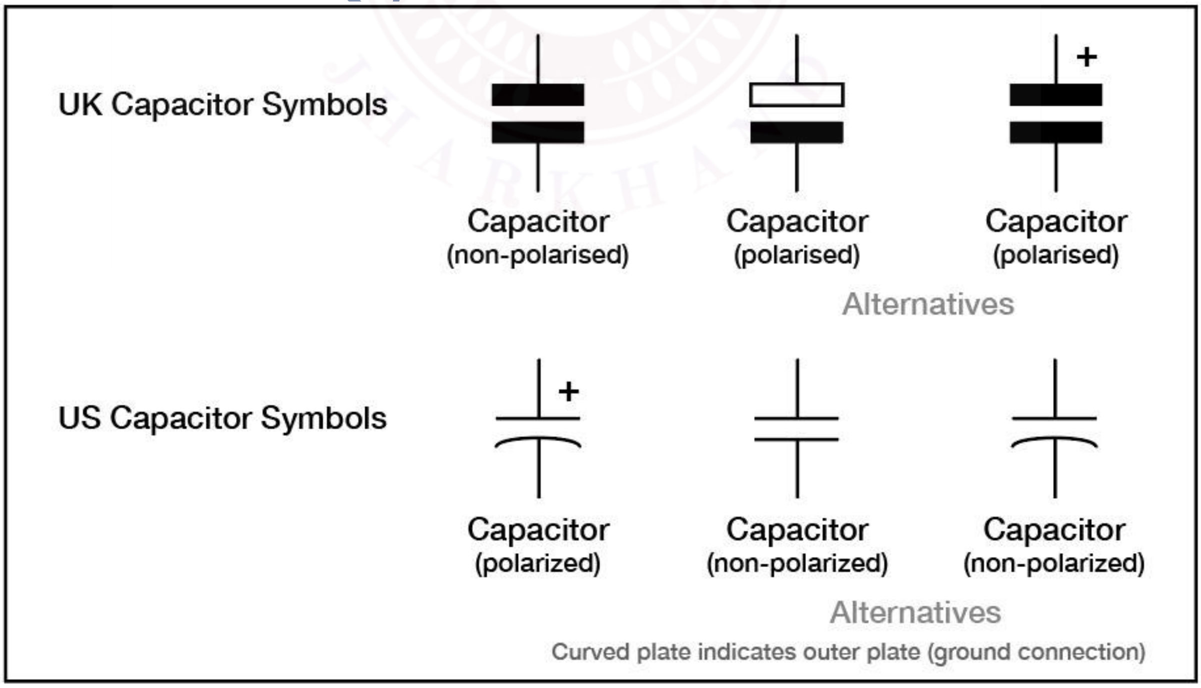

© www.electricaltechnology.org
IEEE Symbols (Old)
Institute of Electrical and Electronics Engineers
IEC Symbols (New)
International Electrotechnical Commission
Resistor (General Symbol)
Trimmer Resistor
Resistor (General Symbol)
Trimmer Resistor
Potentiometer
Thermistor
Potentiometer
Thermistor
Electrical Technology
http://www.electricaltechnology.org/
Rheostat (Variable Resistor)
Photoresistor (LDR)
Rheostat (Variable Resistor)
Photoresistor (LDR)
Resistor & Different Symbols of Resistors

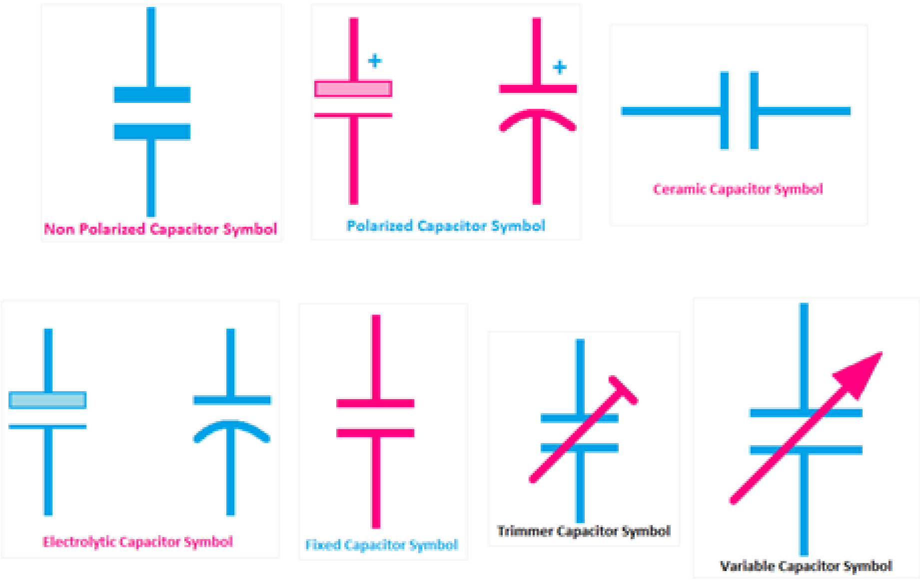

All Types of Resistor Symbols and Diagrams
ANSI Standard
IEC Standard
Variable Resistor Symbol
ANSI Standard
IEC Standard
Preset Resistor Symbol
V
ANSI Standard
U
IEC Standard
Voltage Dependent Resistor Symbol
ANSI Standard
IEC Standard
Light Dependent Resistor Symbol
-t°
ANSI Standard
-t°
IEC Standard
NTC Thermistor or Thermal Resistor Symbol
ANSI
IEC
Fixed Resistor Symbol
+t°
ANSI Standard
+t°
IEC Standard
PTC Thermistor or Thermal Resistor Symbol
Non Reactive Resistor Symbol



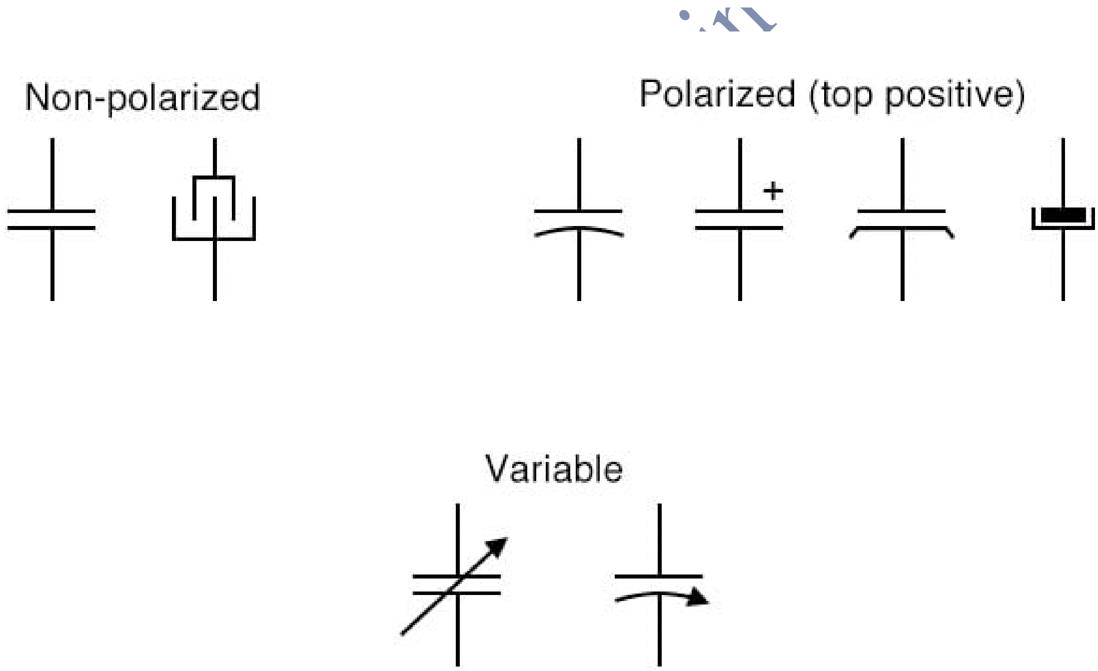
Inductor	Fixed	Variable	Pre-set	Shape
Air Core				
Iron Core				
Ferrite Core				


All Types of Inductor Symbols and Diagrams
Iron Core Inductor Symbol
Ferrite Core Inductor Symbol
Preset Inductor Symbol
Variable Inductor Symbol
Variable Core Inductor Symbol
Air Core Inductor Symbol
CC
Saturable Core Inductor Symbol
Bifilar Inductor Symbol
Shielded Inductor Symbol


UK Capacitor Symbols
Capacitor (non-polarised)
+
Capacitor (polarised)
Capacitor (polarised)
Alternatives
US Capacitor Symbols
Capacitor (polarized)
Capacitor (non-polarized)
Capacitor (non-polarized)
Alternatives
Curved plate indicates outer plate (ground connection)



All Types of Capacitor Symbol



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2. Semiconductors

Meaning and Semiconductor Materials

Meaning

A semiconductor is a material whose electrical conductivity lies between that of a conductor and an insulator — it can conduct under some conditions but not as well as a metal, and its conduction can be controlled. (Basic Electronics Tutorials)

Semiconductors are the foundation of modern electronics because by controlling the number and type of charge carriers (electrons and holes) we can create devices such as diodes, transistors, etc.

Semiconductor materials

Common semiconductor materials include:

- Silicon (Si) – widely used in integrated circuits and many devices.
- Germanium (Ge) – used historically, less common now because of higher leakage and lower band-gap.
- Gallium Arsenide (GaAs) – a compound semiconductor (III-V family) used for high-speed, high-frequency, optoelectronic applications.

Characteristics of Semiconductors

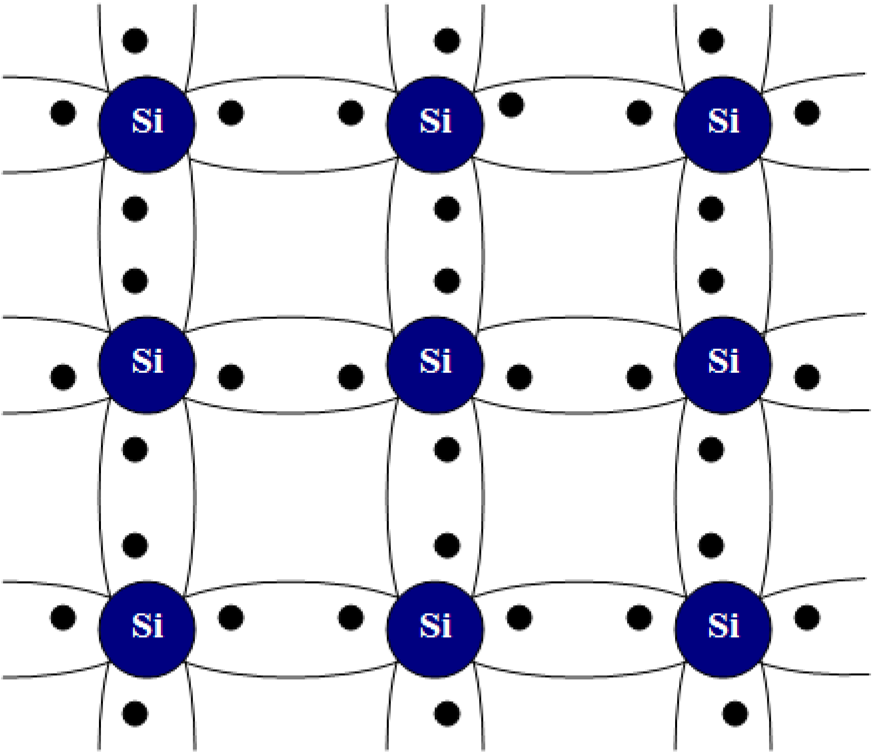
- Moderate energy band gap (Eg) — smaller than insulators, larger than that of metals — which allows electrons to move from valence band to conduction band under external stimuli (temperature, light, field). (gpshergarh.ac.in)
- Conductivity can be significantly modified by doping (adding impurities) so the material's electrical behaviour can be tailored. (Wikipedia)
- Both electrons (negative charge carriers) and holes (positive charge carriers — absence of electrons) contribute to conduction.
- Unlike metals, in many semiconductors conductivity increases with temperature (more carriers are thermally generated) up to a point. (Wikipedia)
- Ability to form p-n junctions (regions of p-type and n-type) which are critical electronic devices (diodes, transistors).
- In high-purity (intrinsic) form, fewer carriers, and in doped (extrinsic) form, many more carriers — giving wide range of conductivity control.

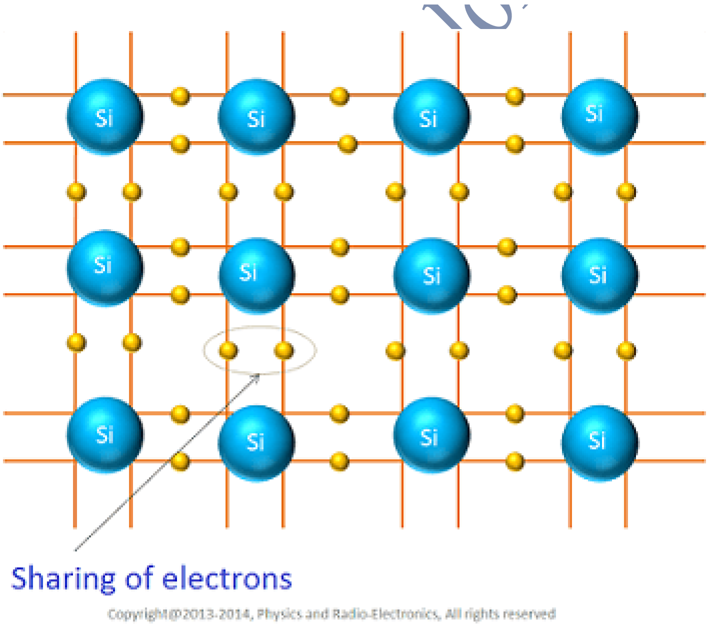
Covalent Bond Diagrams (Si, Ge, GaAs)

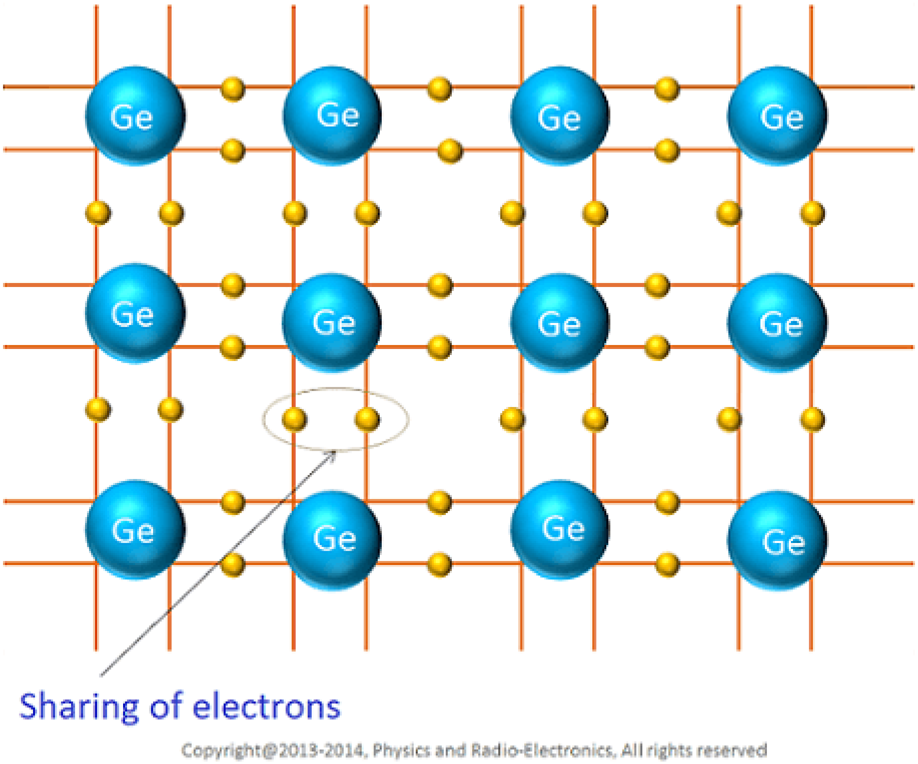
Silicon (Si) & Germanium (Ge)

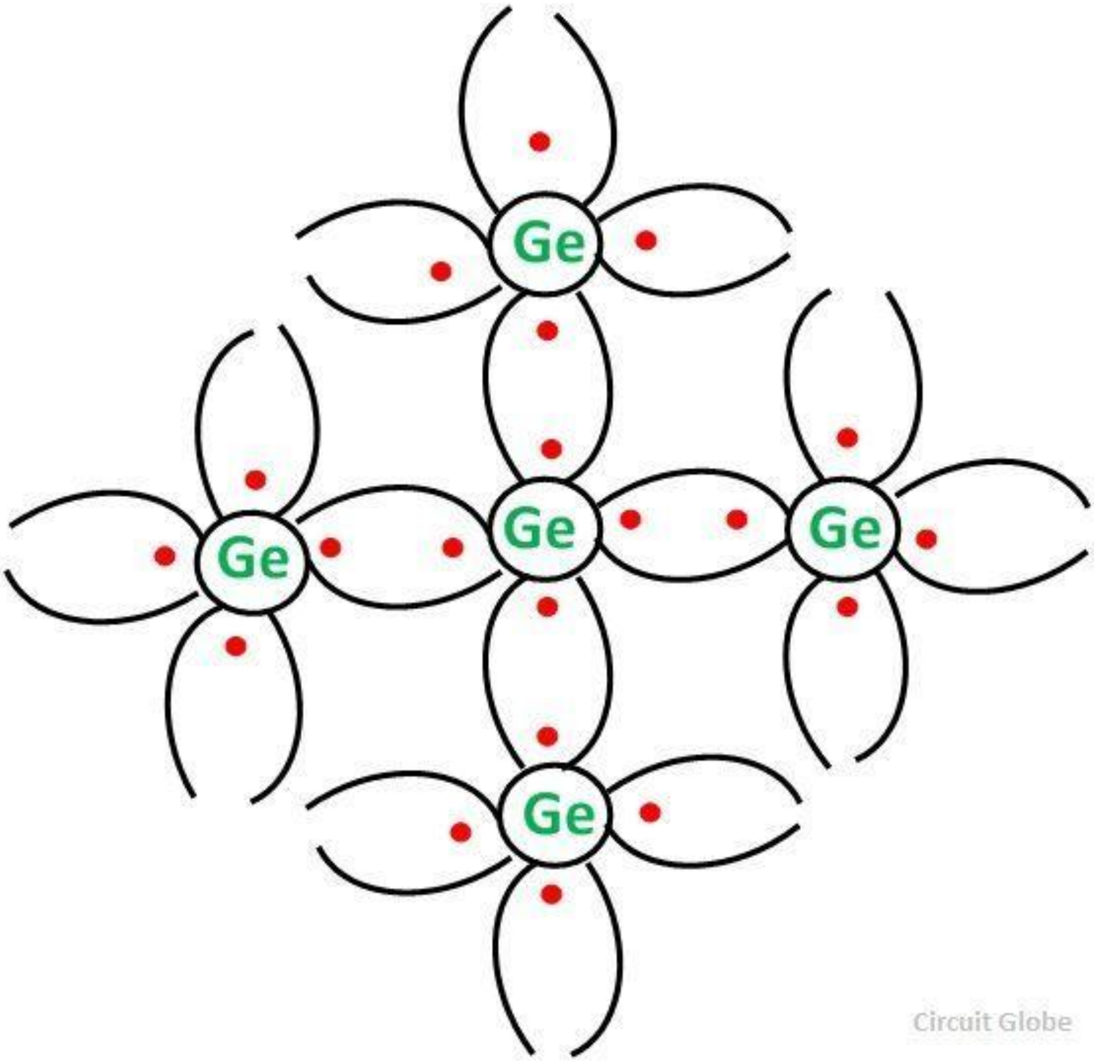
Since Silicon and Germanium belong to Group IV elements of the periodic table, each atom has four valence electrons. In the crystal lattice, each atom shares its four electrons with four neighbouring atoms, forming four covalent bonds — this is what constitutes the semiconductor lattice at room temperature (or lower) when pure. (Testbook)

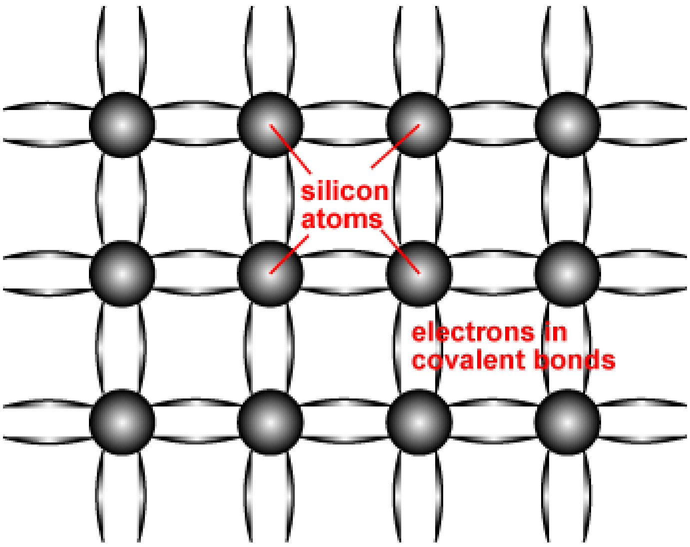
So for example, a silicon lattice:






Ge
Ge
Ge
Ge
Ge
Ge
Ge
Ge
Ge
Ge
Ge
Ge
Sharing of electrons
Copyright@2013-2014, Physics and Radio-Electronics, All rights reserved

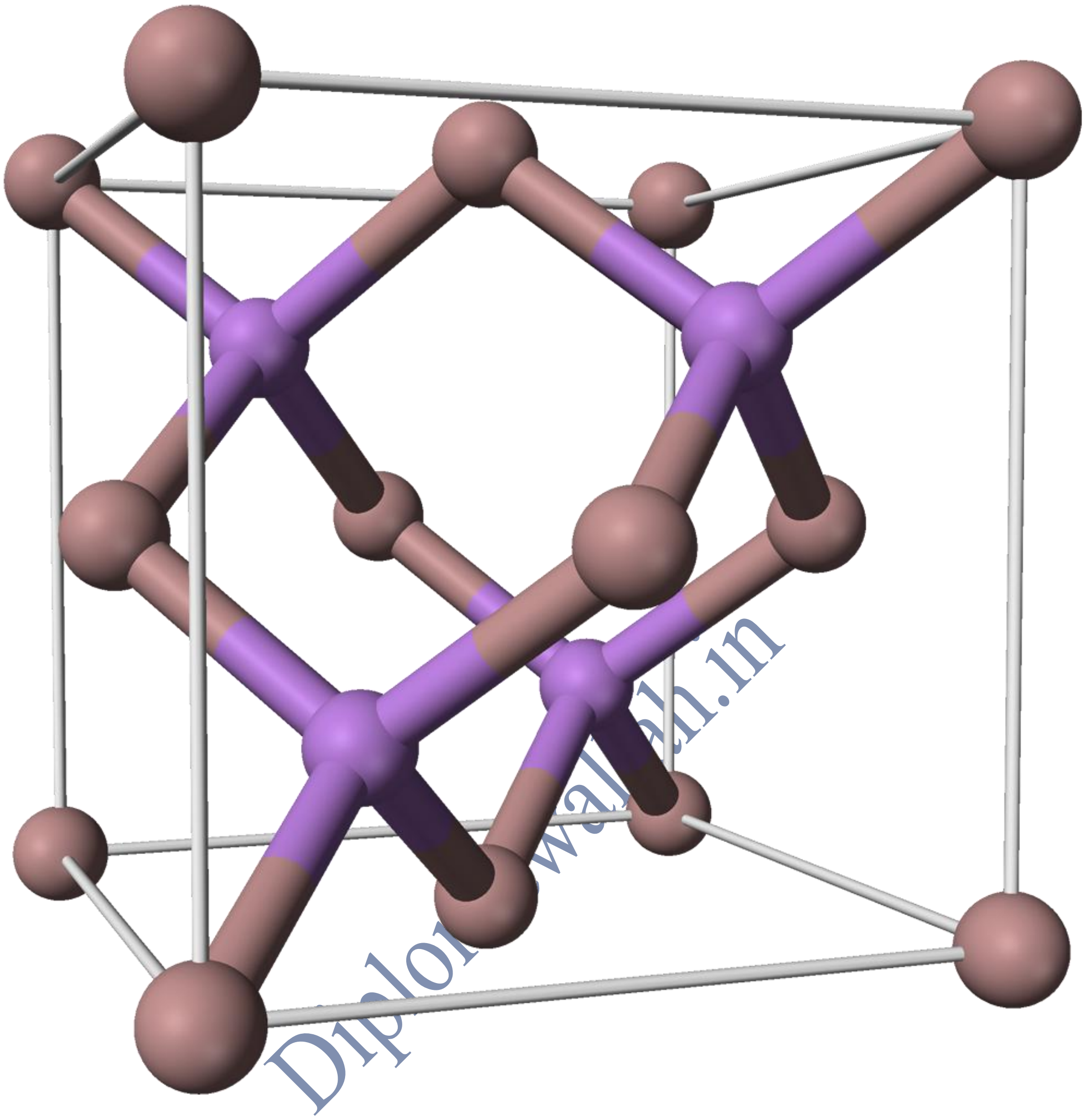

Ge
Ge
Ge
Ge
Ge
Circuit Globe

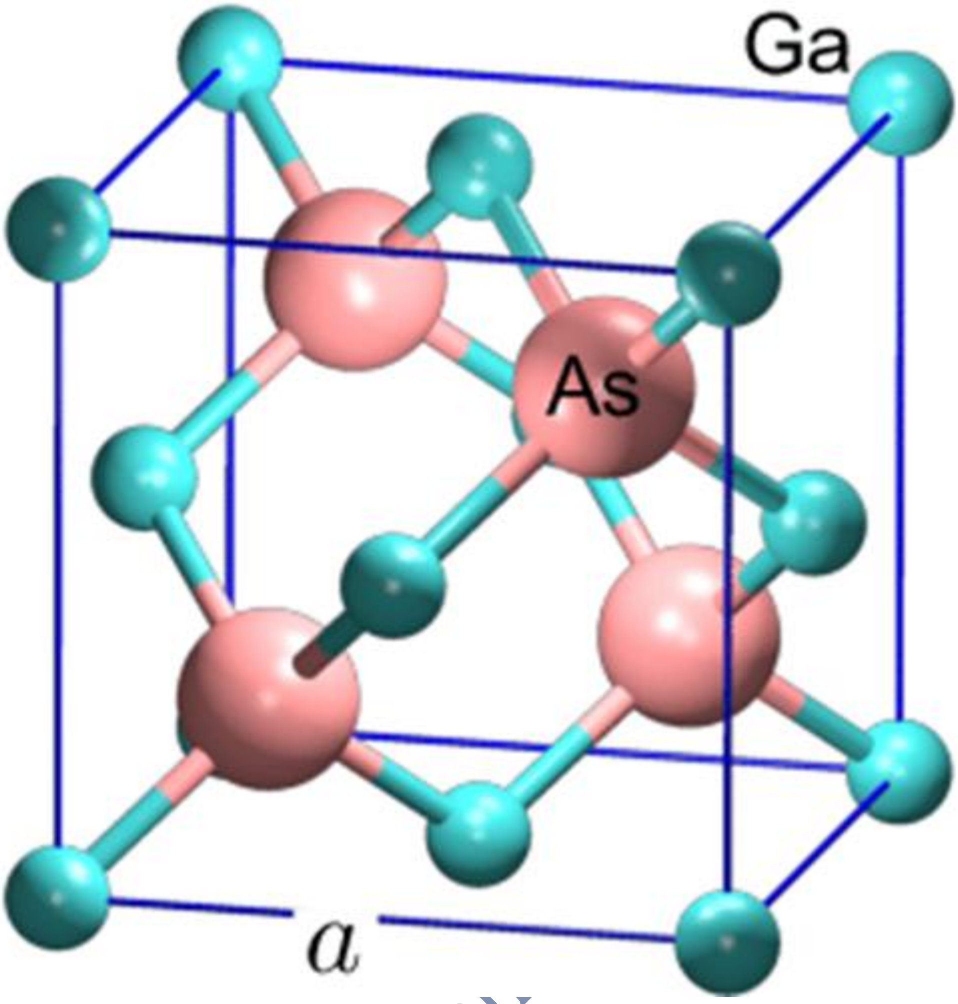

silicon
atoms
electrons in
covalent bonds

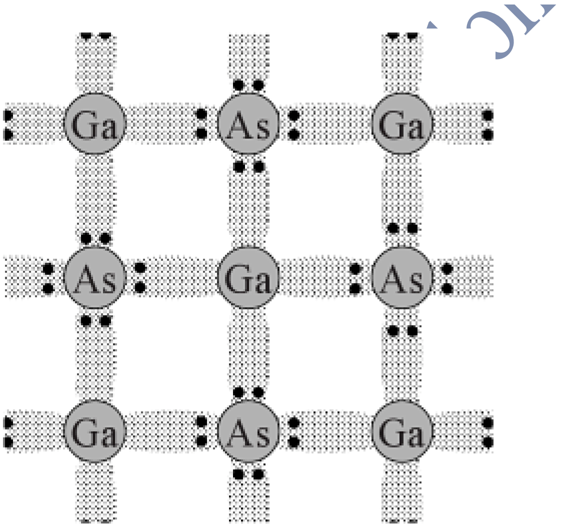
Because of these covalent bonds, at low temperature the electrons are all bound and there are no free charge carriers; as temperature rises or impurity is added, carriers appear.

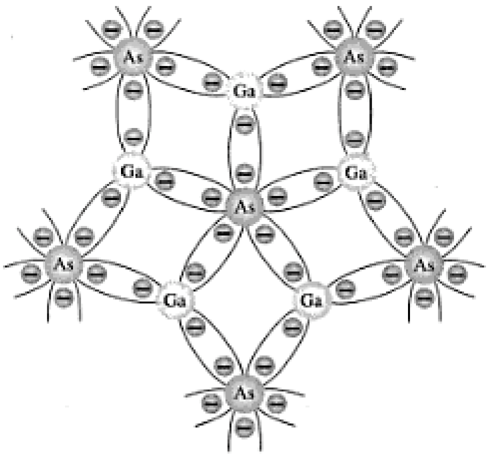
Gallium Arsenide (GaAs)

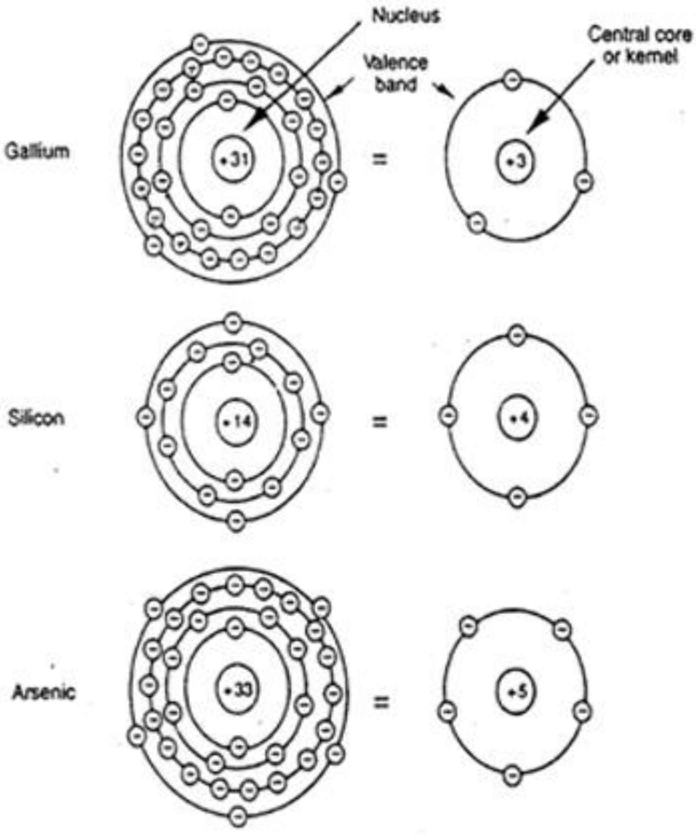
GaAs is a compound semiconductor (Ga from group III, As from group V). The lattice is formed by alternating Ga and As atoms, still forming covalent-type bonds (though with some ionic character) and so the material exhibits semiconductor properties quite distinct (for example, higher electron mobility, direct band-gap) compared with Si.




Ga
As
a


Ga
As
Ga
As
Ga
As
Ga
As
Ga



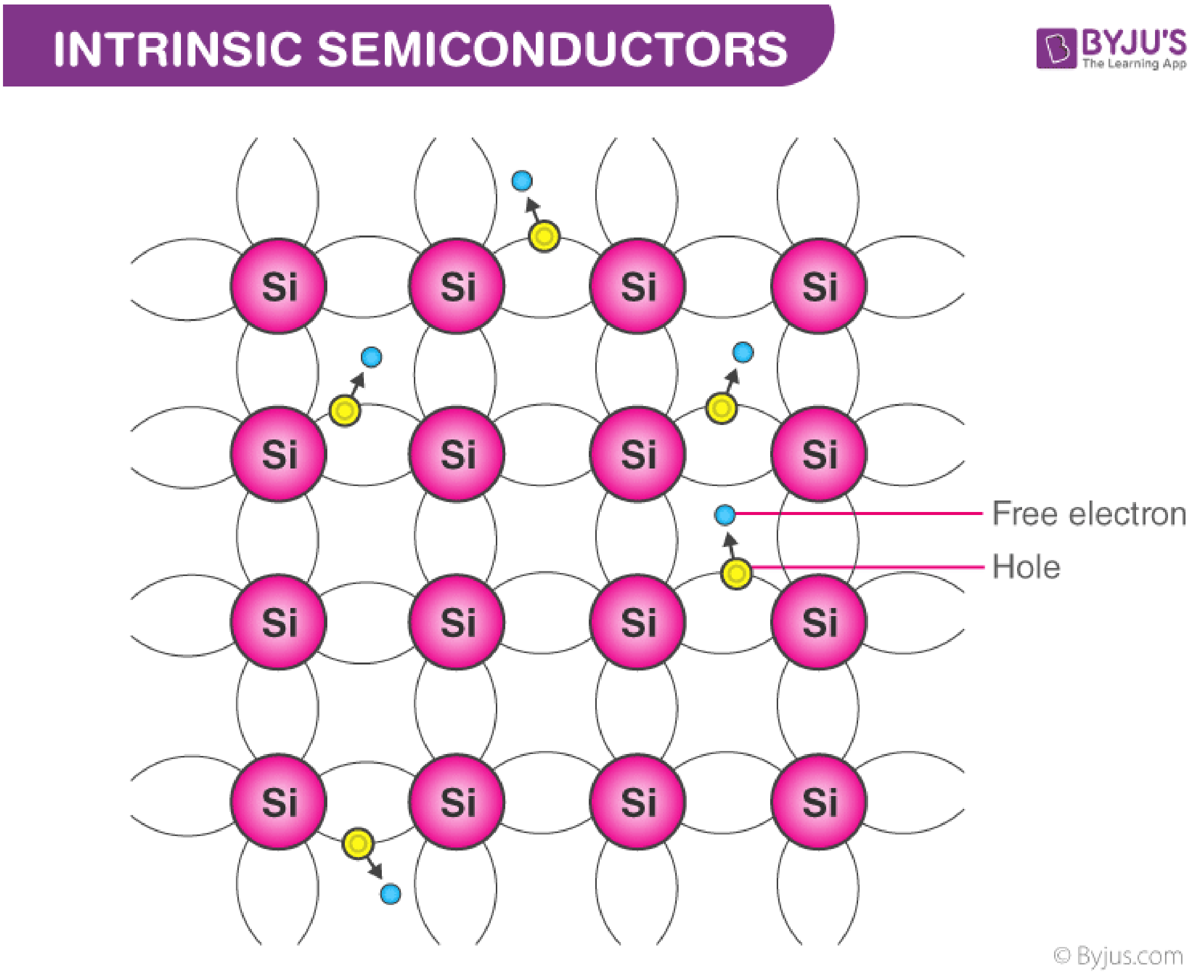


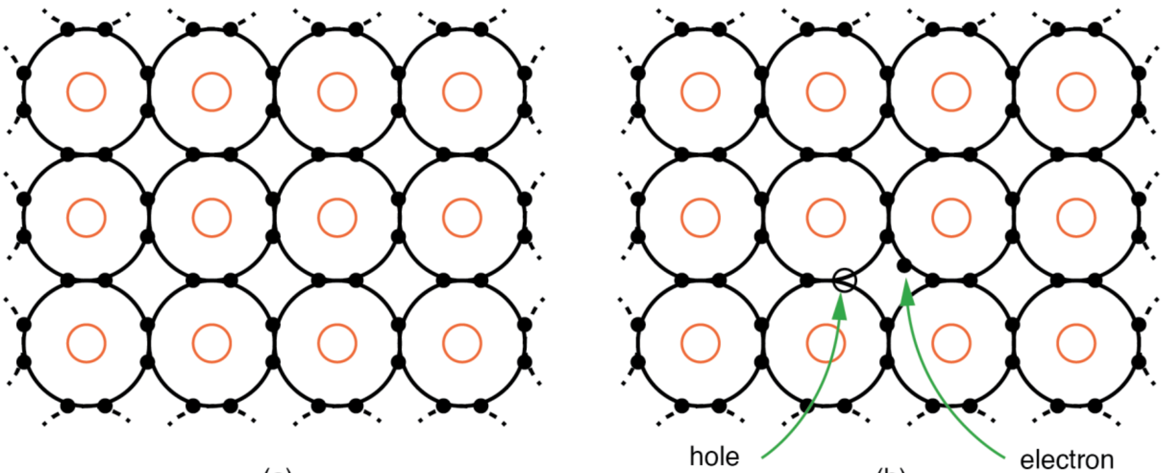
Bohr's model for silicon, gallium and arsenic

In all cases, the bonding structure and the crystal lattice determine how electrons and holes move, and thus how the semiconductor behaves.

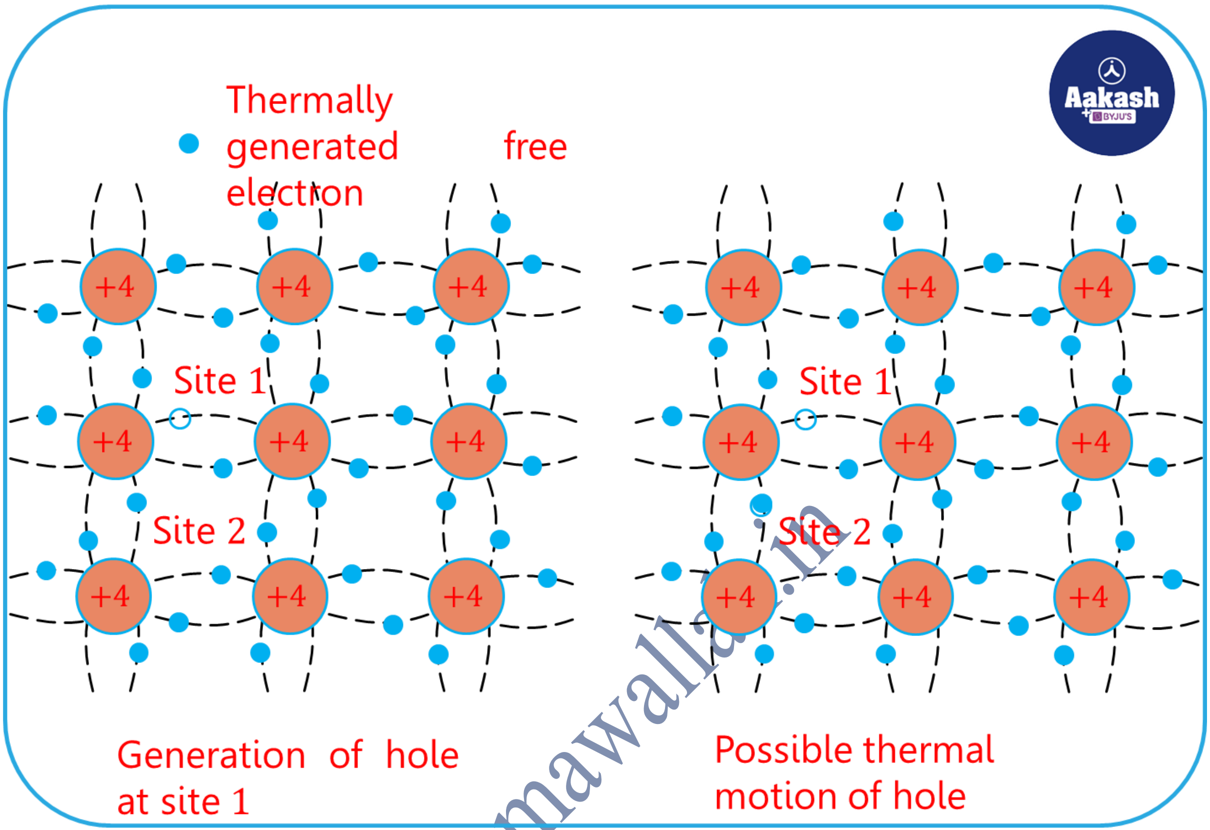
Intrinsic Semiconductors – Flow of Free Electrons & Holes

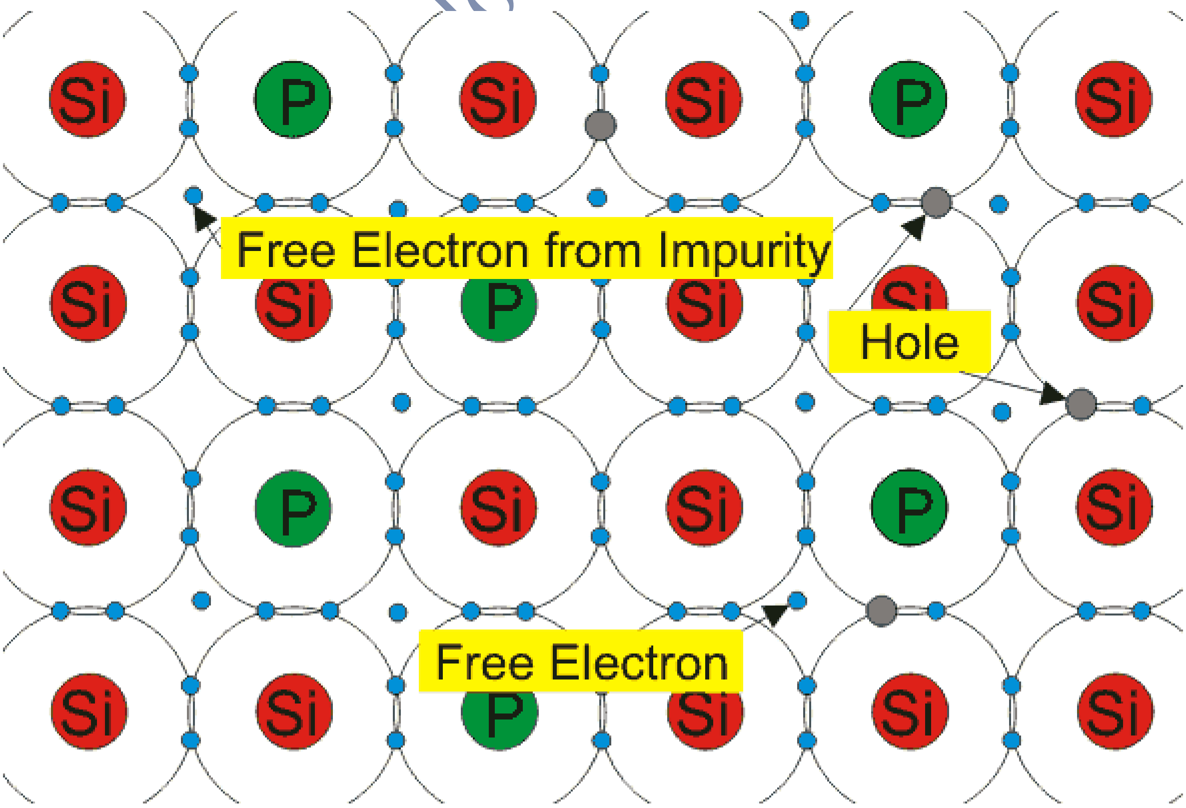
An intrinsic semiconductor is one in its purest form (no deliberate impurity doping). The only carriers available for conduction are those generated thermally (or optically). In such material: number of free electrons ((n)) equals number of holes ((p)). That is: (n = p = n_i), where (n_i) is intrinsic carrier concentration. (Testbook)





(a) (b)


Thermally generated free electron
Site 1
Site 2
Generation of hole at site 1
Possible thermal motion of hole


Free Electron from Impurity
Hole
Free Electron

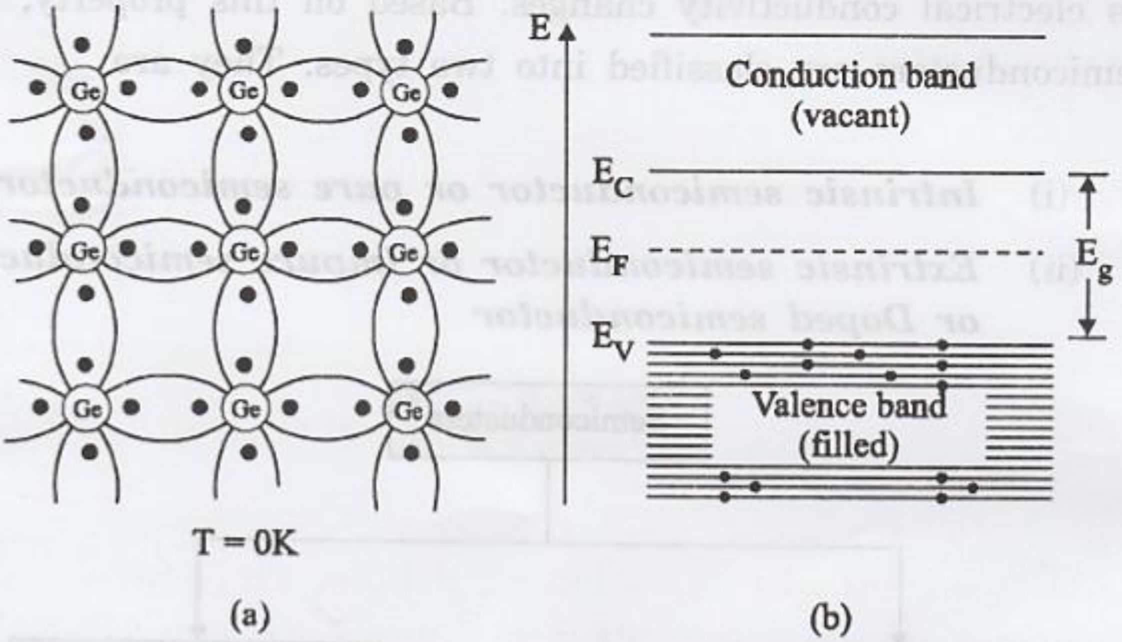
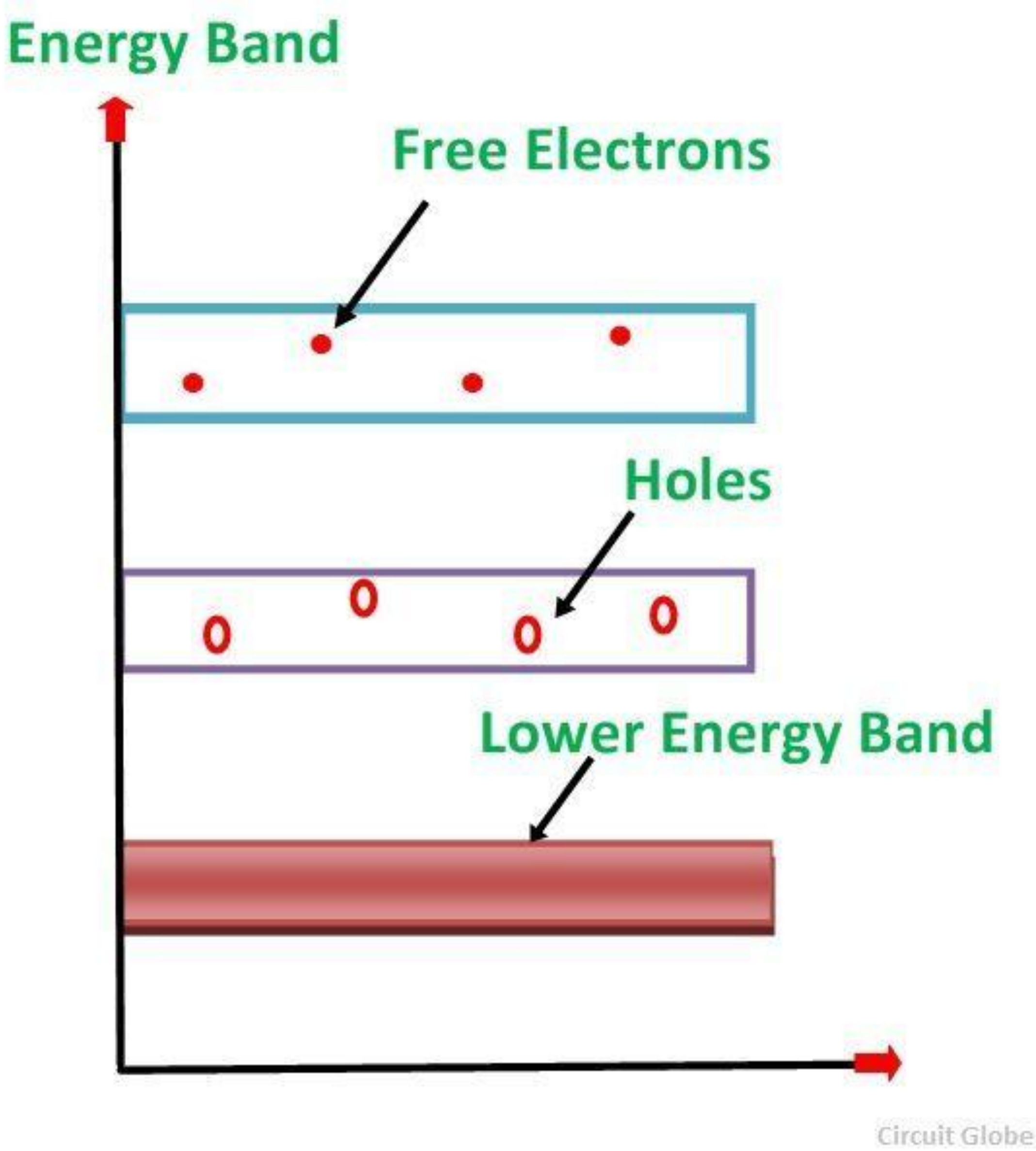
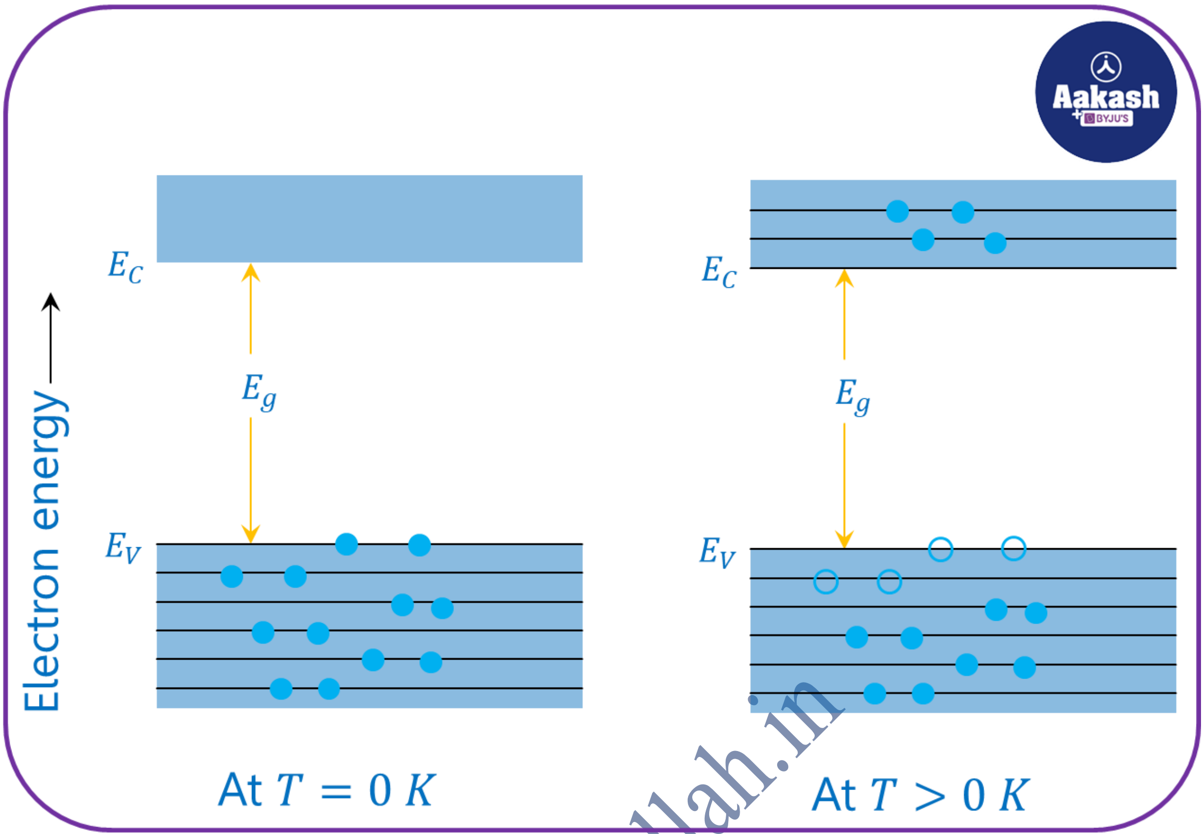


Fig. 3.3 Germanium crystal at 0K


Energy Band
Free Electrons
Holes
Lower Energy Band
Circuit Globe



Explanation of the two types of flow:

- Free electrons: electrons which have gained sufficient energy to jump from valence band to conduction band (leaving behind a hole) and hence can move through the lattice under electric field.
- Holes: the "absence" of an electron in the valence band, which can move as neighbouring electrons jump into the hole, effectively making the hole move in the opposite direction of electron motion. Because both carriers are present and mobile, intrinsic semiconductors conduct via both electrons and holes.

However, intrinsic semiconductors have relatively low conductivity at room temperature compared with well-doped (extrinsic) semiconductors, because carrier concentration is small.

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3. Doping a Semiconductor & Diode Formation

Doping a Semiconductor

Why doping?

Because intrinsic semiconductors have limited conductivity, the process of introducing selected impurities (dopants) into the semiconductor lattice is used to **increase the number of free carriers** (either electrons or holes) and thus *tune* the electrical properties for device use. (BYJU'S)
Doping can raise conductivity by many orders of magnitude. (BYJU'S)

Two types of extrinsic semiconductors

1. **N-type Semiconductor**:
   - Formed by doping a pure (group IV) semiconductor (such as Si) with a pentavalent impurity (group V element) such as Phosphorus (P), Arsenic (As), or Antimony (Sb). These atoms have five valence electrons. When substituted into the lattice, four of the electrons bond covalently with neighbouring atoms, but the 5th electron is loosely bound, so it becomes a free electron in the conduction band (or very close to it).
   - Therefore, the majority carriers in an n-type semiconductor are electrons; the holes are the minority carriers. (Wikipedia)
   - These donor atoms become positively charged ions (once they donate the extra electron) but they are fixed in the lattice.
2. **P-type Semiconductor**:
   - Formed by doping with a trivalent impurity (group III element) such as Boron (B), Aluminium (Al), or Gallium (Ga). These atoms have only three valence electrons. When substituted into the lattice, they form three covalent bonds but one bond is incomplete (a "hole" is created). This hole can accept an electron from a neighbouring atom, leaving a new hole behind — thus holes effectively move through the lattice.
   - In a p-type semiconductor the majority carriers are the holes; electrons are the minority carriers. (Wikipedia)

Majority vs Minority Carriers

- Majority carriers: the type of charge carrier present in greater concentration (electrons for n-type; holes for p-type).

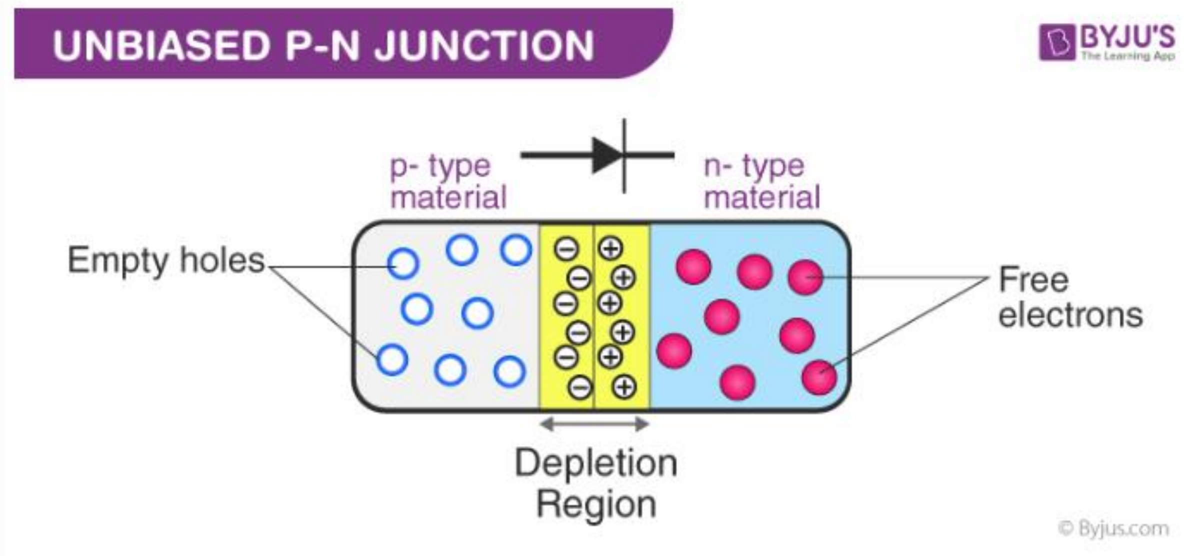
- Minority carriers: the carrier present in lesser concentration (holes for n-type; electrons for p-type).
  This distinction is crucial when analysing behaviour of junction devices (diodes, transistors) because performance often depends on minority carrier behaviour (e.g., recombination) as well as majority.

Diode – Formation & Depletion Region

Formation of a p-n junction

When we join or bring together a piece of p-type semiconductor with a piece of n-type semiconductor, a p-n junction is formed. At the interface:

- Electrons from the n-side diffuse into the p-side (because there is a gradient: high electron concentration in n-side, low in p-side).
- Holes from the p-side diffuse into the n-side.
- As electrons and holes diffuse they recombine: electrons fill holes.
- This leaves behind fixed ions: on the n-side, donor ions become positively charged (since they donated electrons); on the p-side, acceptor ions become negatively charged (since they captured electrons).
- The region around the junction where mobile carriers have diffused away and left fixed ions is called the **depletion region** (or depletion layer).



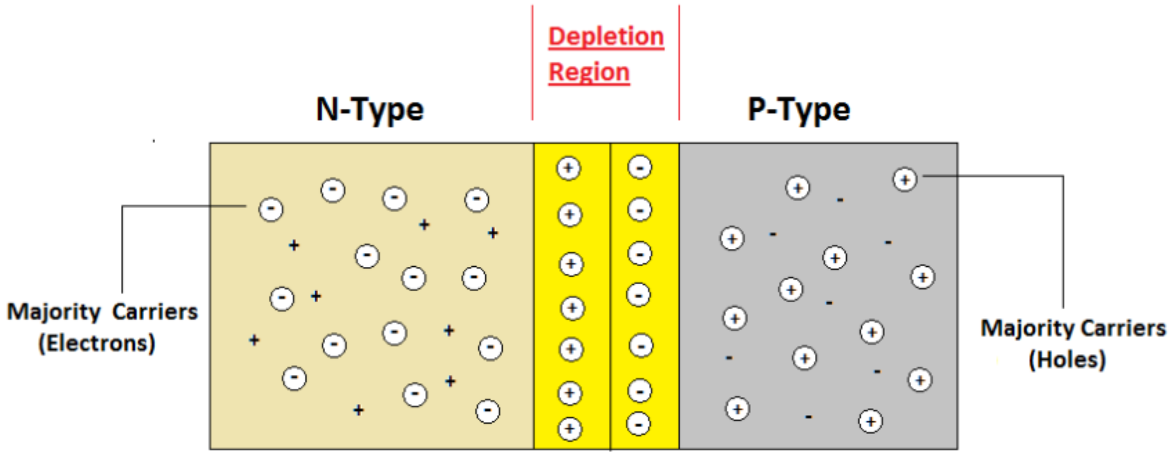
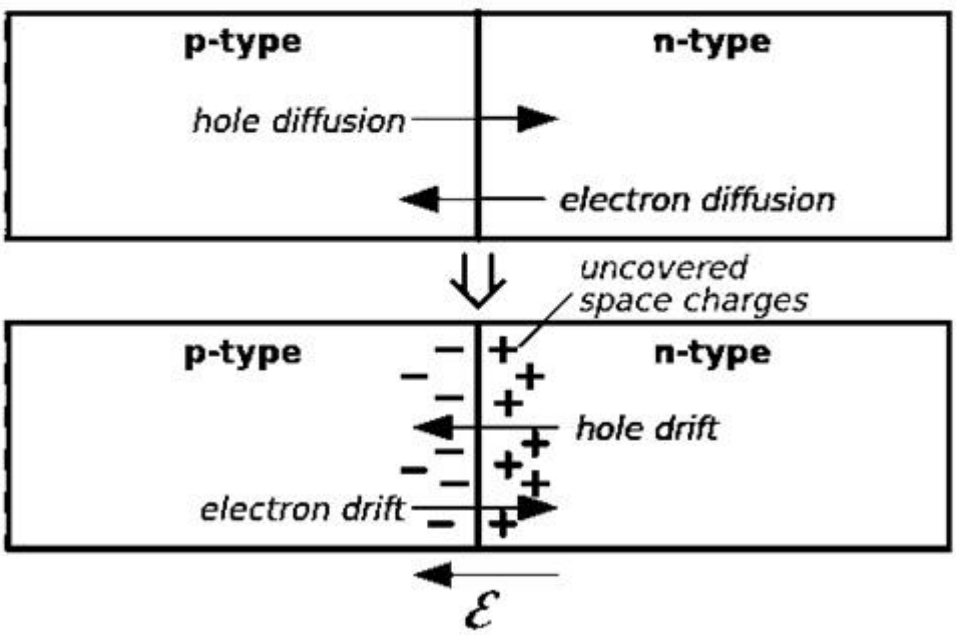
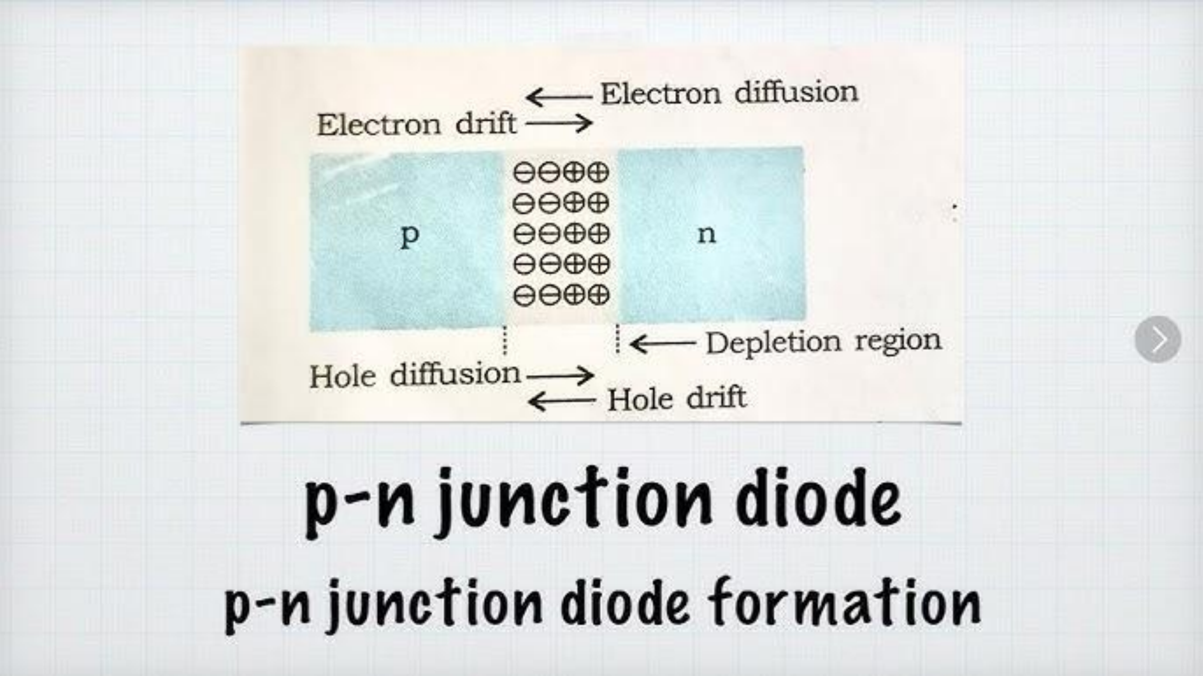
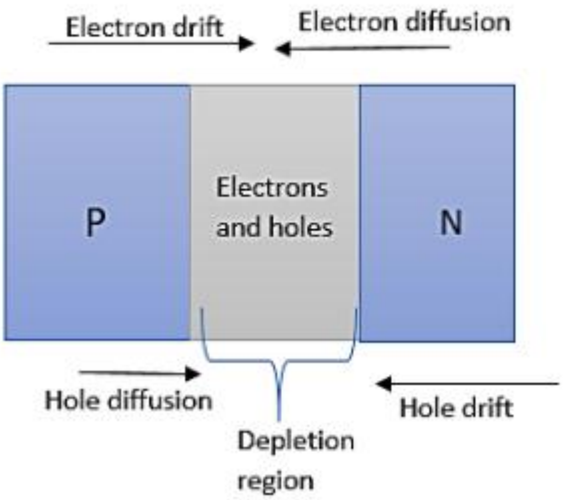
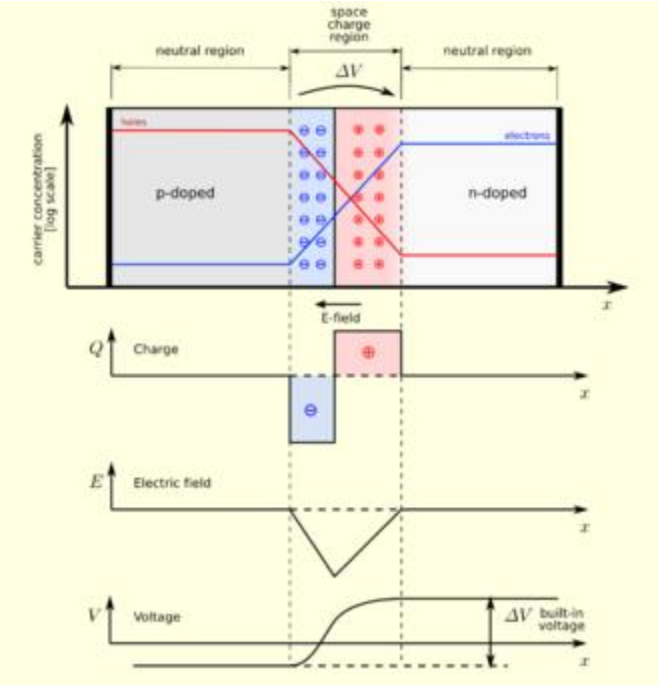


Figure: Depletion region in a p-n junction




Electron diffusion
Electron drift
p
n
Depletion region
Hole diffusion
Hole drift
p-n junction diode
p-n junction diode formation


Electron drift
Electron diffusion
P
Electrons
and holes
N
Hole diffusion
Hole drift
Depletion
region



Depletion region and barrier potential

- In the depletion region there are essentially no mobile charge carriers (neither free electrons nor free holes) — it is “depleted”. The fixed ions create an electric field (space-charge region) which acts as a barrier to further diffusion of carriers.
- This electric field establishes a built-in potential (junction potential) across the depletion region which must be overcome for current to flow.
- Under **zero bias** (no external voltage applied), diffusion current (carriers moving by concentration gradient) and drift current (carriers pushed by internal field) are in equilibrium → no net current.
- Under **forward bias** (positive voltage applied to p-side relative to n-side): the external voltage reduces/modifies the barrier potential, the depletion region narrows, carriers cross more easily, and significant current flows.
- Under **reverse bias** (negative voltage to p-side relative to n-side): the barrier is increased, the depletion region widens, very little current flows (only small leakage). (Basic Electronics Tutorials)

Diode symbol & characteristic behaviour

- The symbol of a diode: a triangle pointing to a line (anode to cathode).
- Characteristic: current flows easily in forward direction after threshold, blocks current in reverse direction until breakdown.
- This single p-n junction device is the basis of many electronic circuits (rectifiers, clipping circuits, protection diodes, etc).

Summary of this Section

- Doping transforms an intrinsic semiconductor into an extrinsic one, by introducing donor or acceptor atoms, thereby increasing carrier concentrations and tuning conductivity.
- N-type: donor dopants → electrons majority carriers.
- P-type: acceptor dopants → holes majority carriers.
- When p and n regions are joined, a depletion region forms at the junction, with fixed ions and an internal electric field; this leads to the behaviour of a diode (allowing current one way, blocking the other).

Final Overview

Putting it all together:

- You now have detailed theory for **passive components**: resistors, inductors, capacitors — their roles, symbols, units, types, how to pick them, applications in circuits.
- You also have deep understanding of **semiconductors**: what they are, key materials (Si, Ge, GaAs), characteristics, covalent bonding, intrinsic behaviour (electrons + holes).
- Then we moved to **doping and extrinsic semiconductors**, including n-type/p-type concepts, majority/minority carriers, and the formation of p-n junction (diode), along with the physics of the depletion region and how the diode functions.

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