DELD

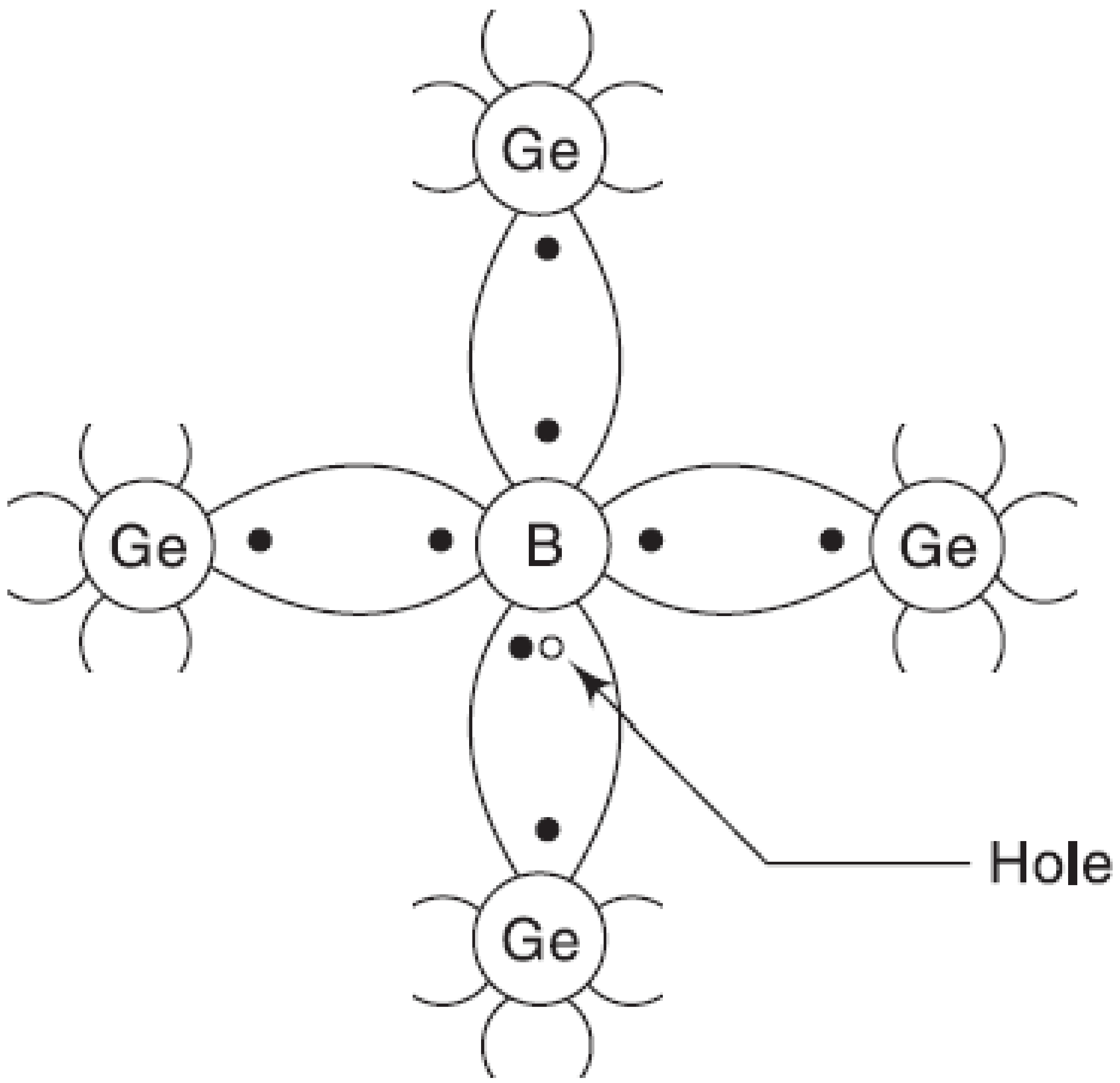
Unit 1

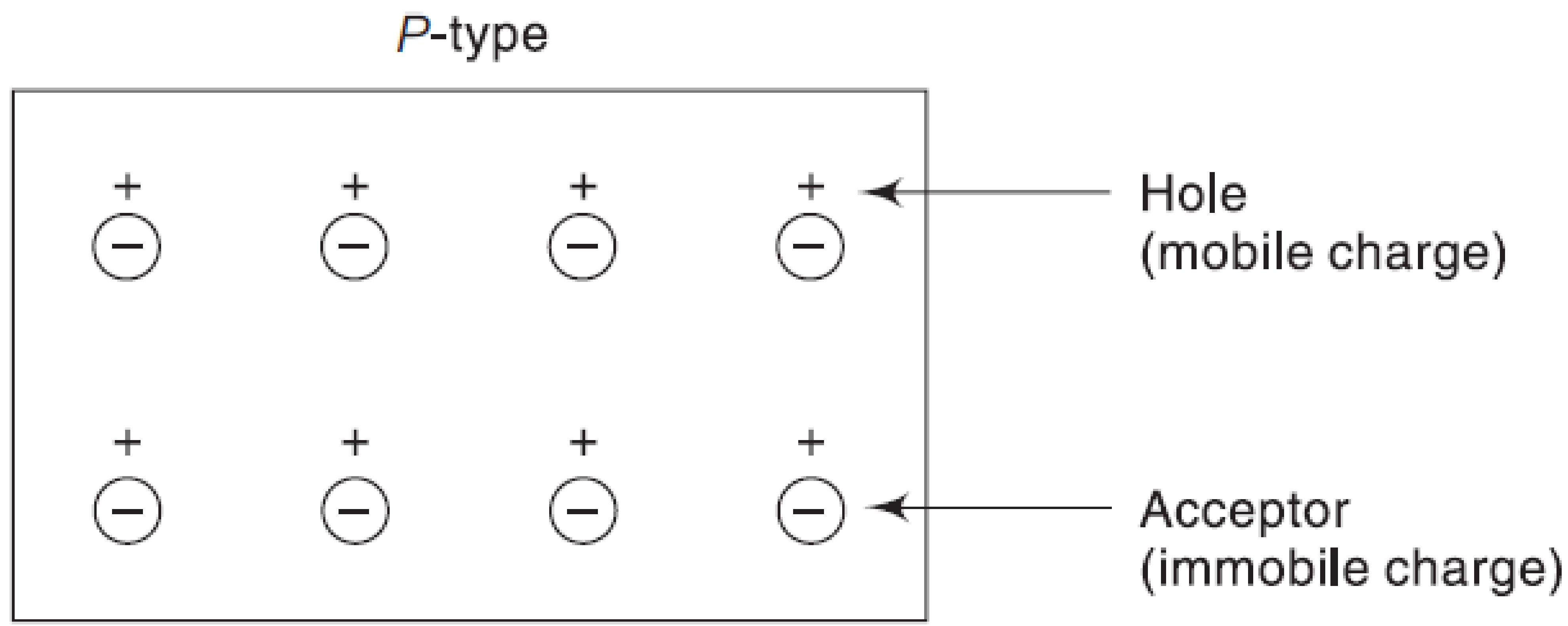
PN Diode and Transistor

Electronics Engineering Department

P – Type Semiconductor

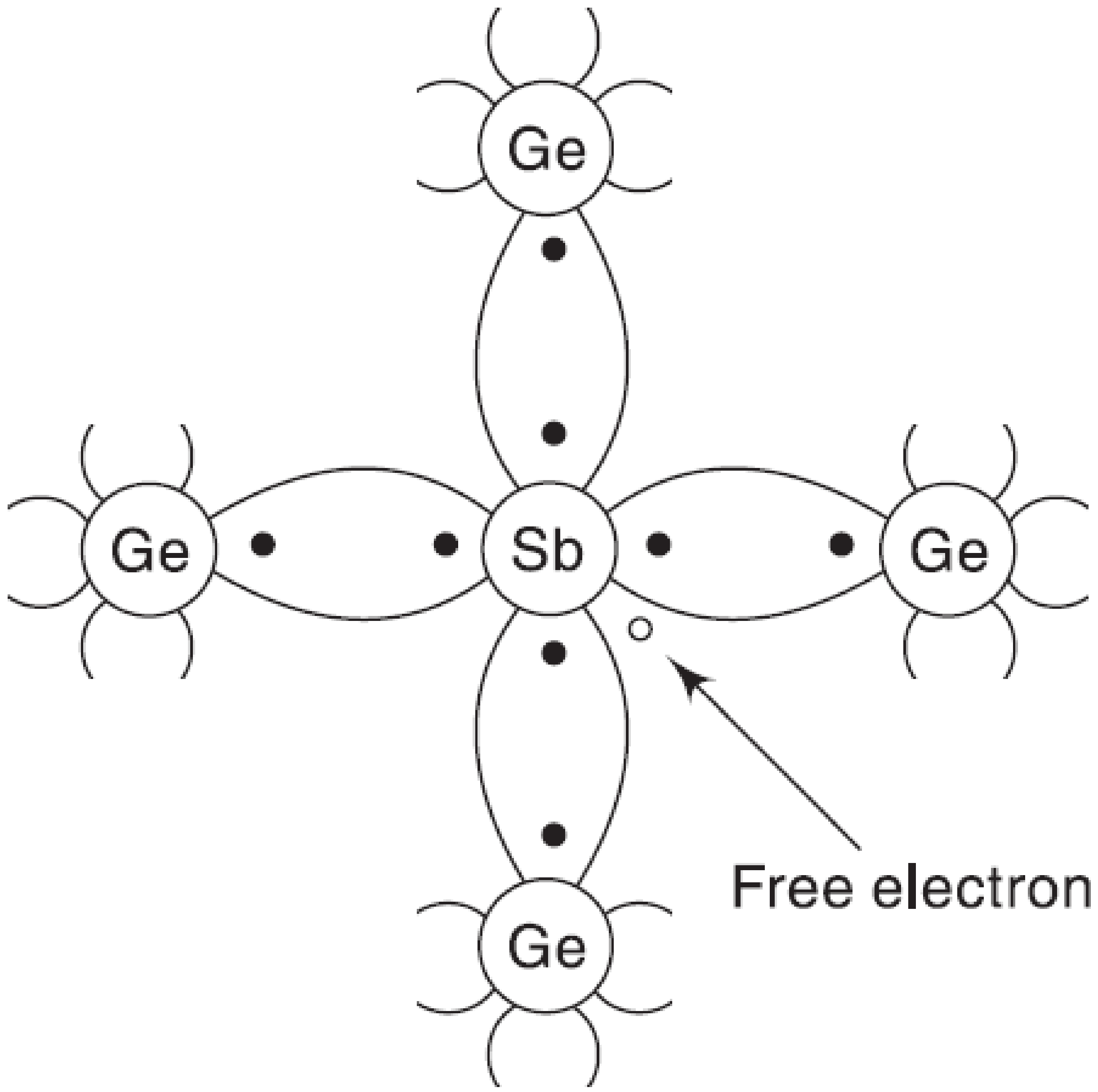
Germanium doped with Boron (Trivalent Impurity)

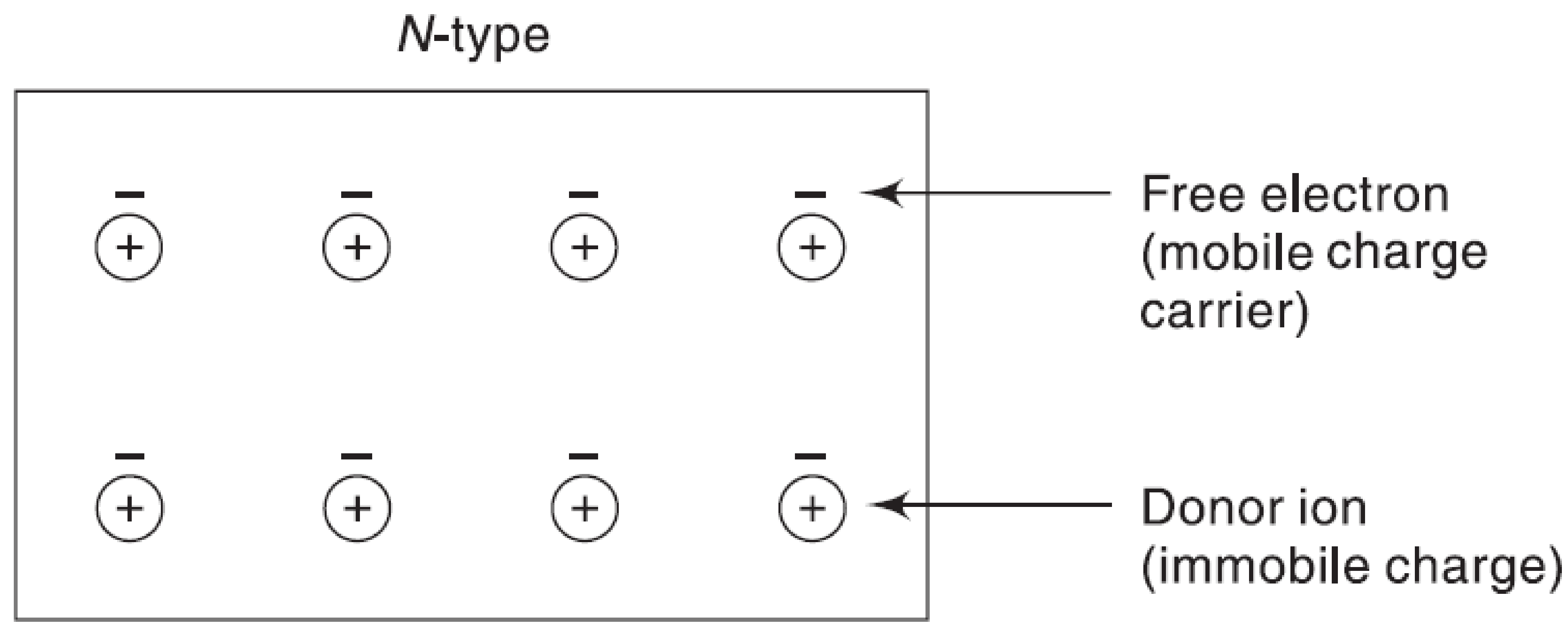




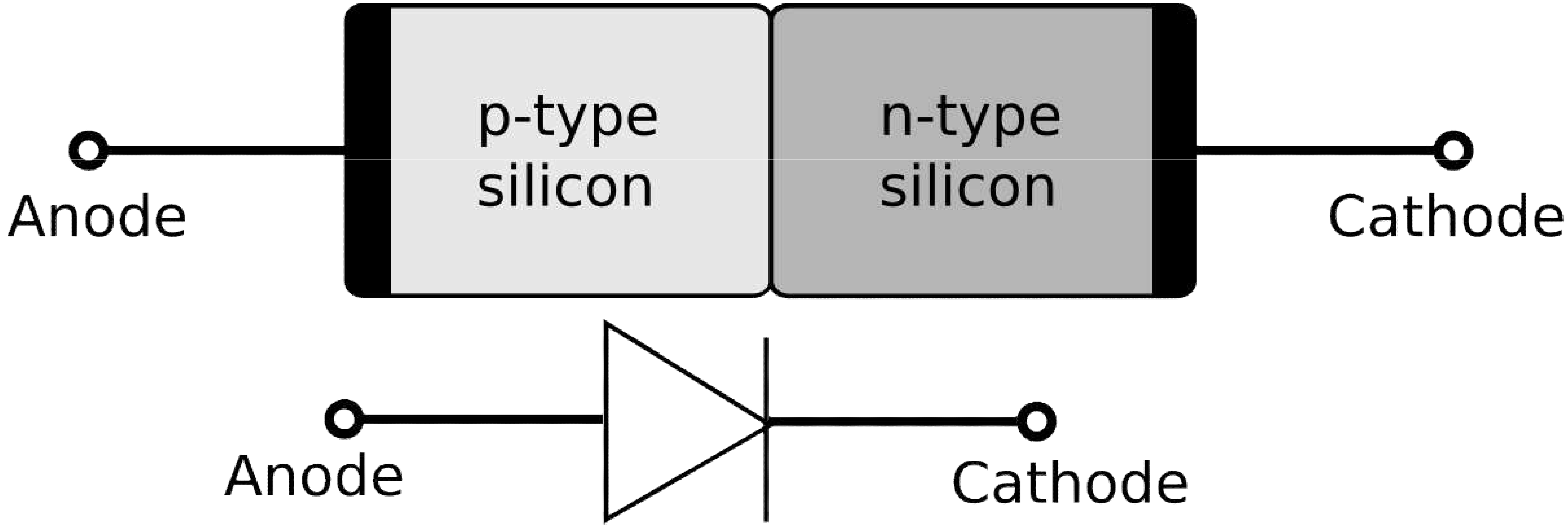
N – Type Semiconductor

Germanium doped with Antimony (Pentavalent Impurity)

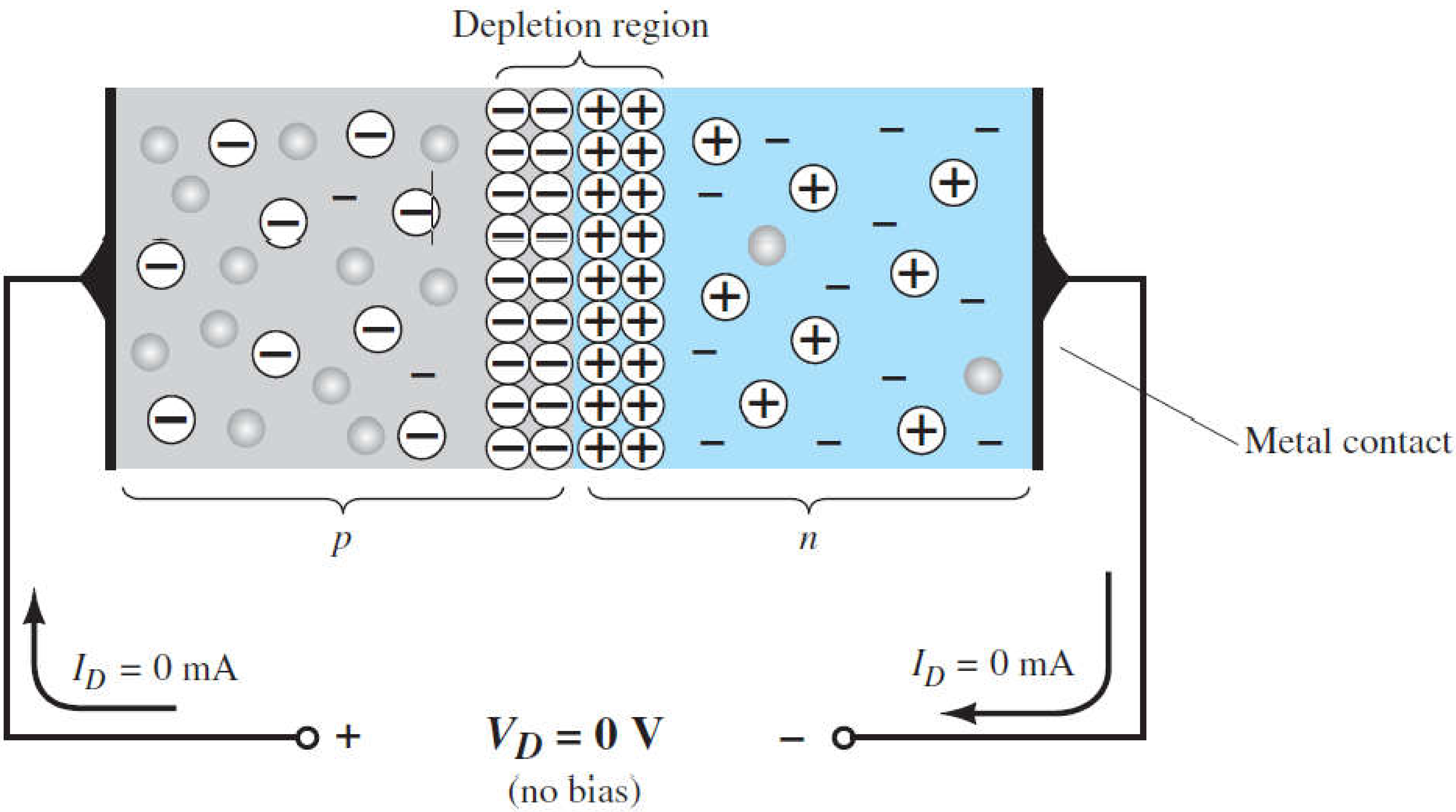




PN Junction



Depletion Layer



Depletion Layer

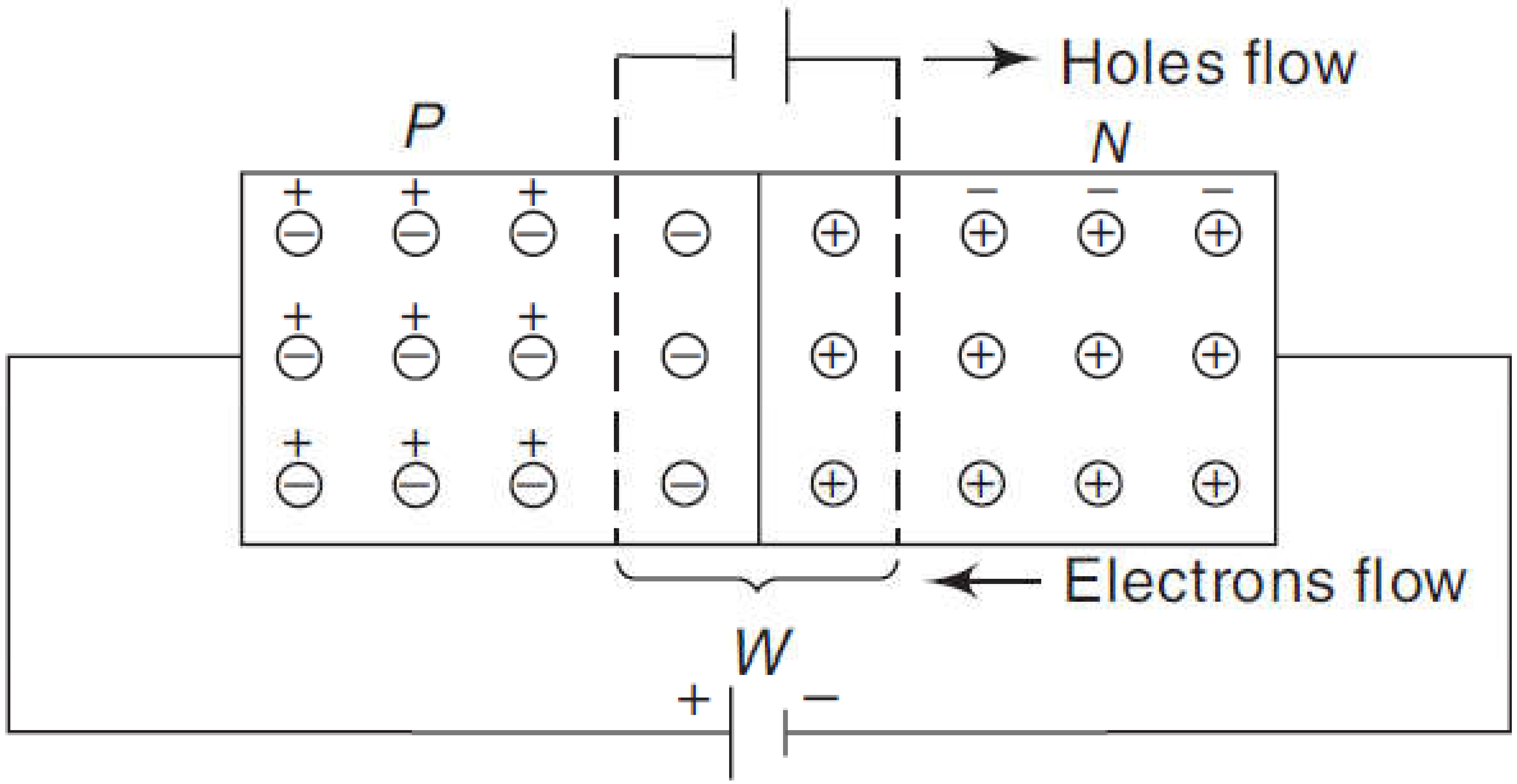
- The excess electrons in the N- Region cross the junction and combine with the excess holes in the P – region.
- N- Region looses electrons and becomes positively charged
- P - Region looses holes and becomes negatively charged
- At some point this migration stops (Concentration becomes same)
- Any additional electrons from N side are repelled by the negative charge of the P – Region
- Similarly, additional holes from the P side are repelled by the positive charge of the N –Region

Depletion Layer Cont…

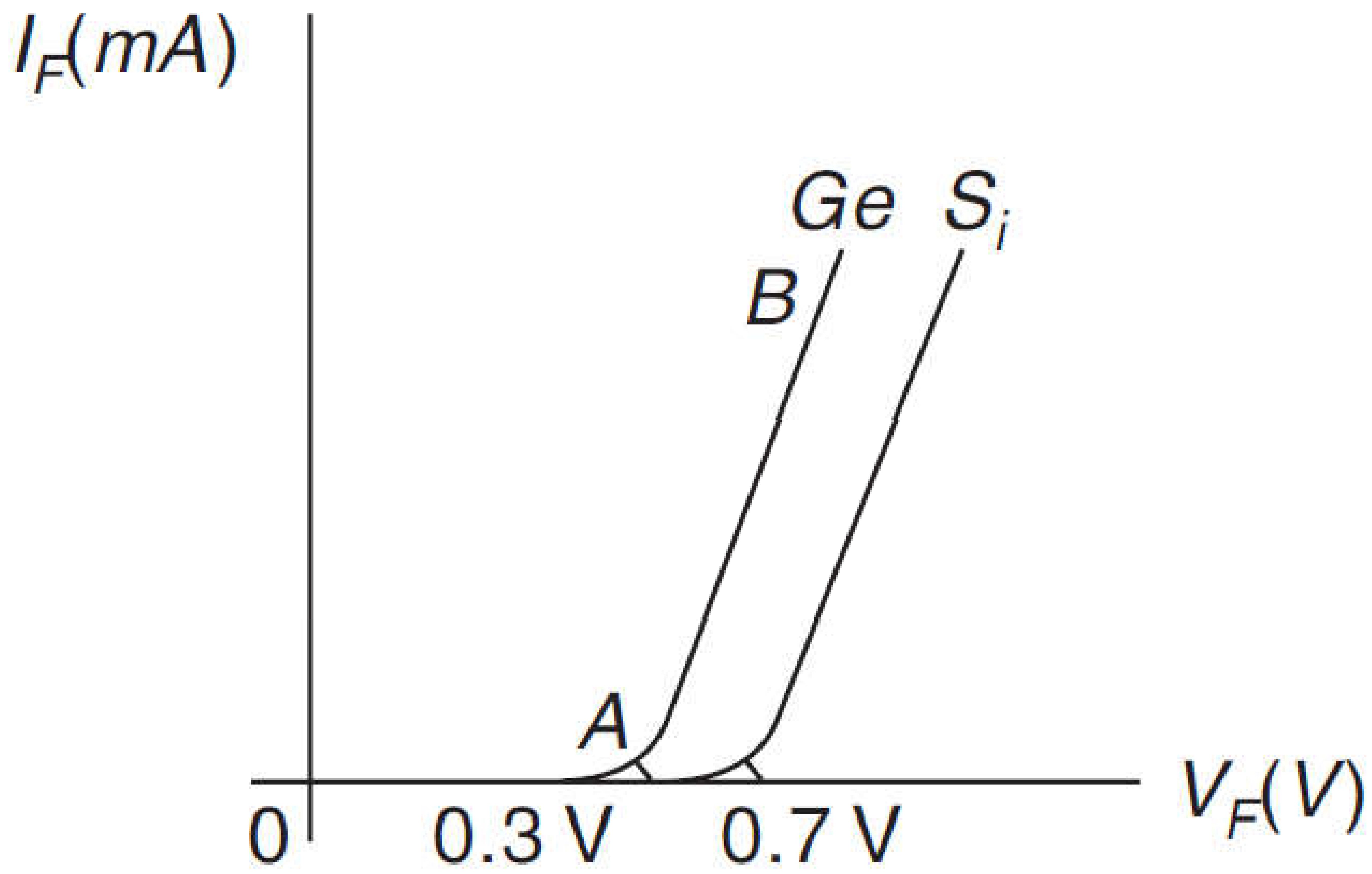
- This results in a thin layer on both the sides at the junction which contains only immobile charge carriers. This is known as depletion layer. Range is in micrometers
- Width depends on doping
- Heavily doped – less width and vice-versa
- Electrons in the N region have to climb the potential hill in order to reach the P – Region. This potential is known as Potential Barrier.
- Ge – 0.3 volts, Silicon – 0.7 volts

Forward Bias

- Positive terminal of the battery is connected to p-region and negative terminal is connected to n-region
- Width of depletion layer decreases
- Current flows in the forward direction and diode acts as a short circuit



Forward Characteristics



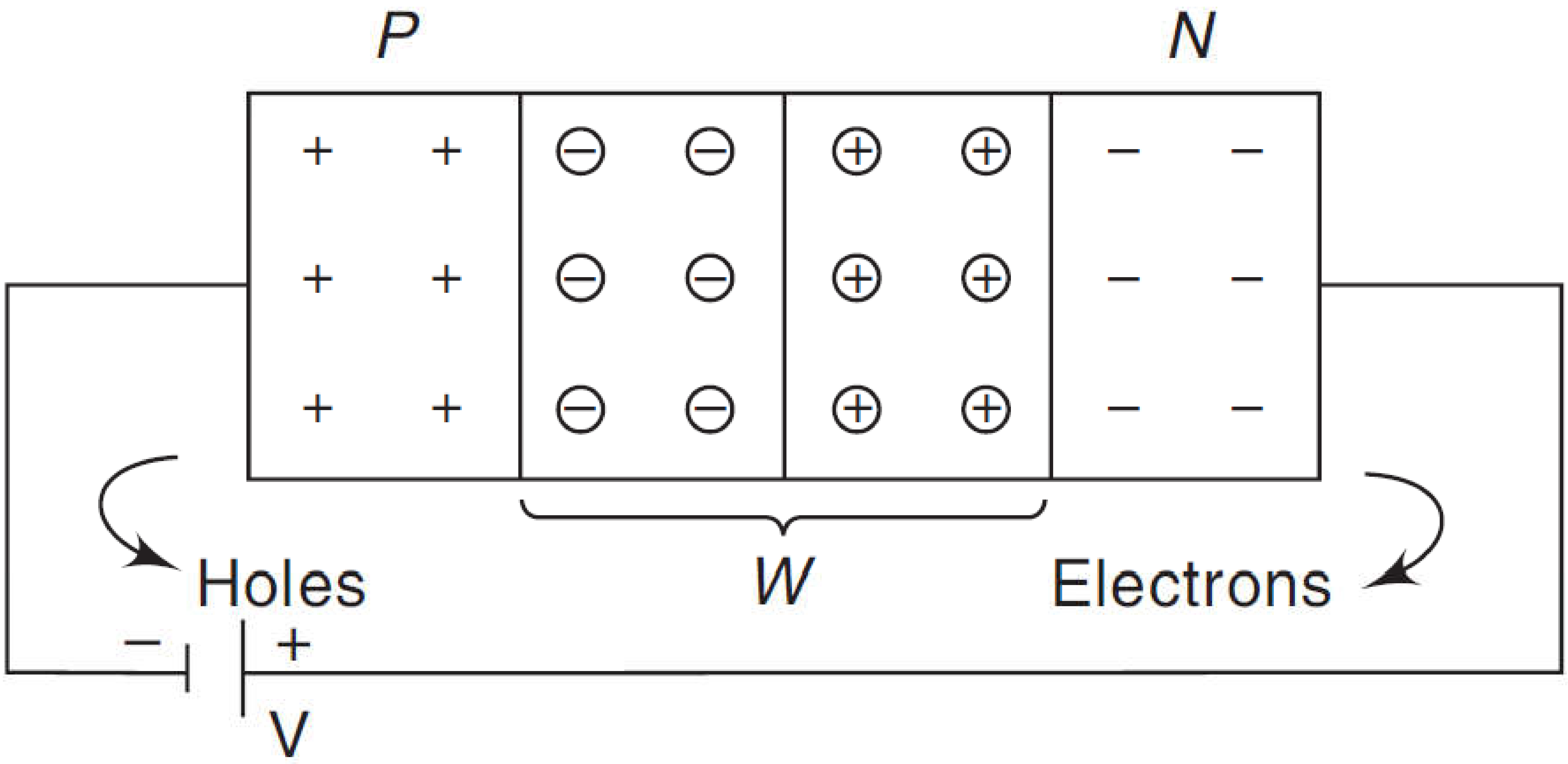
Diode Equation

$$I_D = I_s(e^{V_D/nV_T} - 1)$$

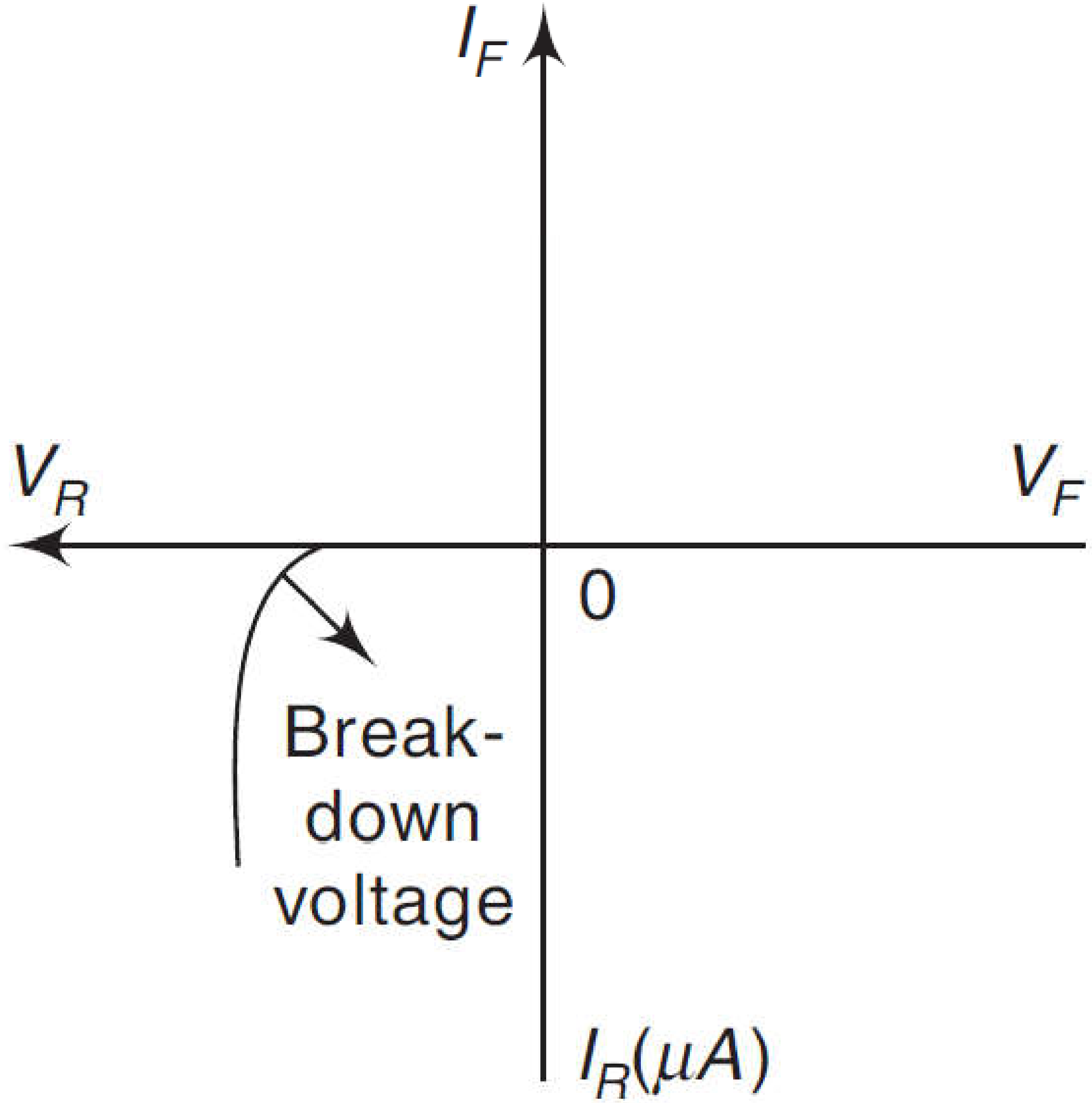
- Is – Reverse Saturation Current
- Vd is the applied Forward Biased voltage
- n – Ideality Factor (if not mentioned, assume as 1)
- Vt – Thermal voltage (25 milli volts at room temperature: 27 degrees/300 degree K)

Reverse Bias

- Positive terminal of the battery is connected to N – side and Negative terminal of the battery is connected to P – Side
- The free electrons and the free holes are attracted back towards both the battery terminals
- The charge carriers move away from the depletion layer
- Width of depletion layer increases
- No current flows and the diode acts as an open circuit



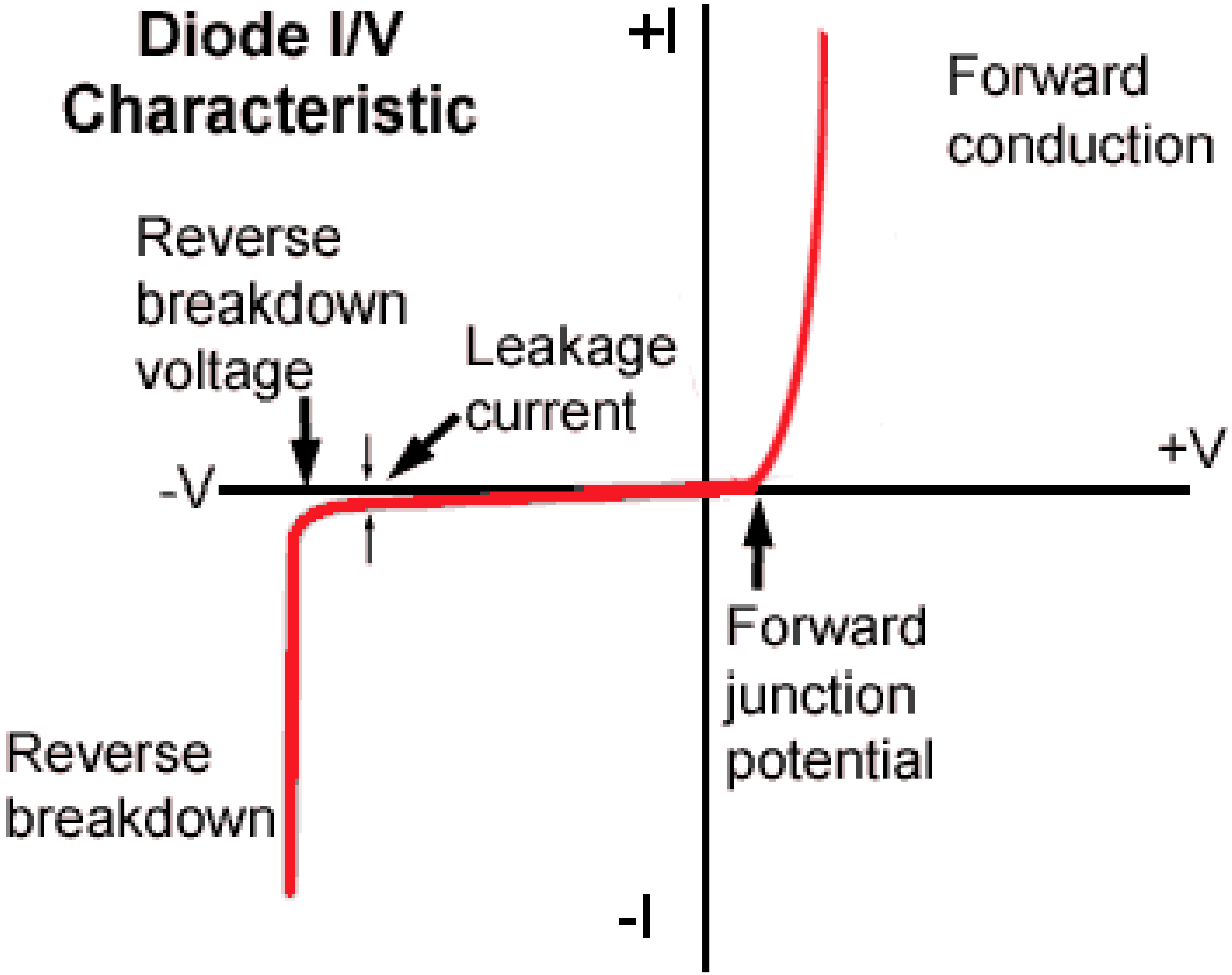
Breakdown Voltage



❑ Go on increasing the reverse bias. At certain voltage, The current increases at a very rapid rate in a direction opposite to that of the positive voltage region.

❑ The reverse-bias potential that results in this dramatic change in characteristics is called the **Breakdown Voltage**.

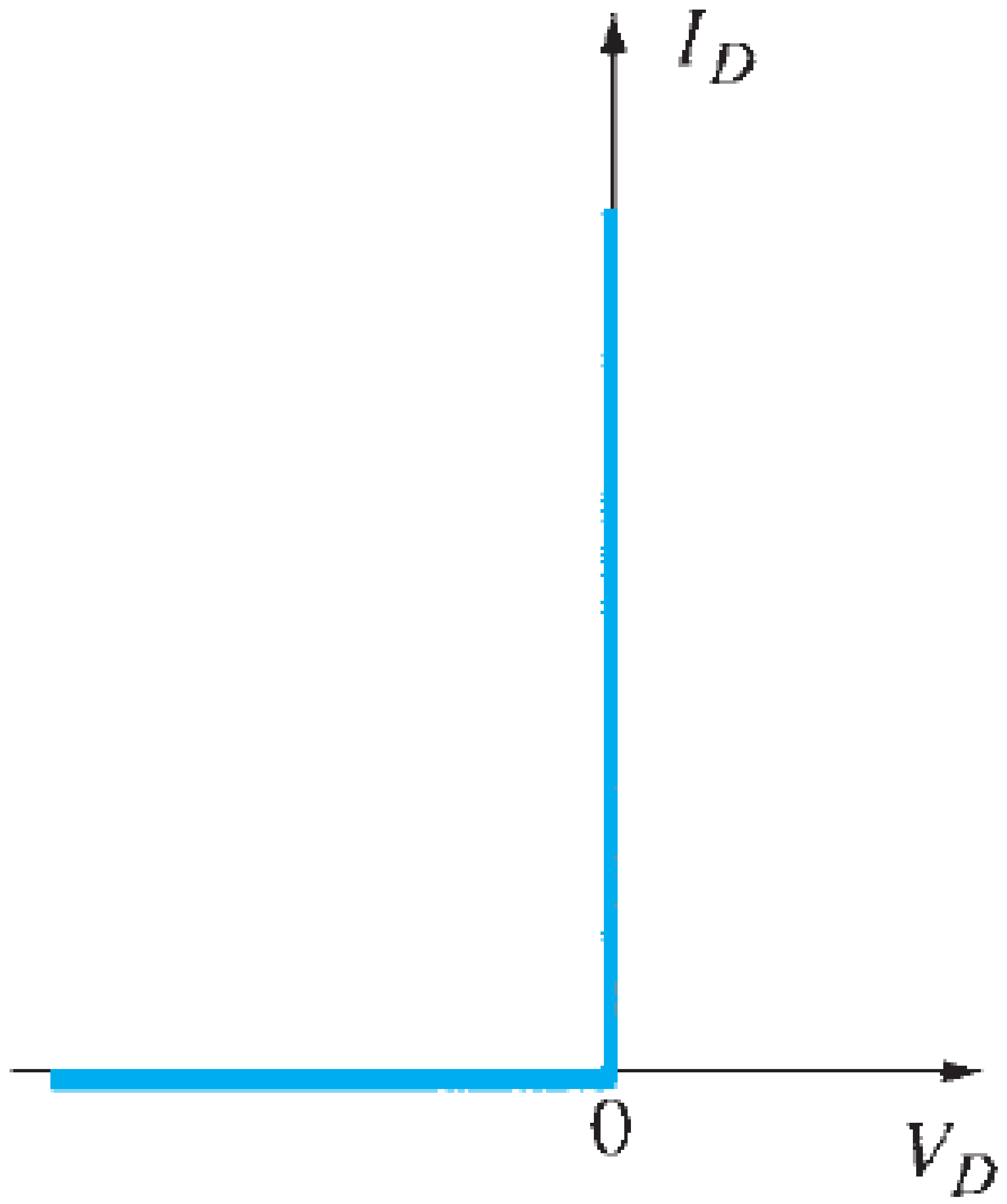
Diode Characteristics

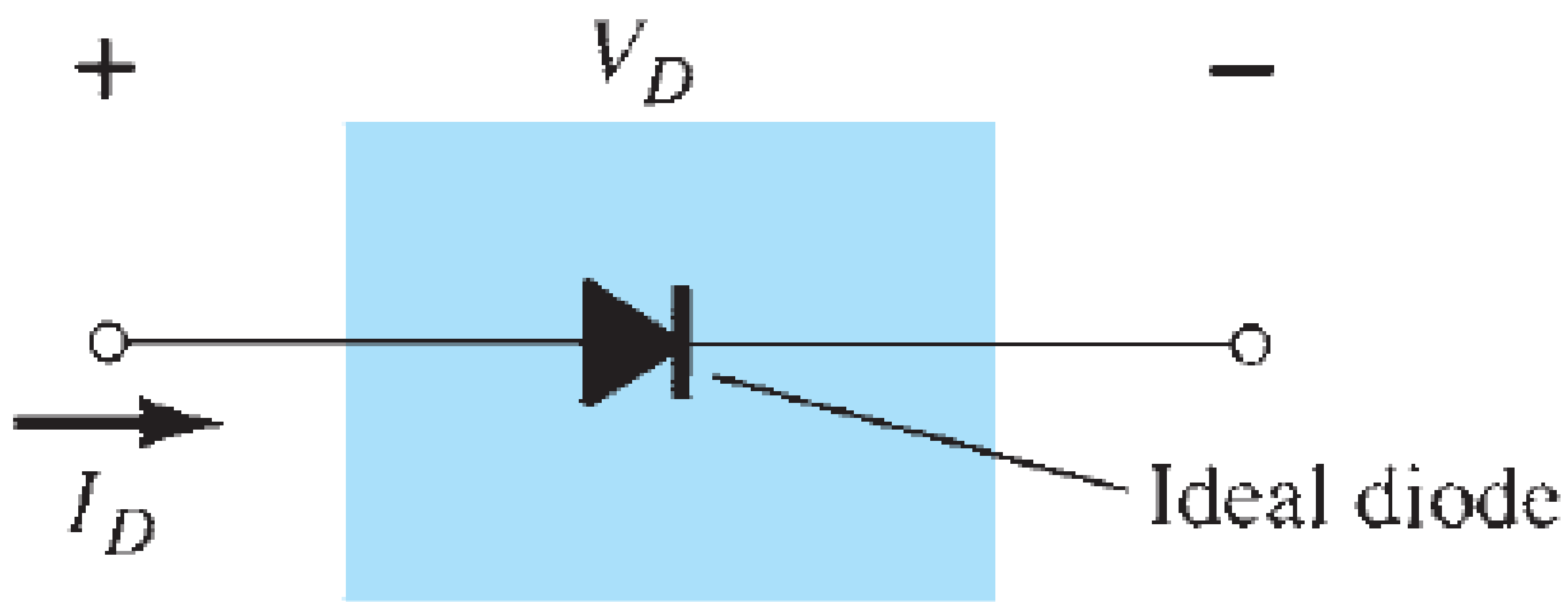


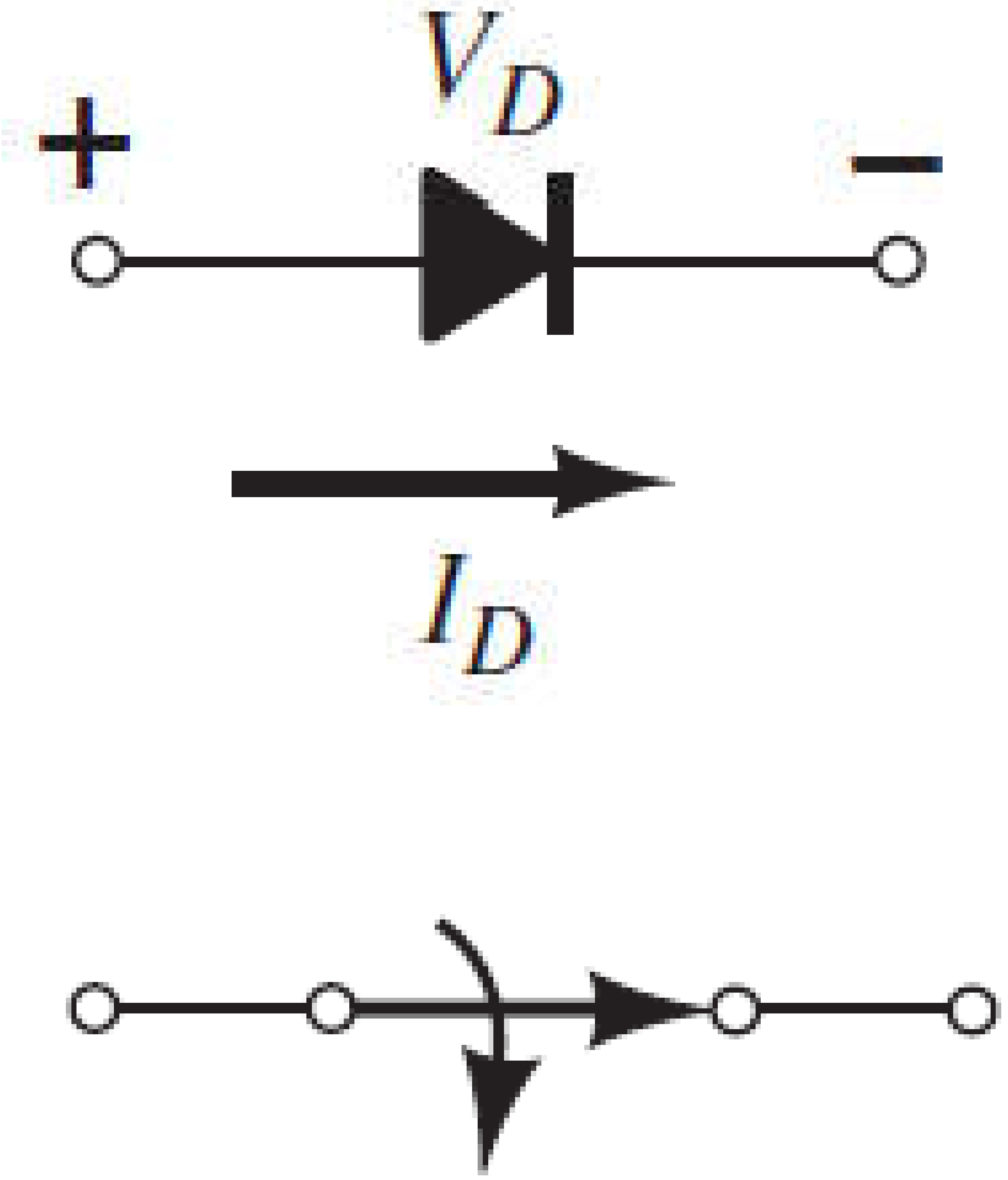
Equivalent Circuits

Ideal Diode

Diode will behave as short circuit as soon as the voltage across it becomes greater than zero



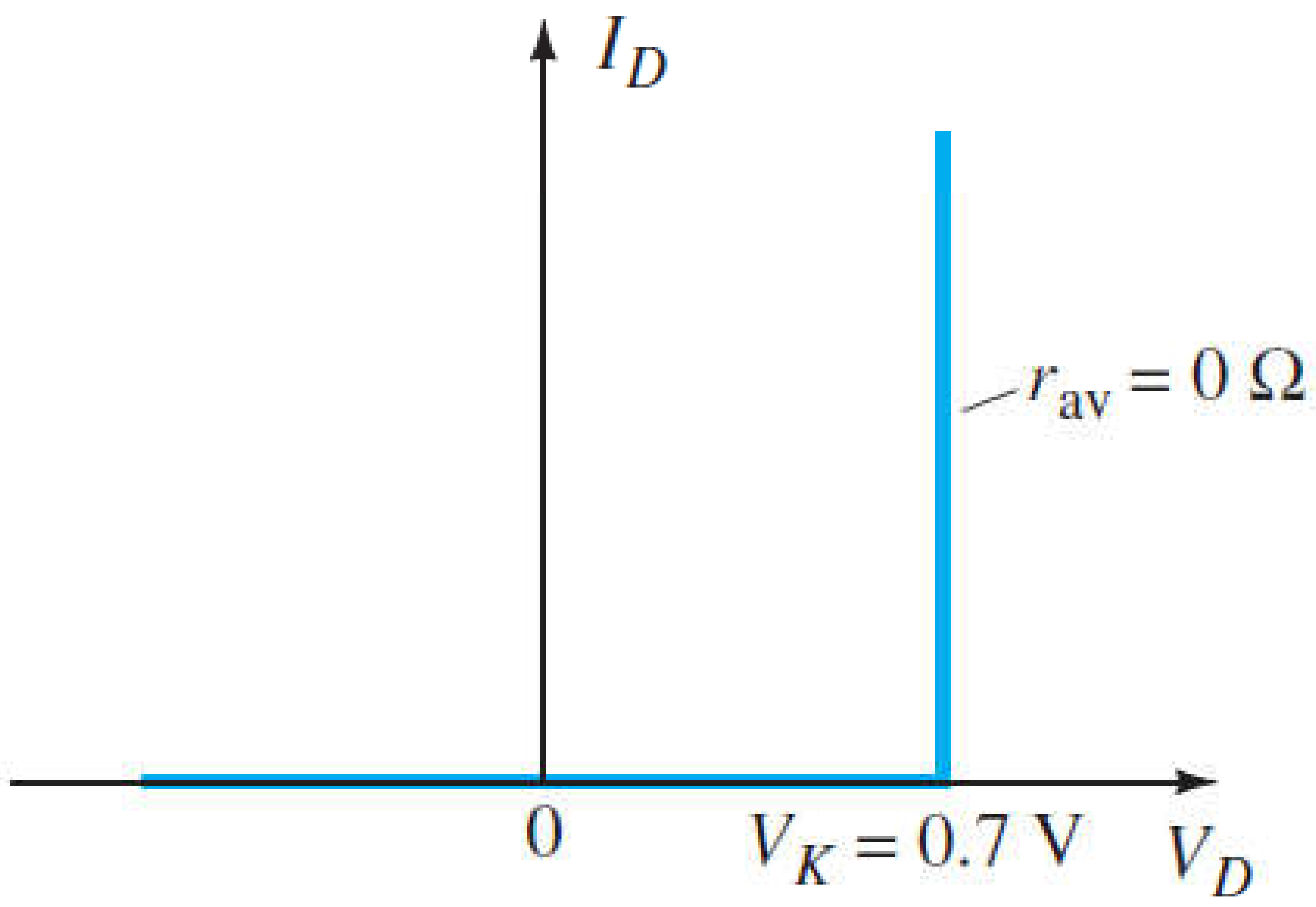


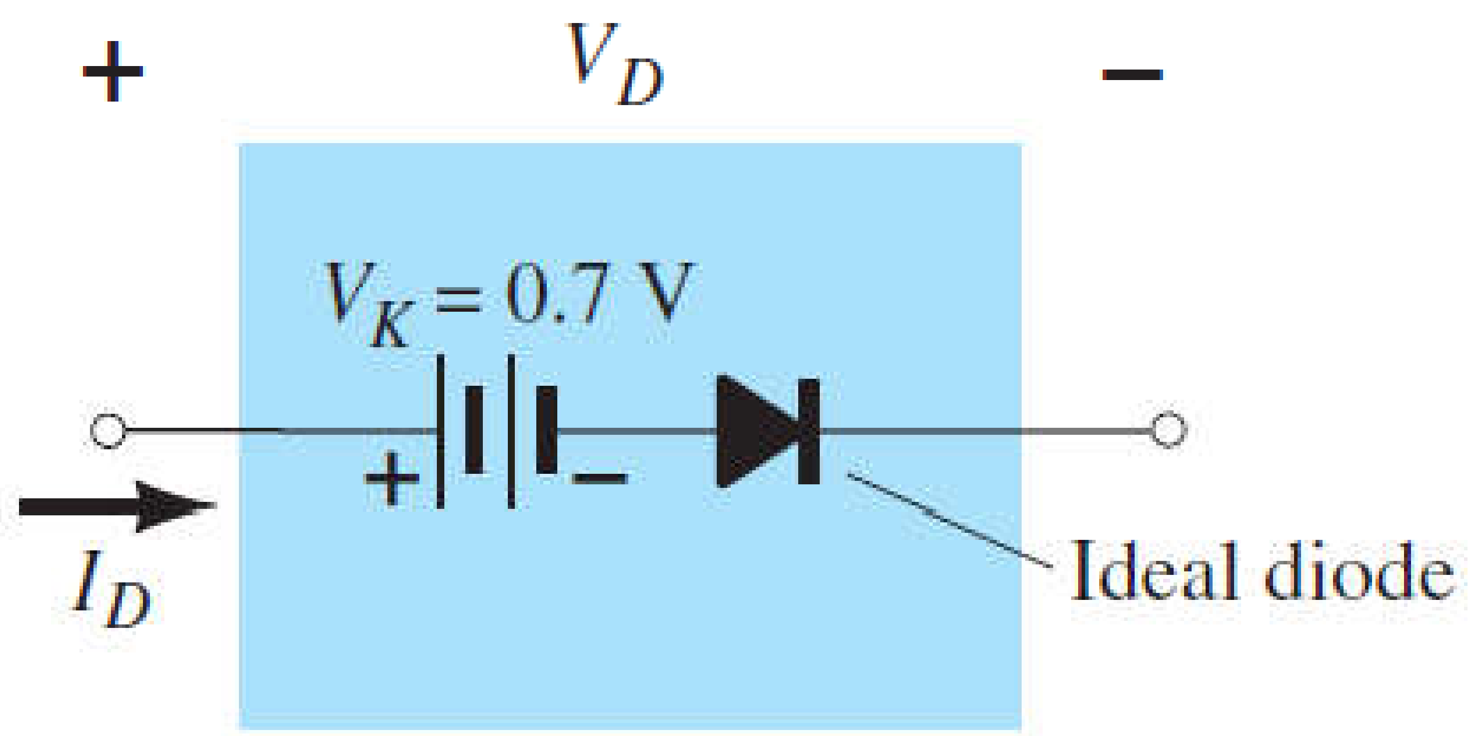


+
V_D
−
I_D
−
V_D
+
I_s

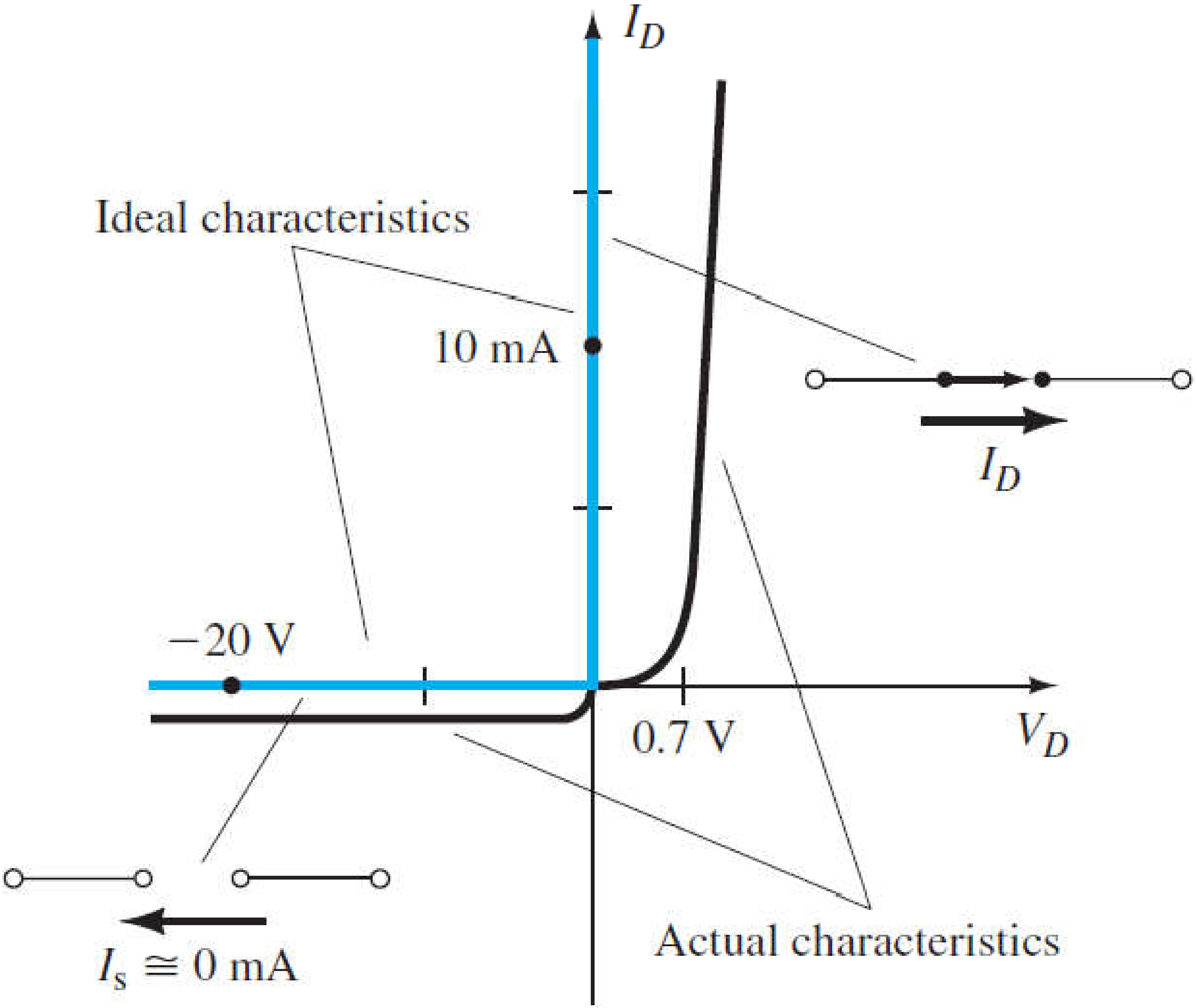
Practical Diode

We must overcome the potential barrier of 0.7 volts (silicon) for a diode to make it forward bias



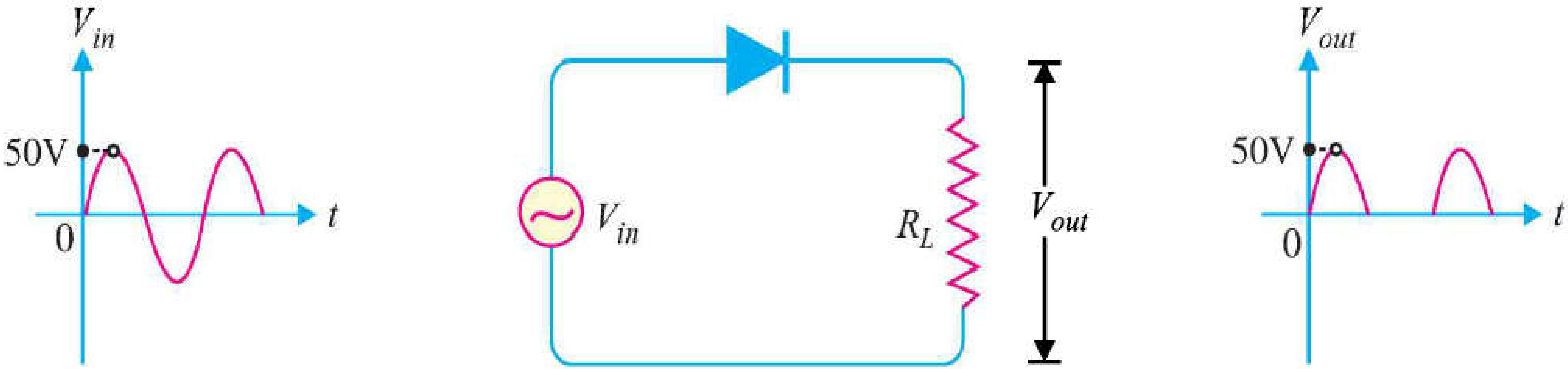


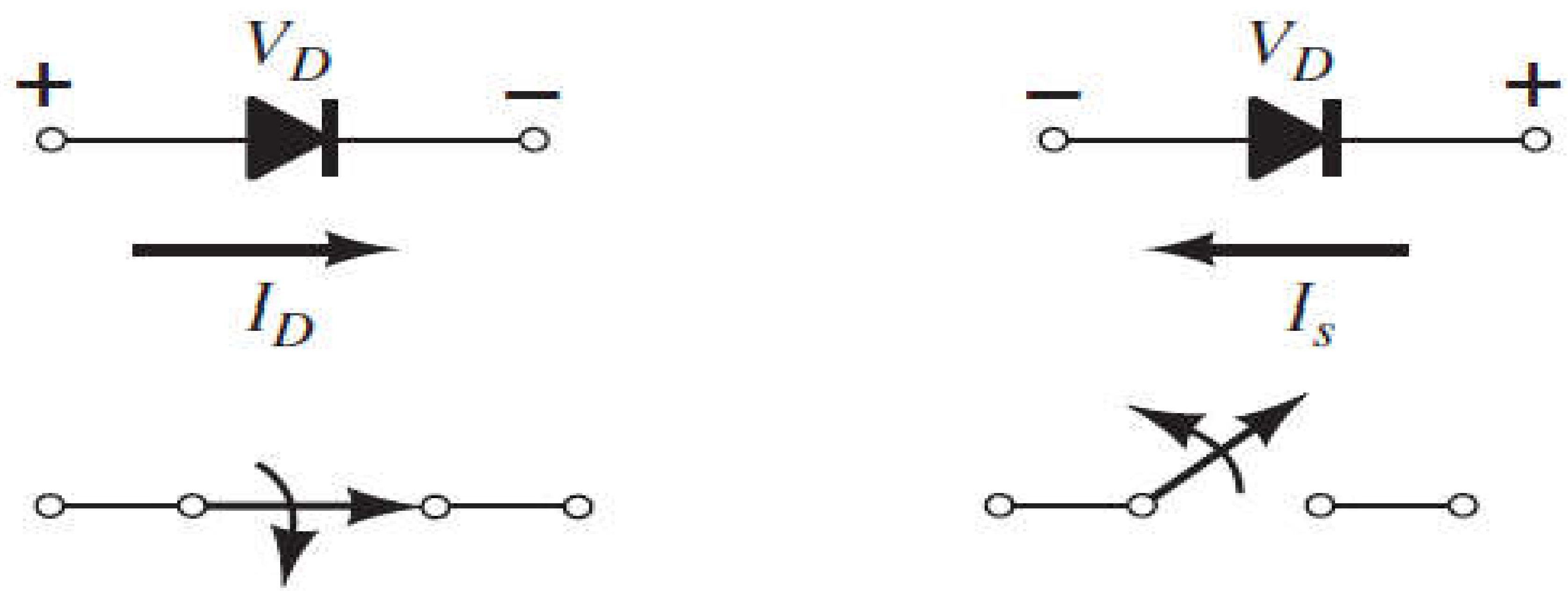
Ideal vs. Actual Characteristics



Diode as a Rectifier

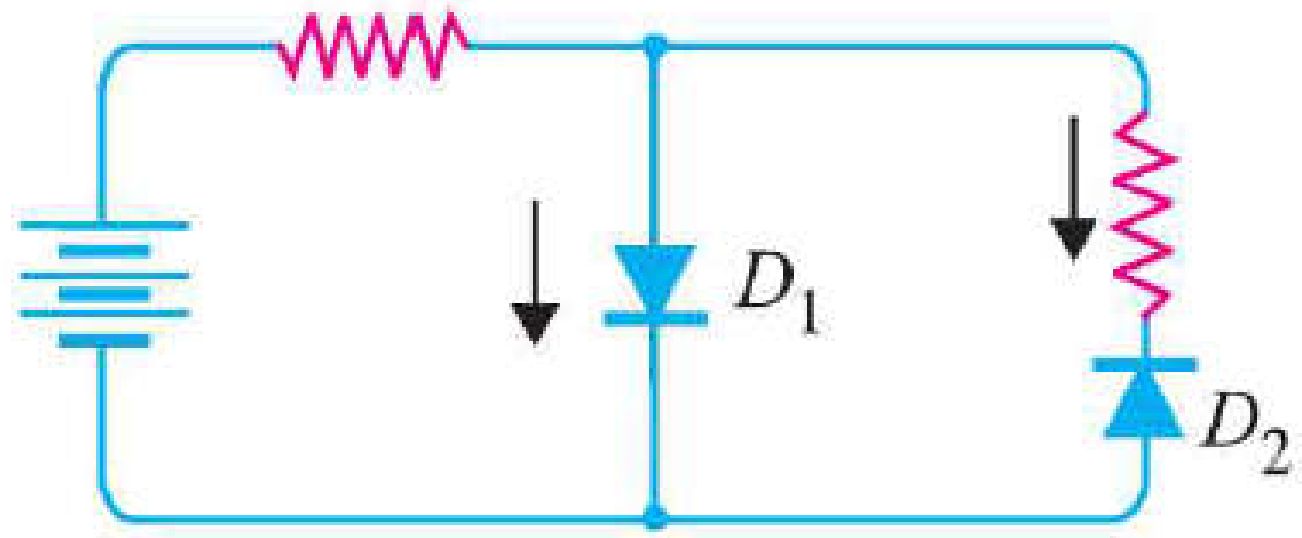
- Diode behaves as a switch
- Forward Biased – Closed Switch, connects AC Supply to load
- Reverse Biased – Open Switch, disconnects AC with load



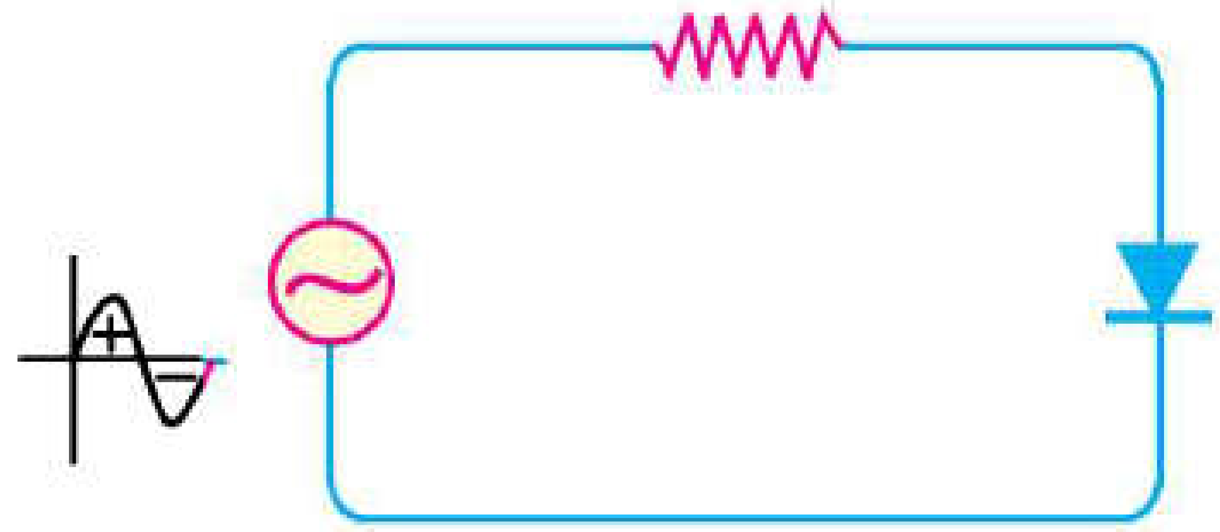


Concept Check…

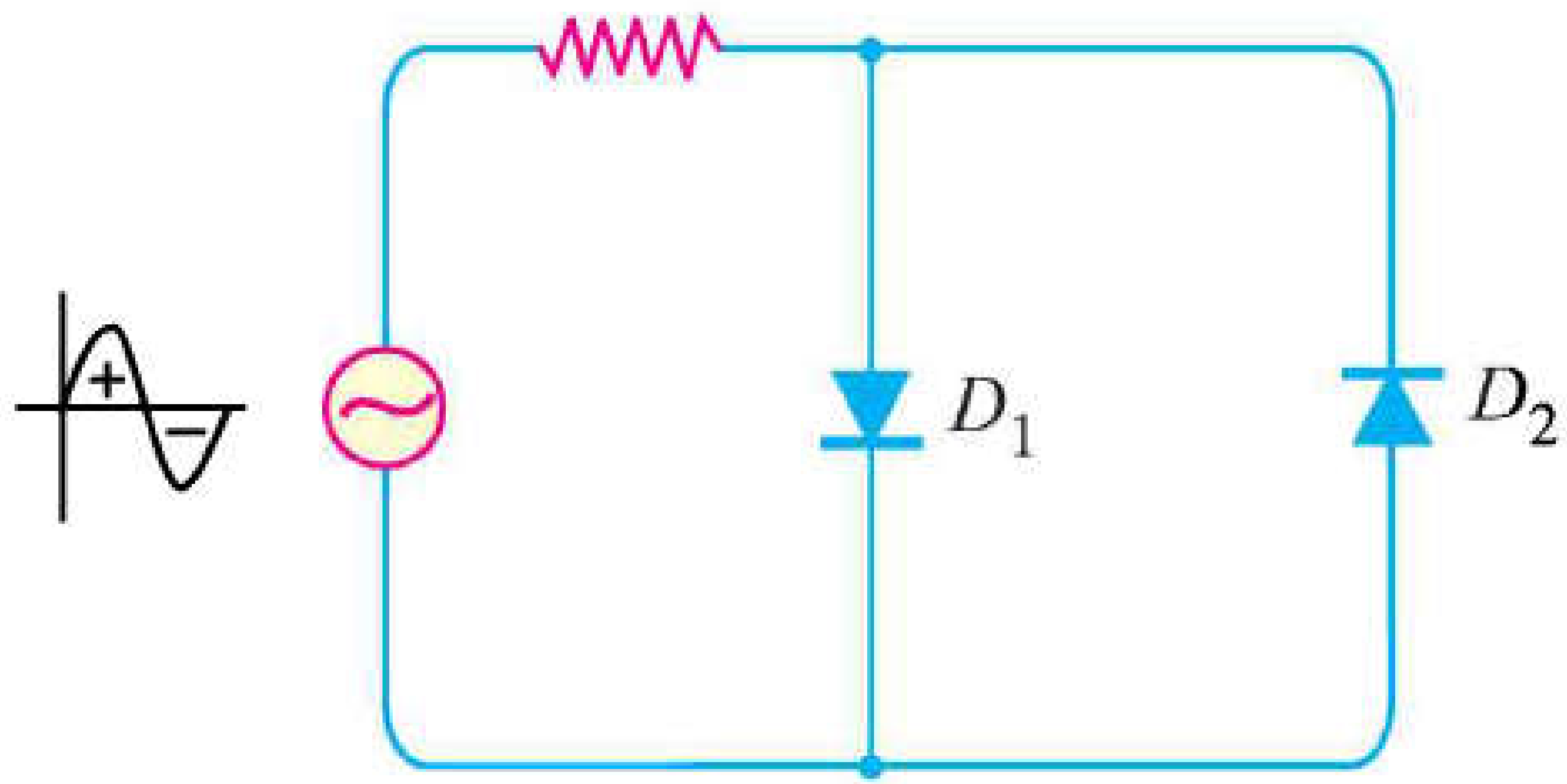
Identify whether the diode/diodes is/are forward or reverse biased?



(i)



(ii)



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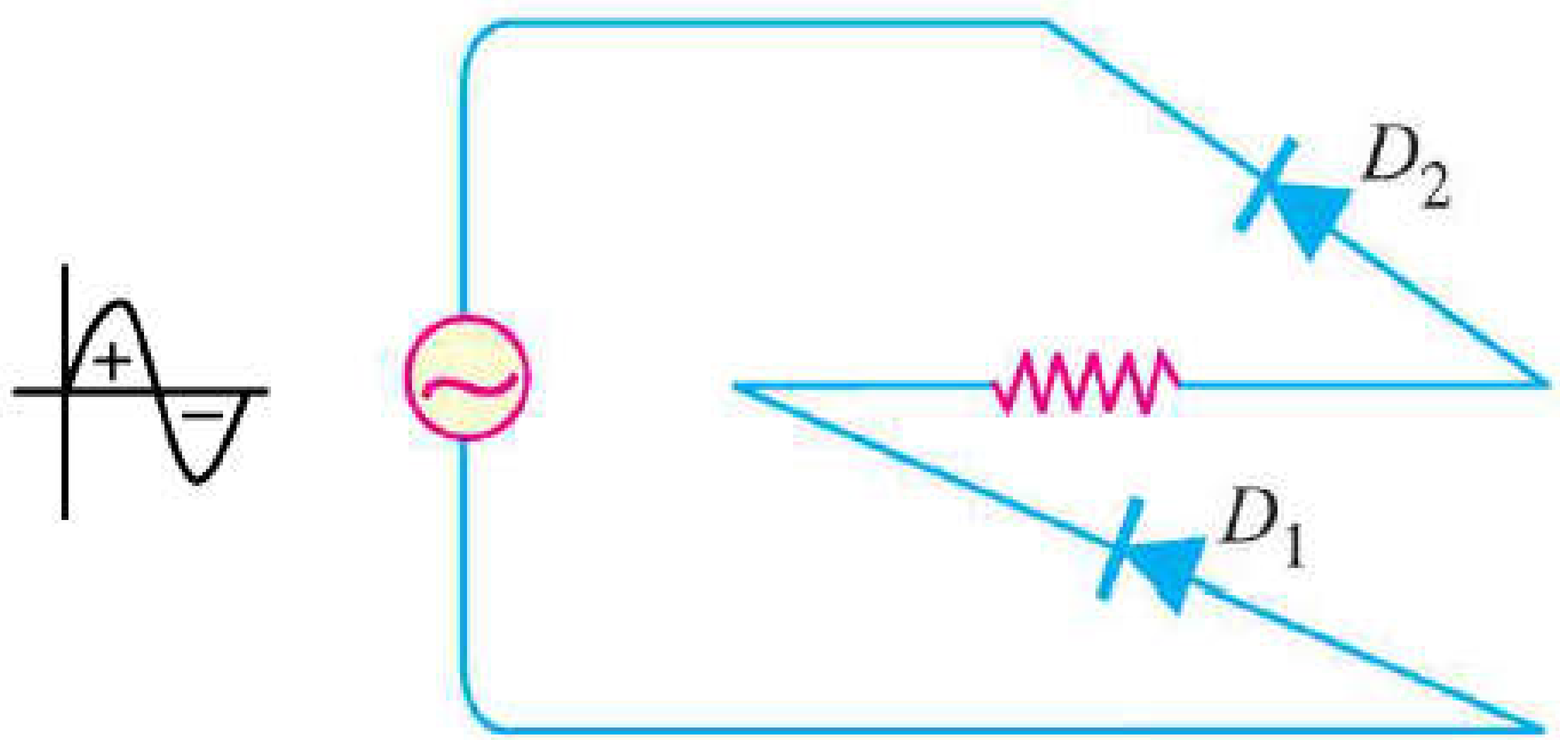
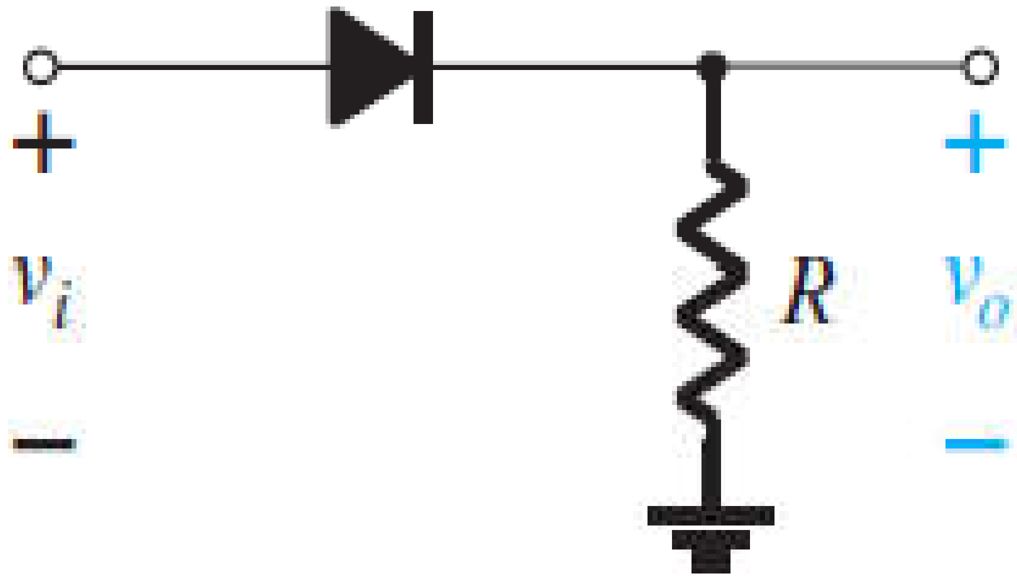
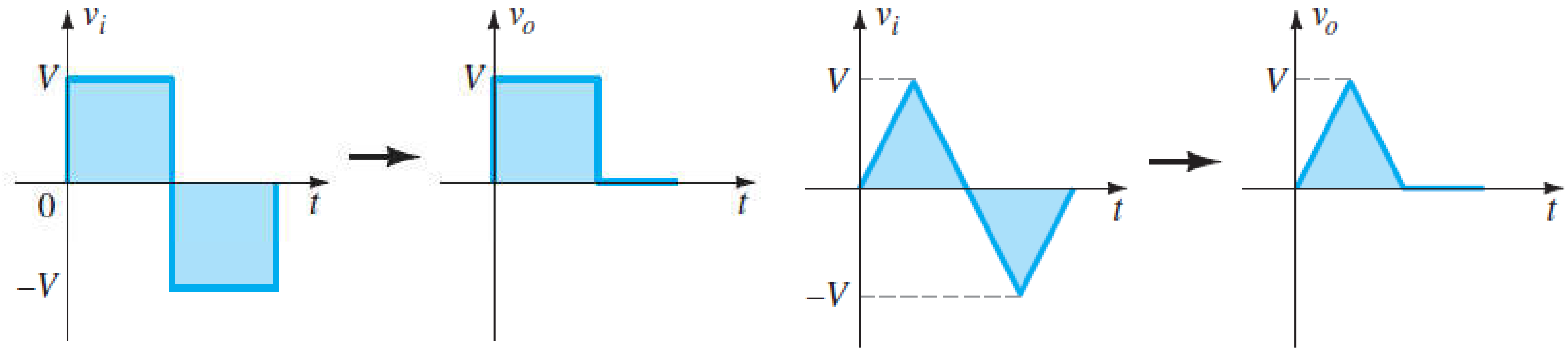


(iv)

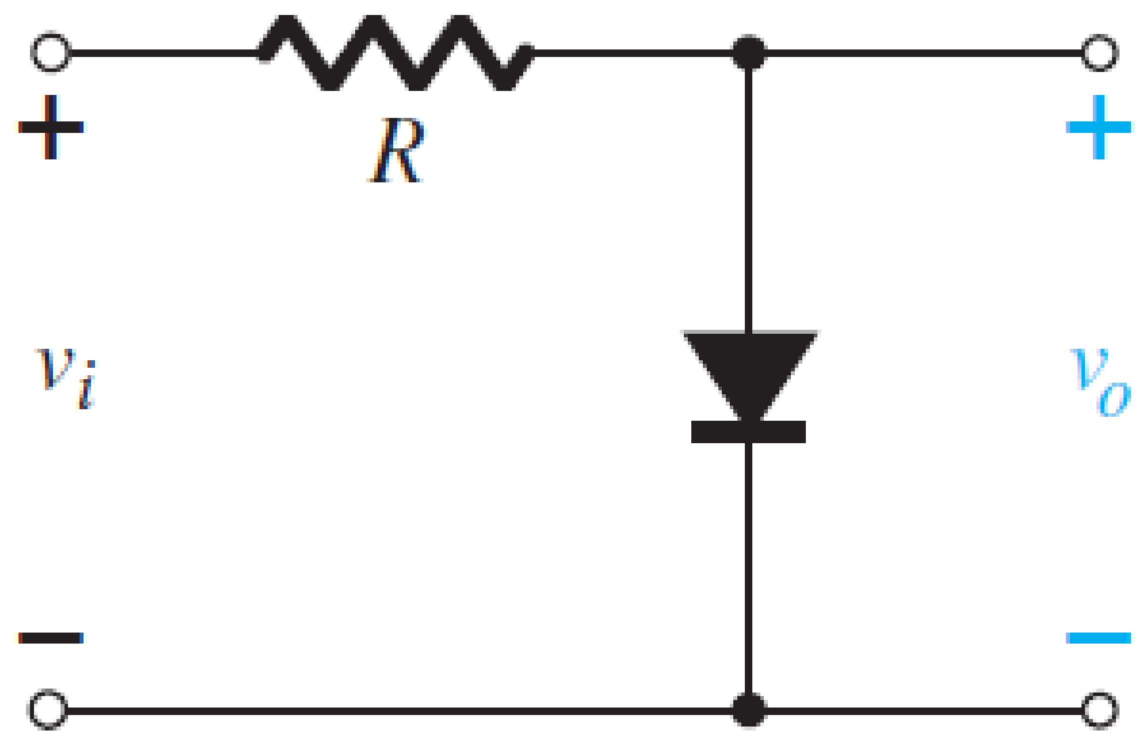
Diode as a Clipper (Series)

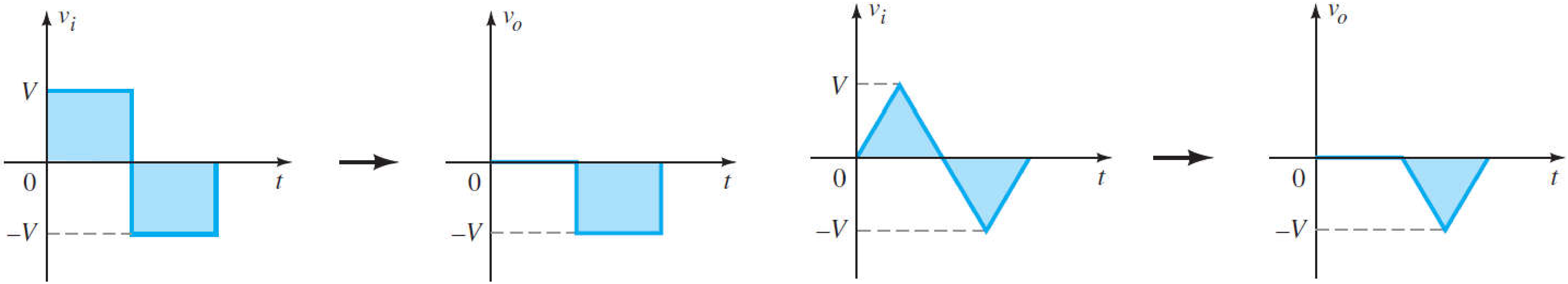
Clipping a portion of an input signal without distorting the remaining part of the waveform



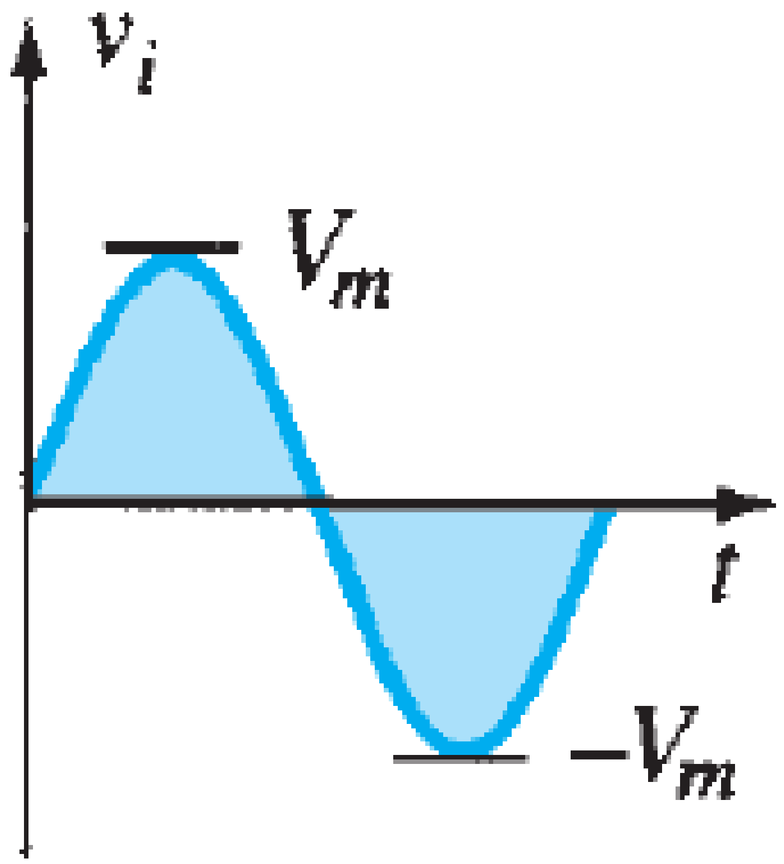


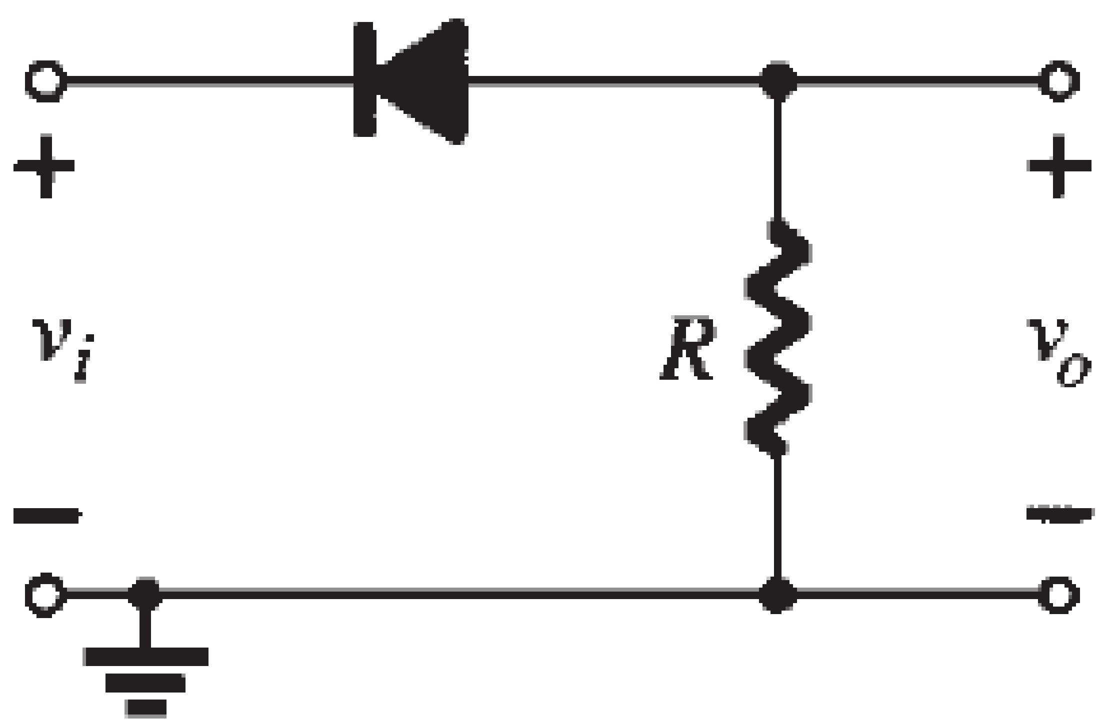
Diode as a Clipper (Parallel)

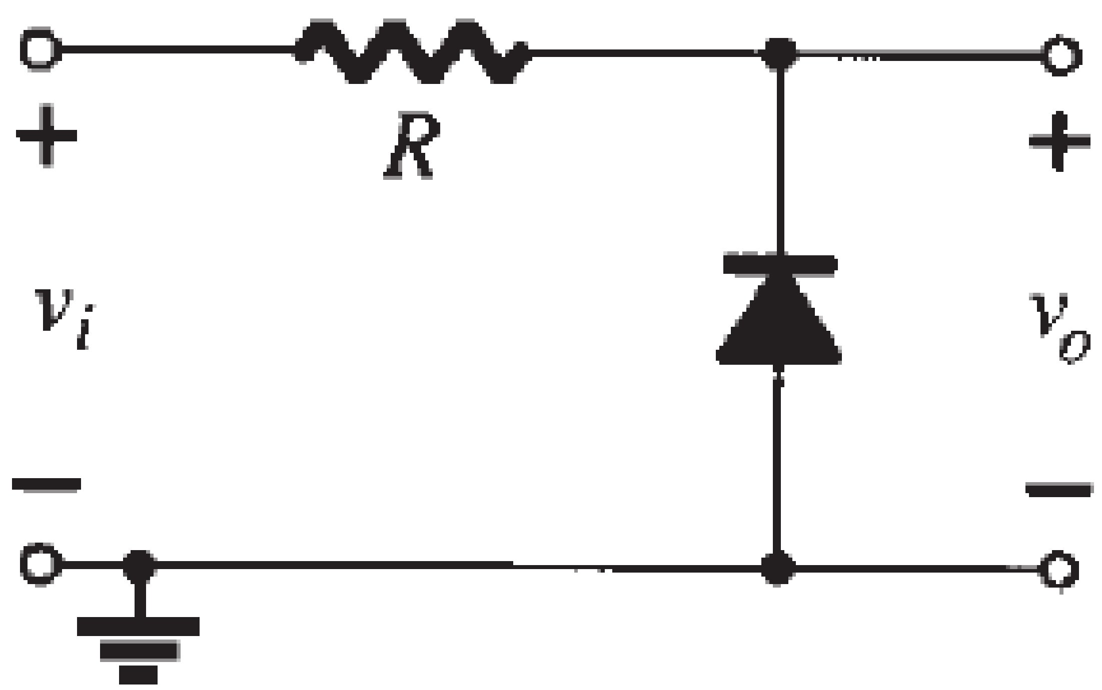




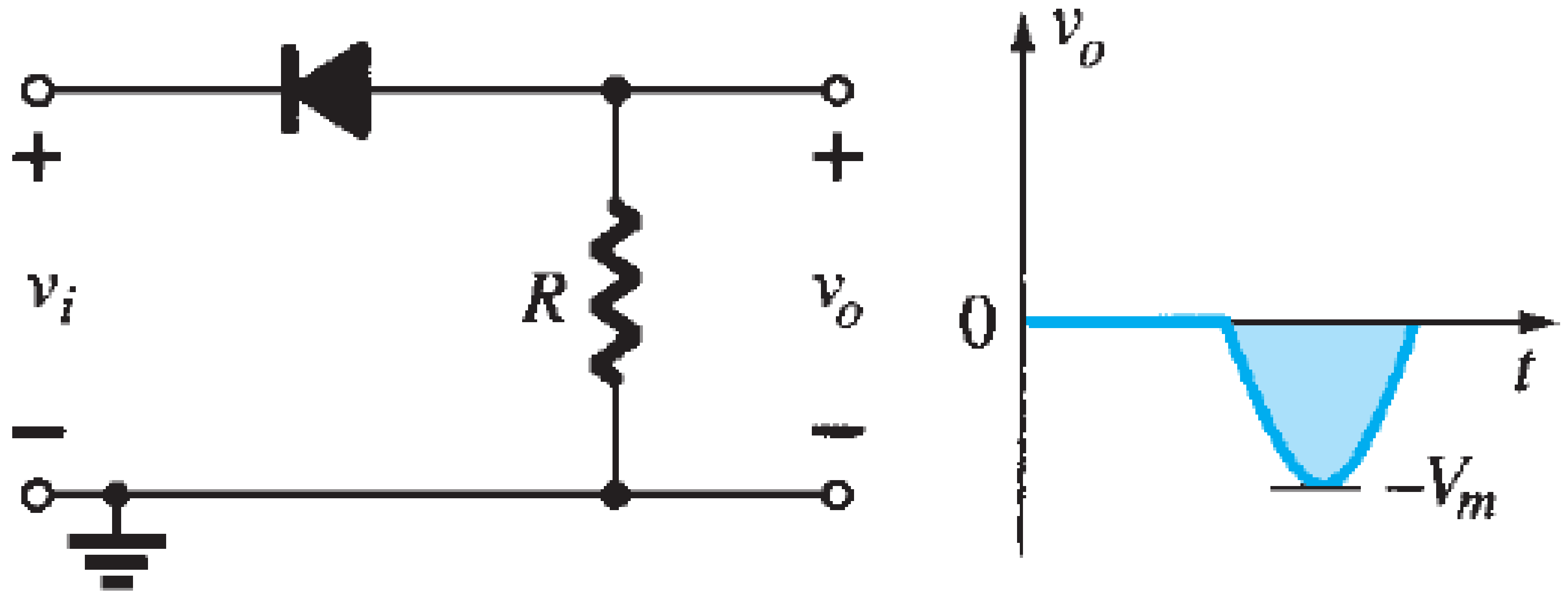
Concept Check…

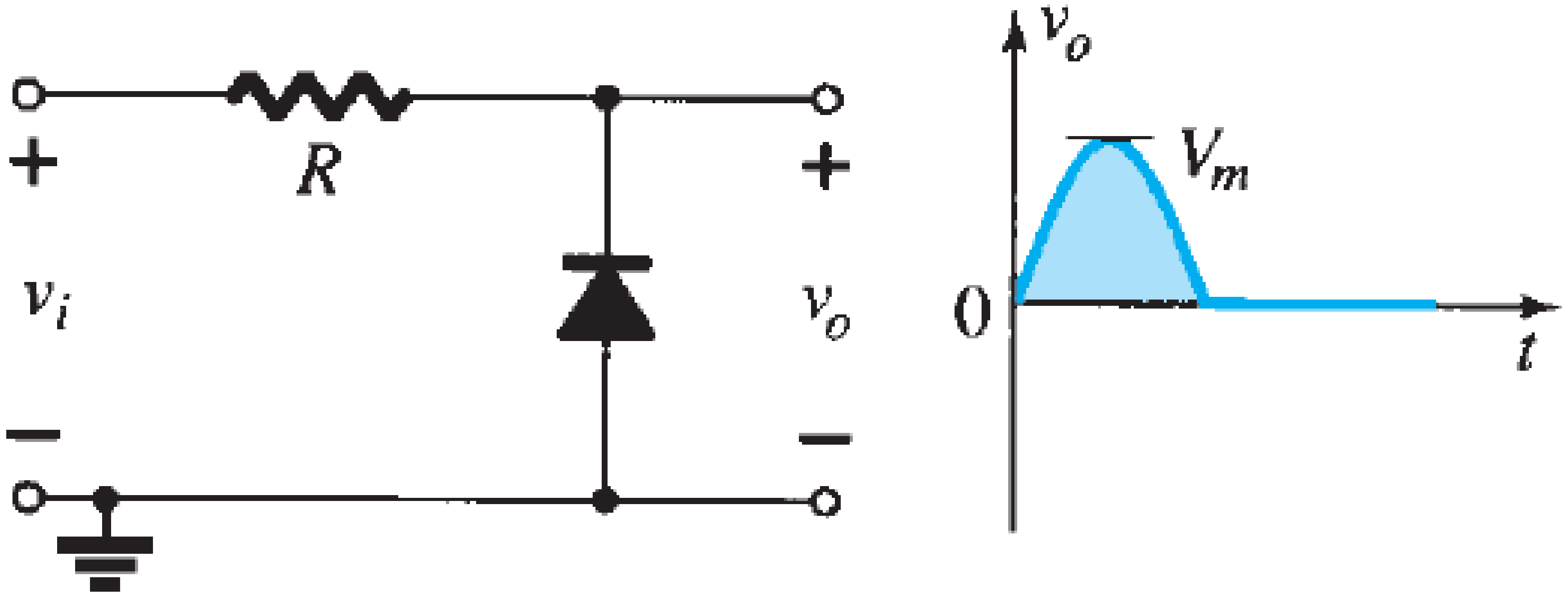






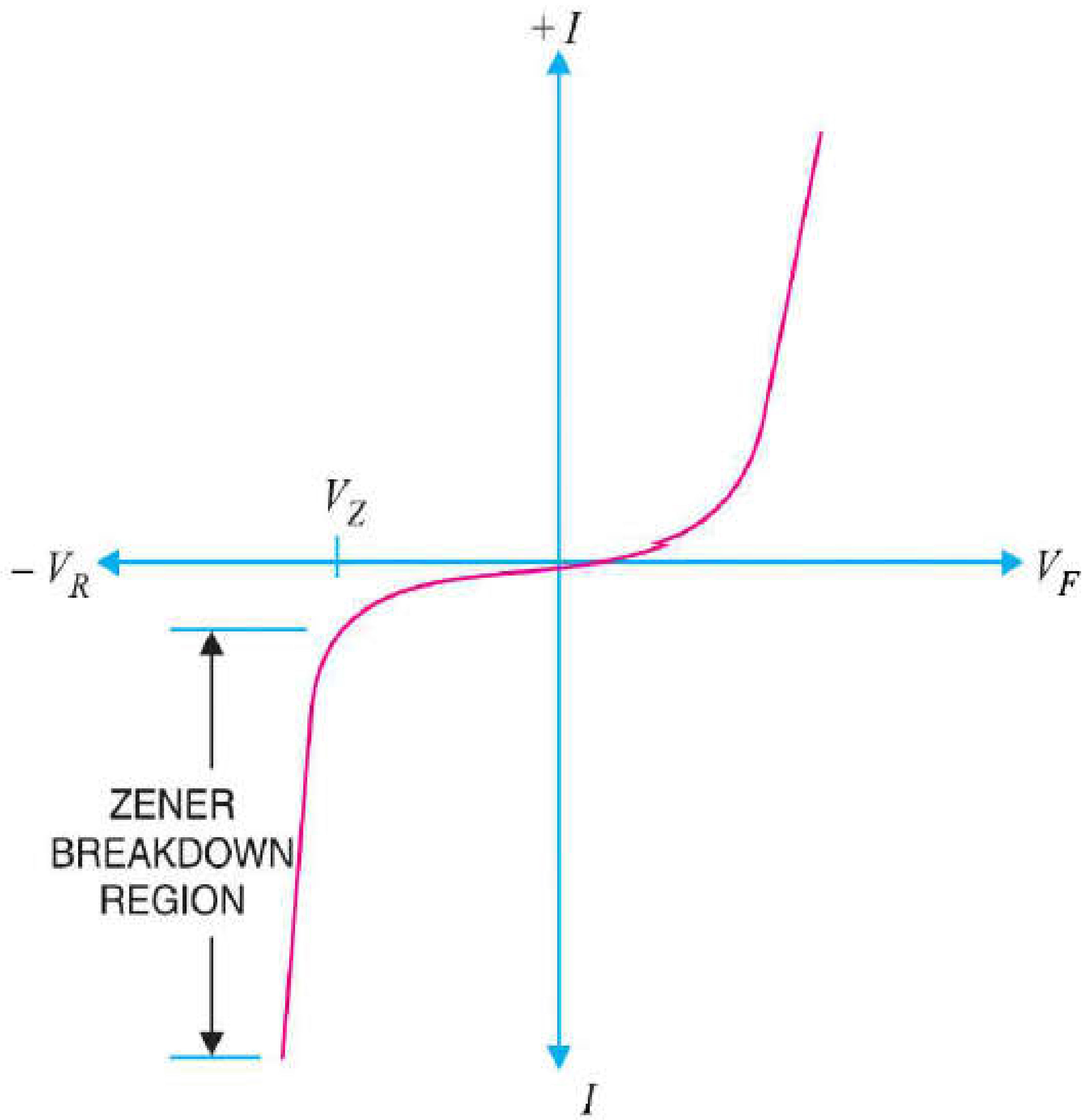
Solution





Zener Diode

- ❑ A special diode designed to operate in reverse breakdown region
- ❑ An ordinary diode will get damaged due to excessive current
- ❑ A zener diode is heavily doped to reduce the breakdown voltage as well as depletion layer width
- ❑ As a result the diode has a **sharp** reverse breakdown voltage
- ❑ Characteristics show two imp points
  - ❑ After breakdown, the diode current increases rapidly
  - ❑ The reverse voltage across the diode remains constant.
  - ❑ This phenomenon of voltage remaining constant helps us to use Zener diode in voltage regulation.

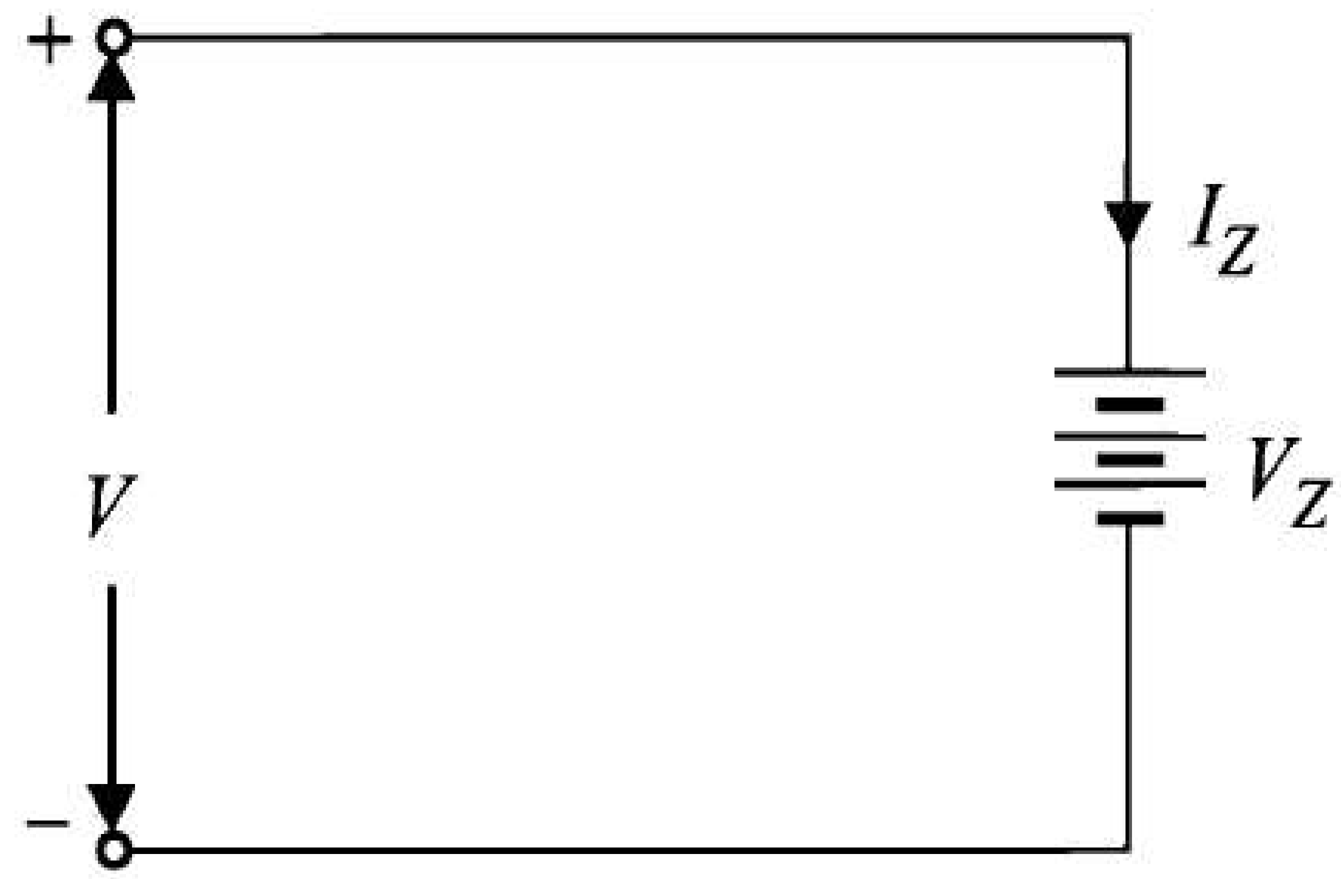


Zener Diode’s Equivalent Ckt

- ❑ Always operated in reverse bias
- ❑ When forward biased, will behave as a normal diode
- ❑ When the reverse voltage across the diode is greater than or equal to the breakdown voltage, it can be replaced by a battery e qual to the Vz (Zener Voltage or Breakdown Voltage)

(i)

$V \geq V_Z$

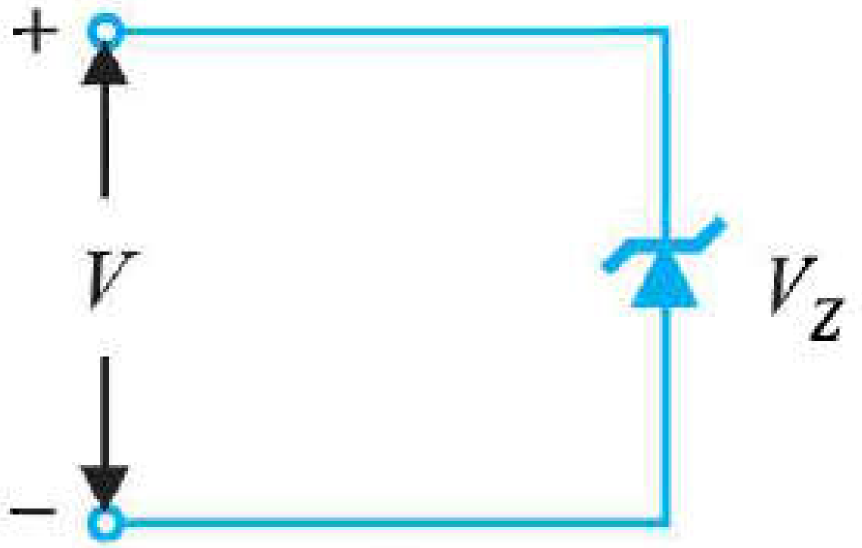


(ii)

Equivalent circuit of zener for ‘‘on’’ state

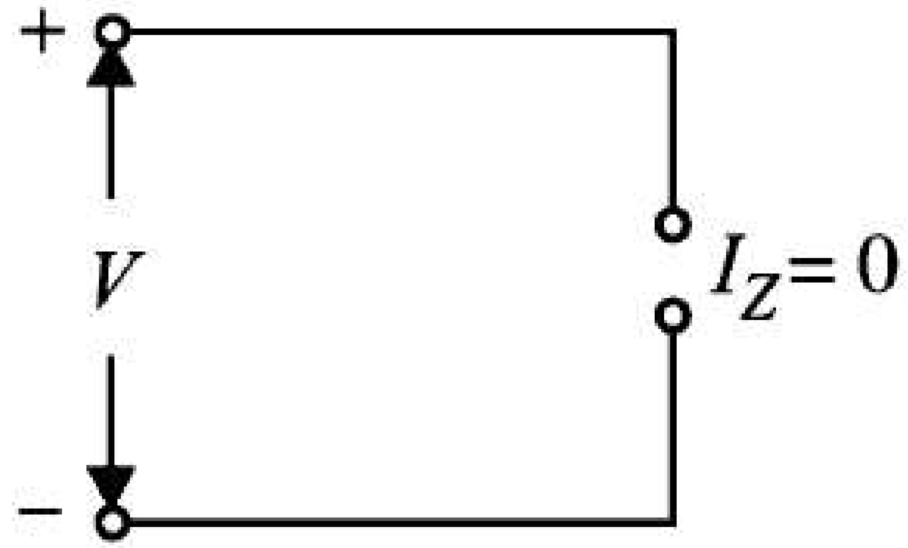
Zener Diode's Equivalent Ckt

❑ However if the reverse voltage is less than the breakdown voltage, it will work as open circuit as shown below.



(i)

$V_Z > V > 0$



(ii)

Equivalent circuit of zener for ''off'' state

Zener Diode as a Regulator

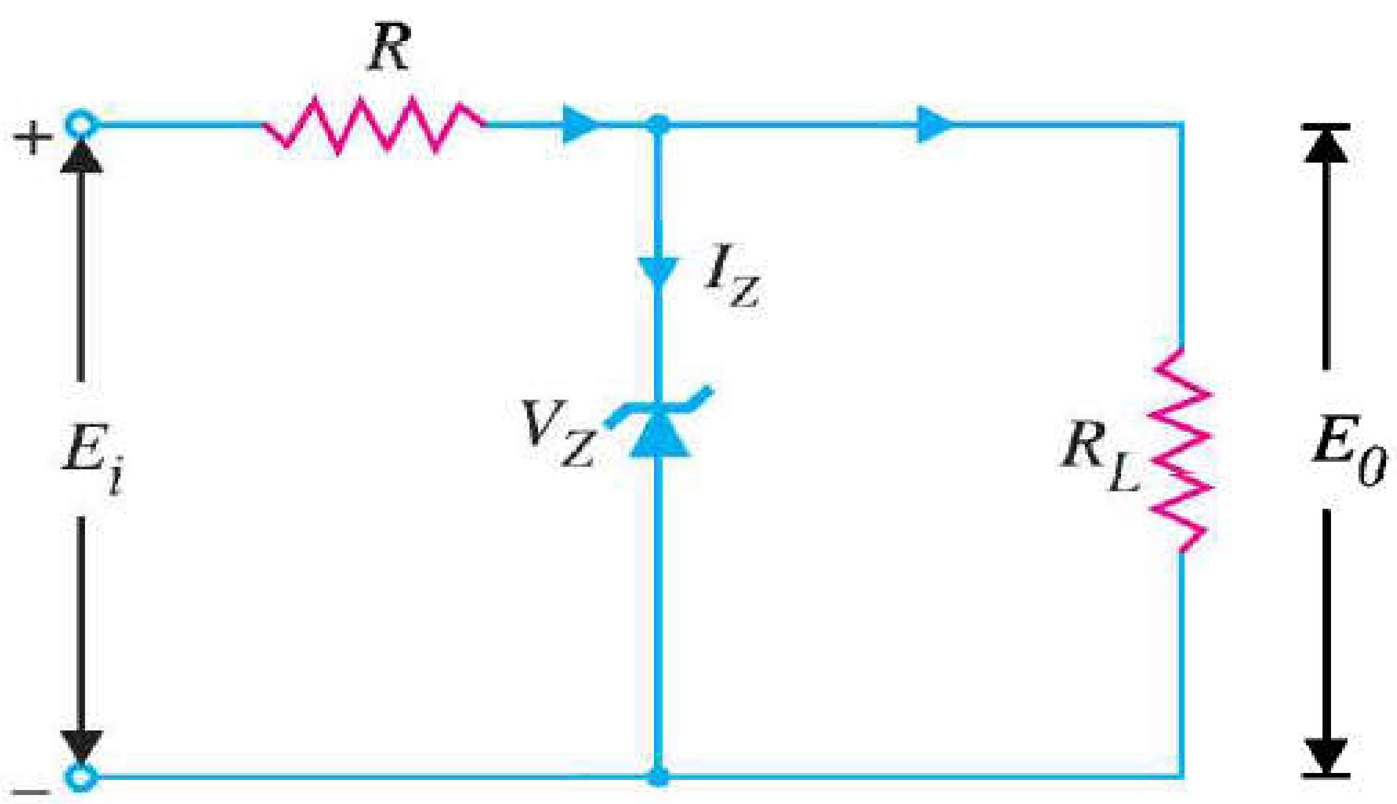
❑ Try to find the state of the zener diode (Off, Forward Biased, Reverse Biased, Reverse Biased and in Breakdown)

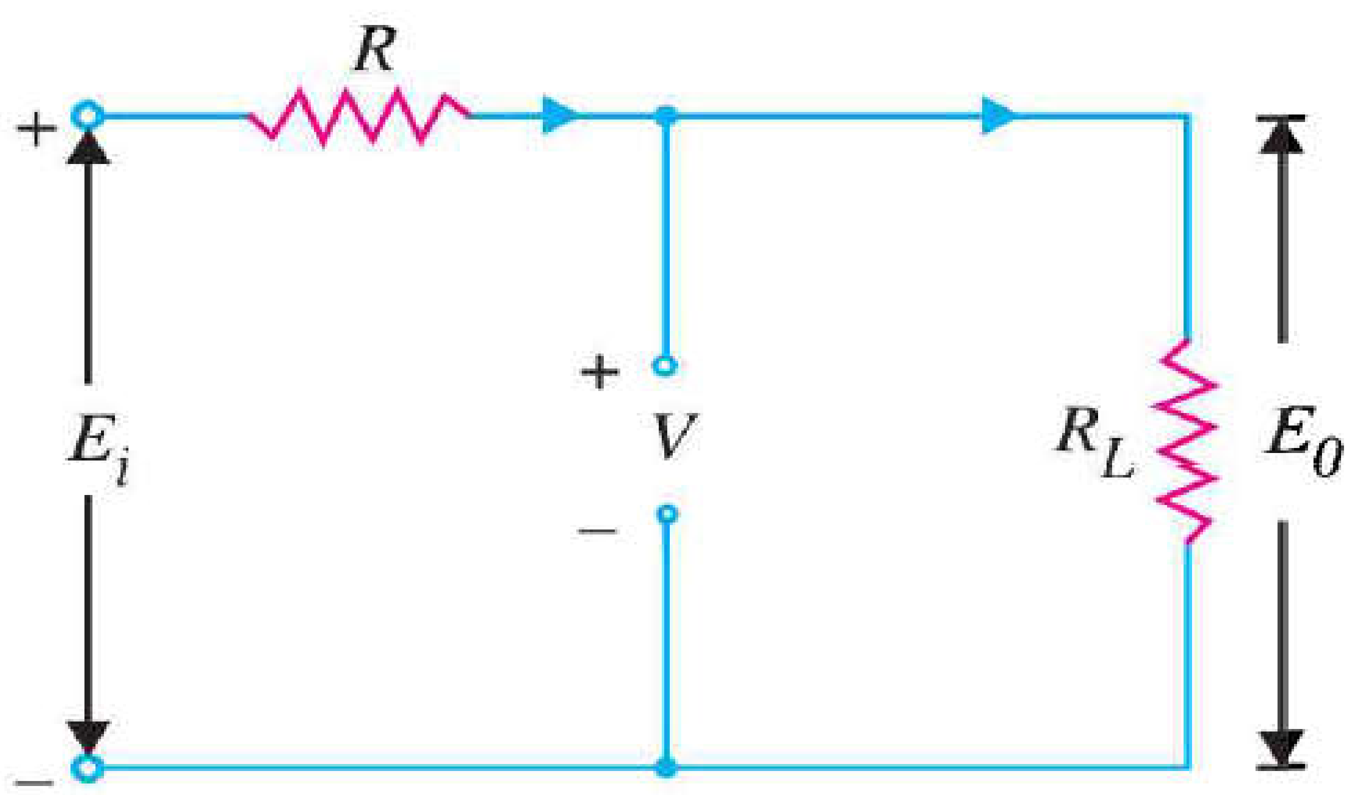
❑ Remove the diode and find the voltage across Load Resistance

❑ If above voltage is greater than specified breakdown voltage of zener diode than replace it by a battey of Vz. The voltage now across both diode as well as the Load resistance will remain constant at Vz.

❑ If it less, then the replace it by an open circuit. In this case there is no regulation and the voltage across the load fluctuates as per the variations in the input power supply.

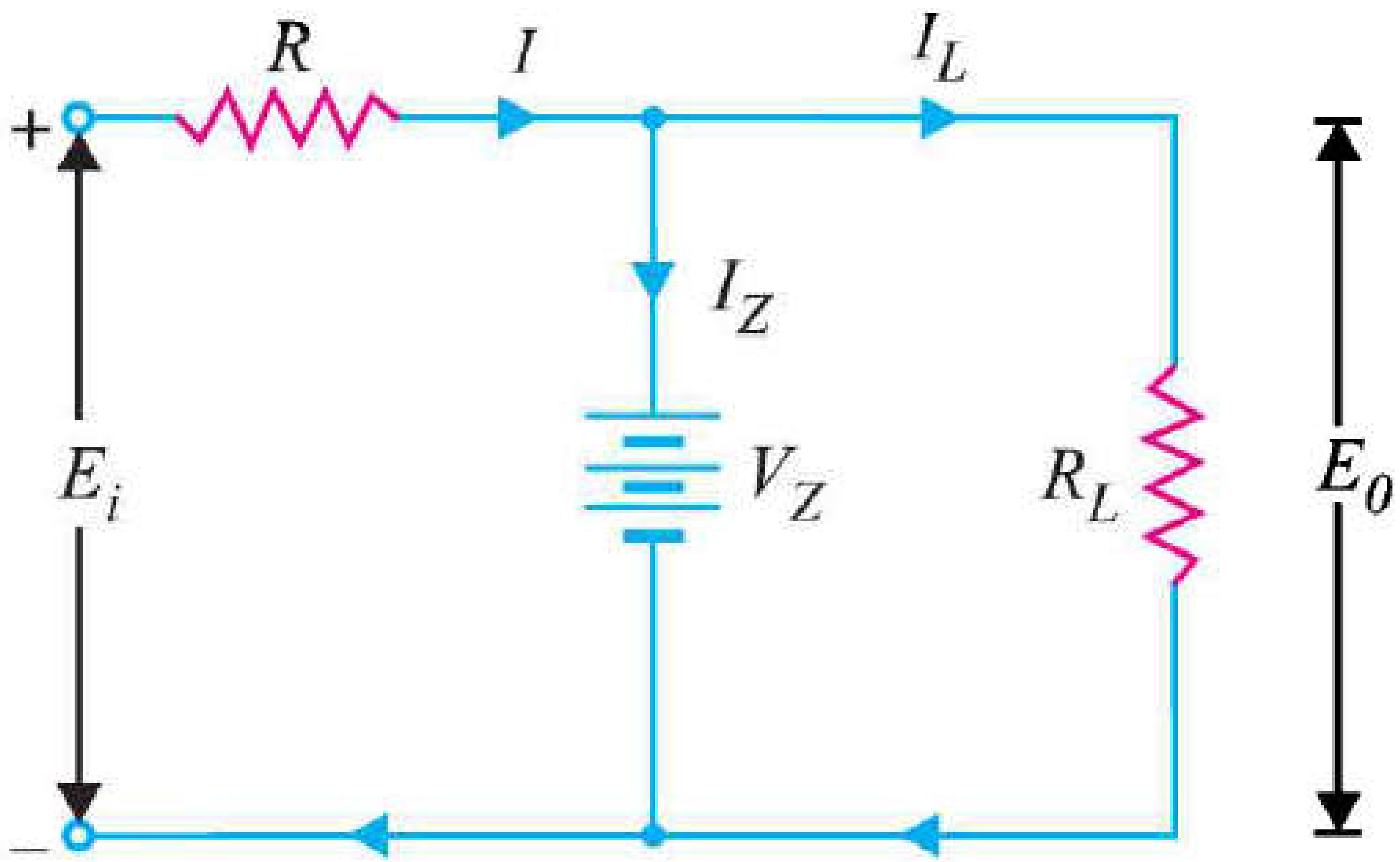
$$V = E_0 = \frac{R_L E_i}{R + R_L}$$

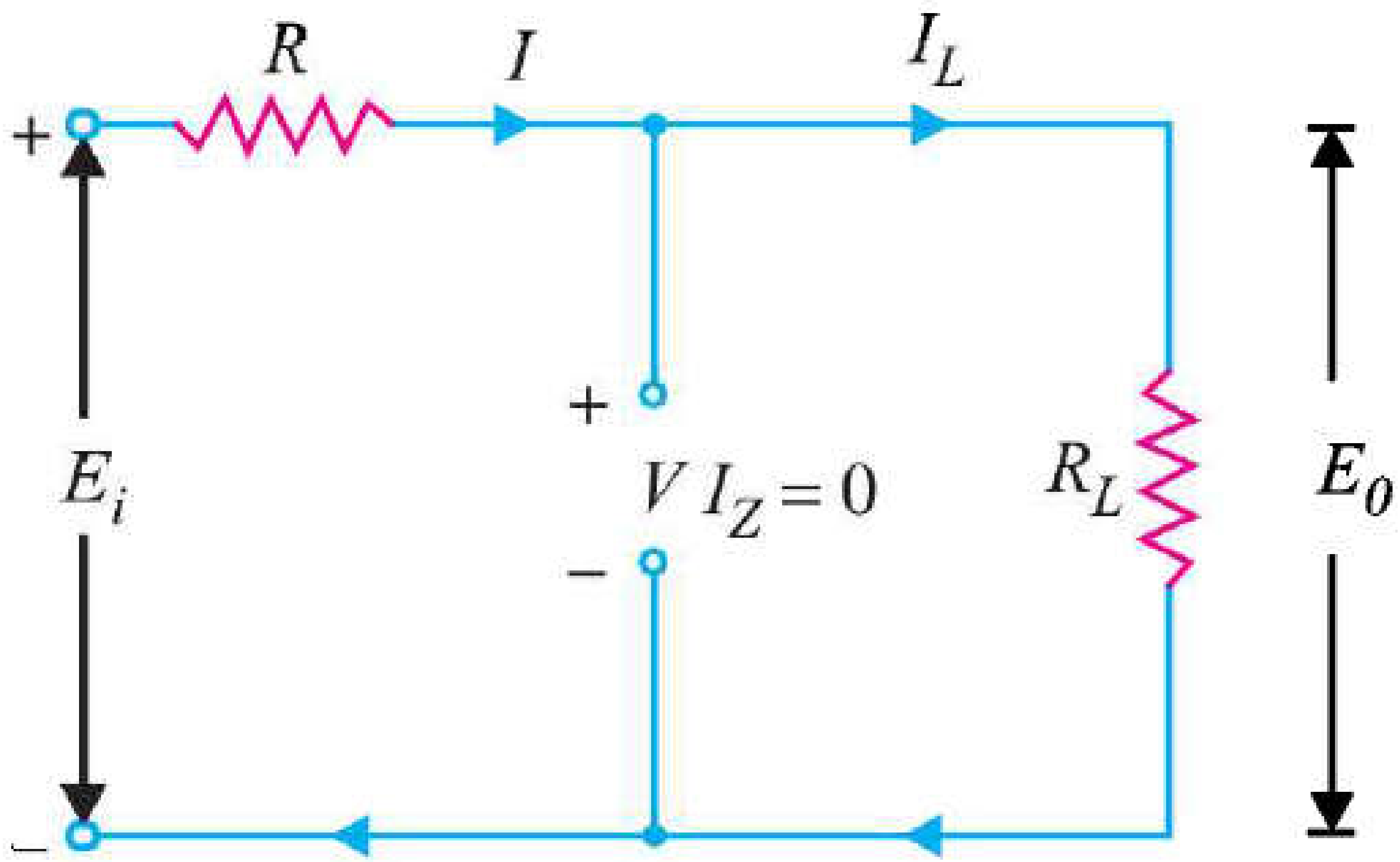




Zener Diode as a Regulator

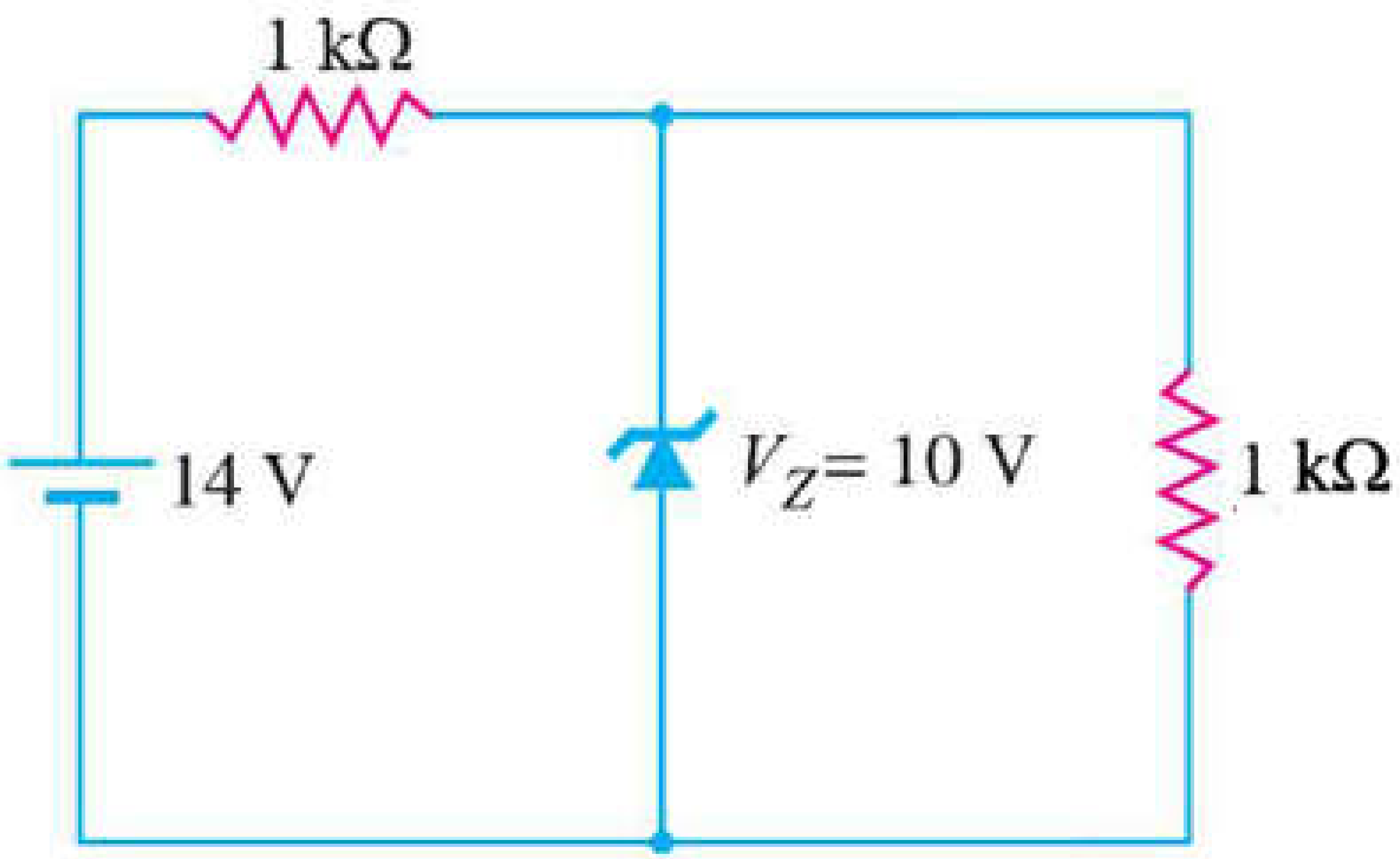
- V > Vz: $E_o = V_z$, $I_z = I - I_L$, $P_z = V_z . I_z$, $I_L = V_z/R_L$
- V < Vz: $I = I_L$, $I_z = 0$, $P_z = 0$ ($P_z = V_z . I_z$), $I_L = E_i/(R+R_L) = I$

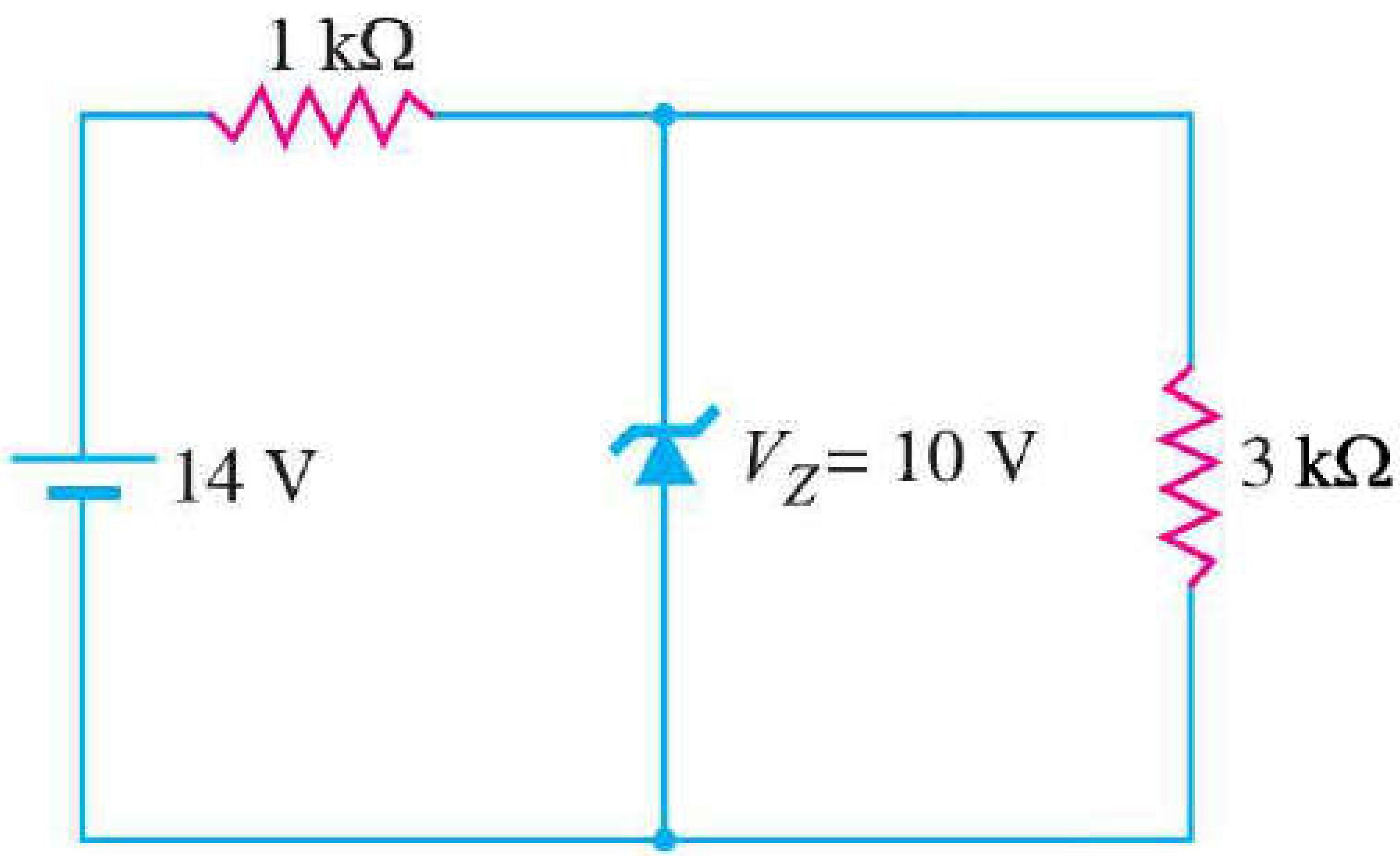




Concept Check

Determine whether Zener diode is on or off? Accordingly specify the output voltage.

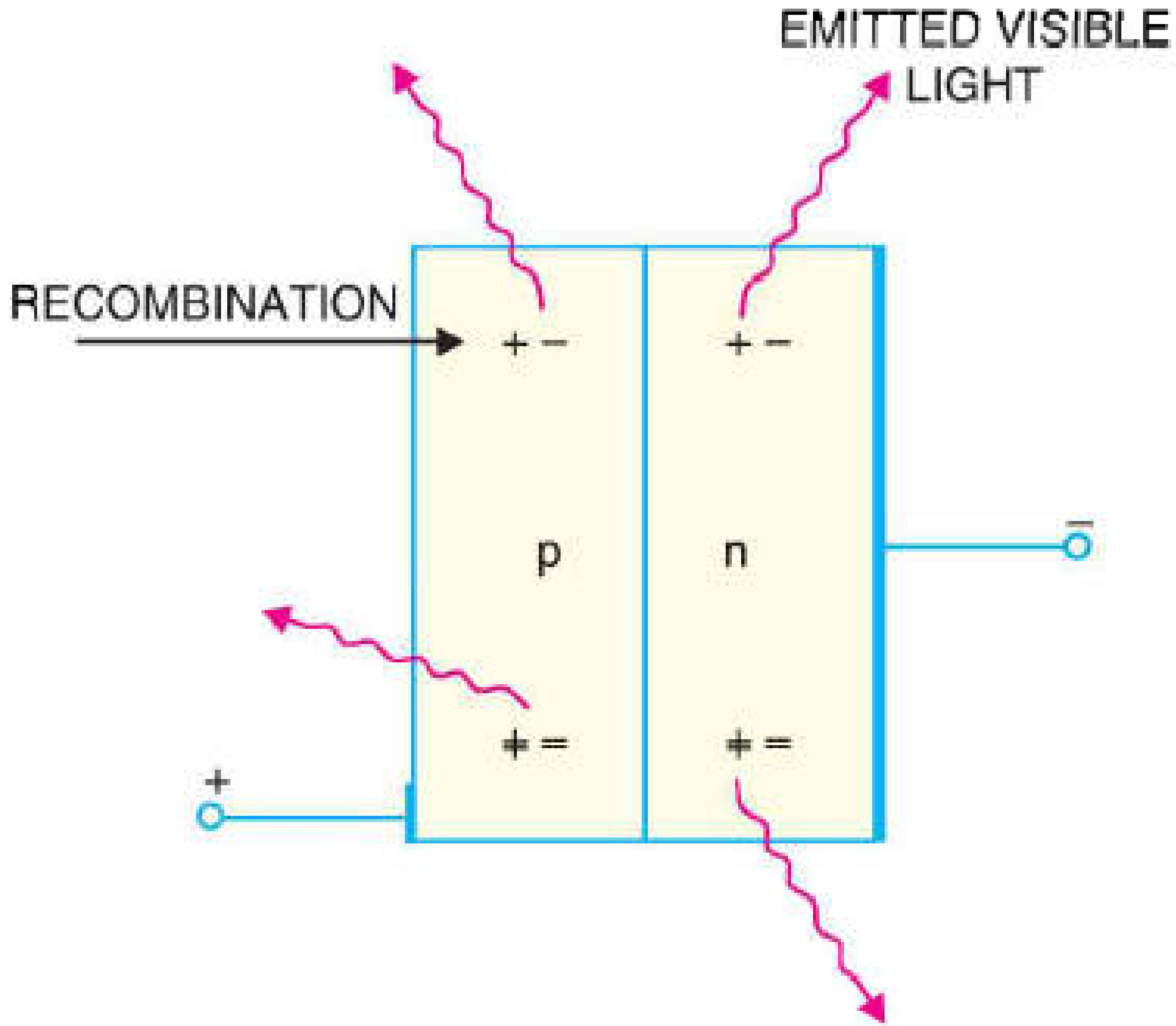


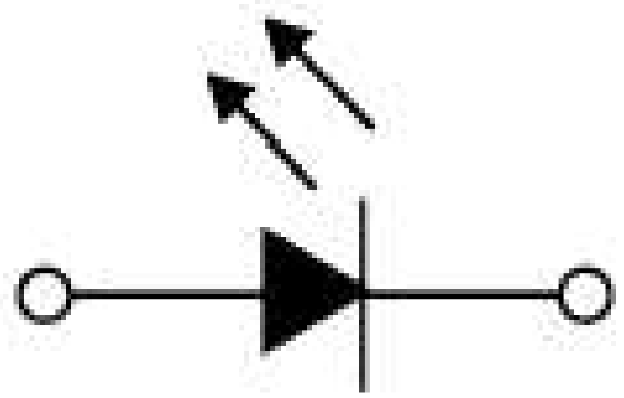


LED (Light Emitting Diode)

- It is a diode which emits visible light when forward biased
- Made from Gallium, Phosphorus or/and Arsenic (GaAs, GaPh, GaInPh). Changing the element and proportion changes the color.
- Gallium Arsenide – Red Light
- Gallium Phosphide – Green Light
- When LED is forward biased, the electrons cross the junction and recombine with holes.
- These electrons being in conduction band are at higher energy levels.
- When they recombine, energy is released in the for m of heat and light.
- For Si and Ge diodes, the entire energy is given in the form of heat and the emitted light is insignificant.
- For LED, the sufficient energy is emitted as light that too in the visible region.
- Works as a normal diode when forward biased.

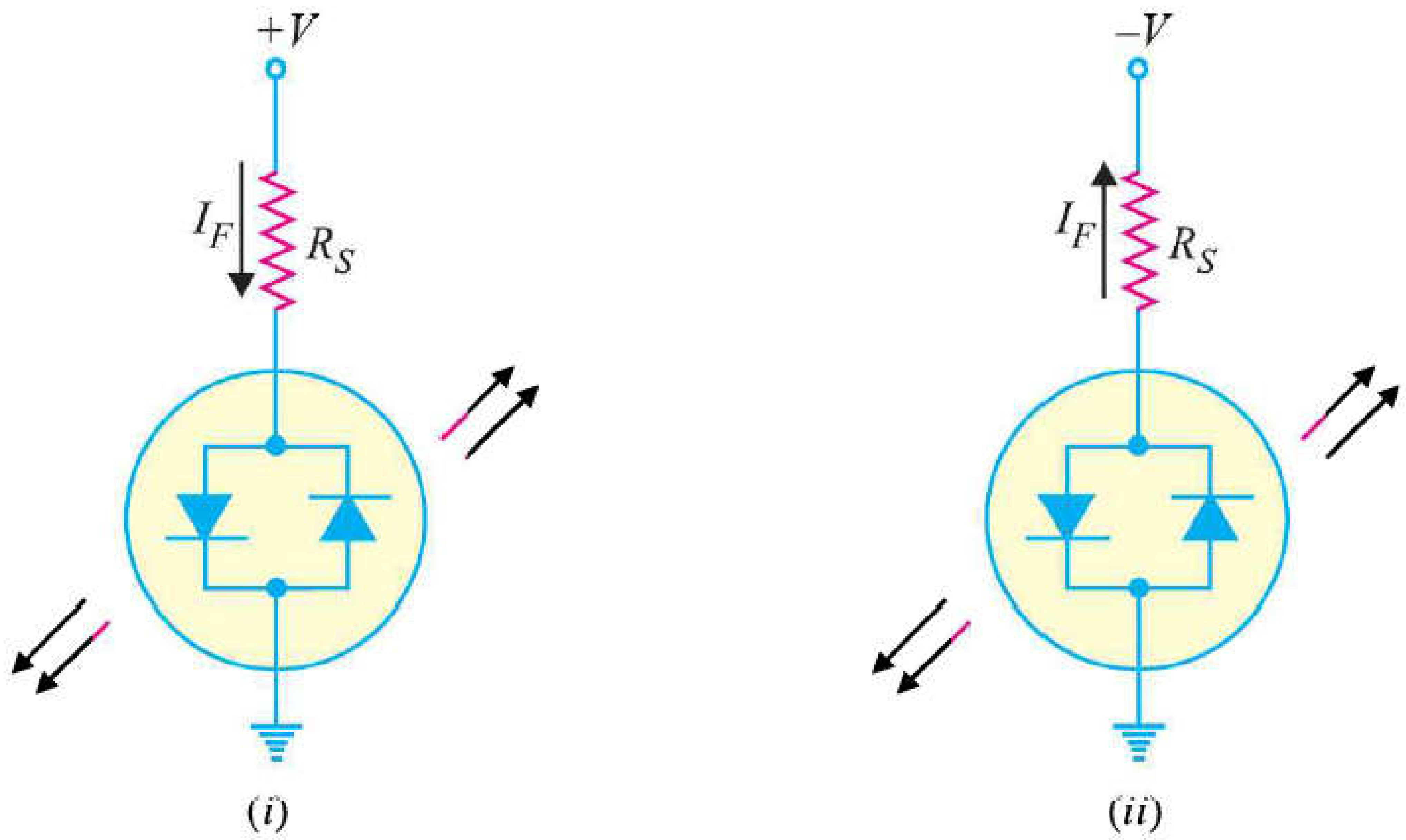
LEDs Cont…





Multi-Color LEDs

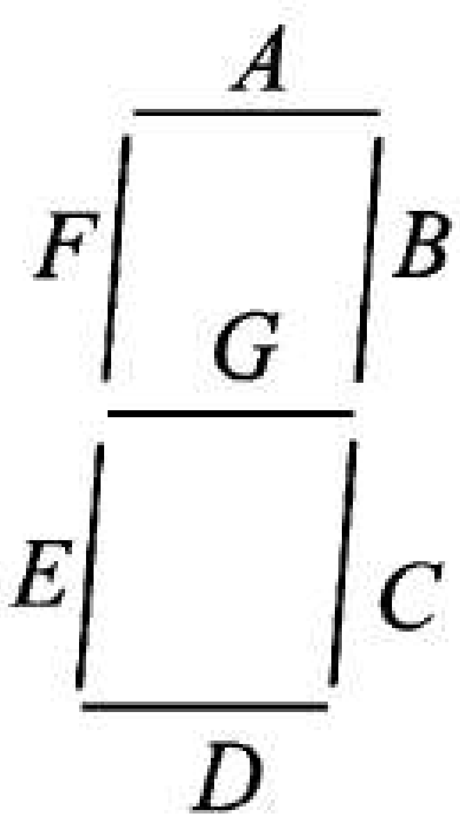
- These LEDs emit one color when forward biased and another when reverse biased
- Comprises of two PN-junctions connected in reverse-parallel mode.
- Usually when forward biased these LEDs emit RED color and when reverse biased they emit GREEN color.
- If these are switched fast between the two polarities then they emit the third color. For example RED and GREEN combination will emit Yellow as third color.



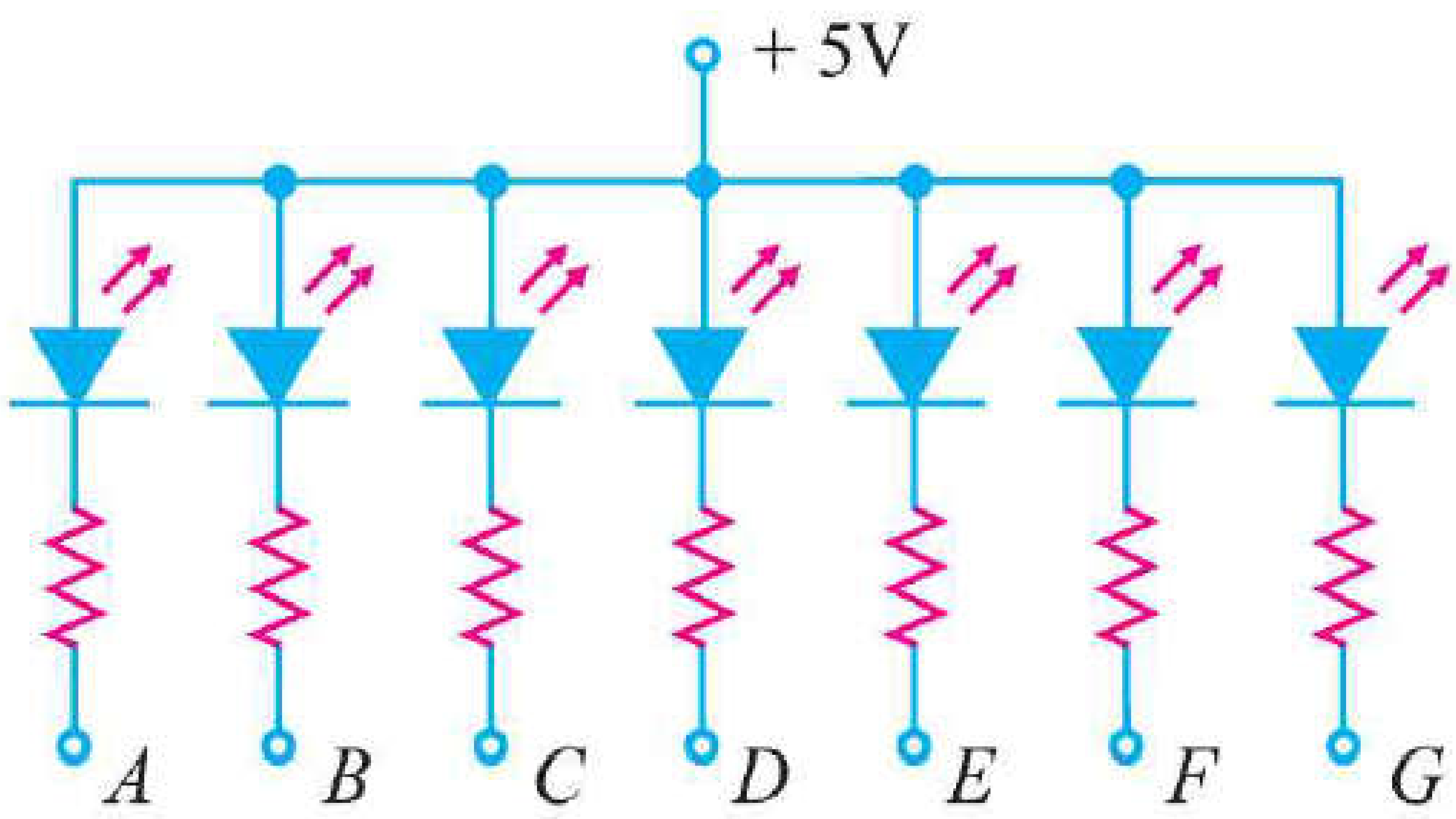
Seven Segment Display

SSD Cont…

- LEDs are grouped to form a Seven Segment Display
- It contains seven LEDs A, B, C, D, E, F and G in shape of a figure ‘8’
- If a particular LED is forward biased then that LED will glow, thereby lighting up that segment or bar.
- By forward biasing various combinations of these seven LEDs, it is possible to display any number between 0 – 9.



(i)



(ii)

❑ Eg. When A, B, C and D are lit, (By forward biasing them), the dis play will show number ‘3’

❑ To get ‘0’ all segments except ‘G’ are lit.

❑ In figure (ii) external resistors are included to limit current thereby preventing LEDs from damage

❑ The configuration is referred to as Common Anode type. We also have Common Cathode type SSDs.

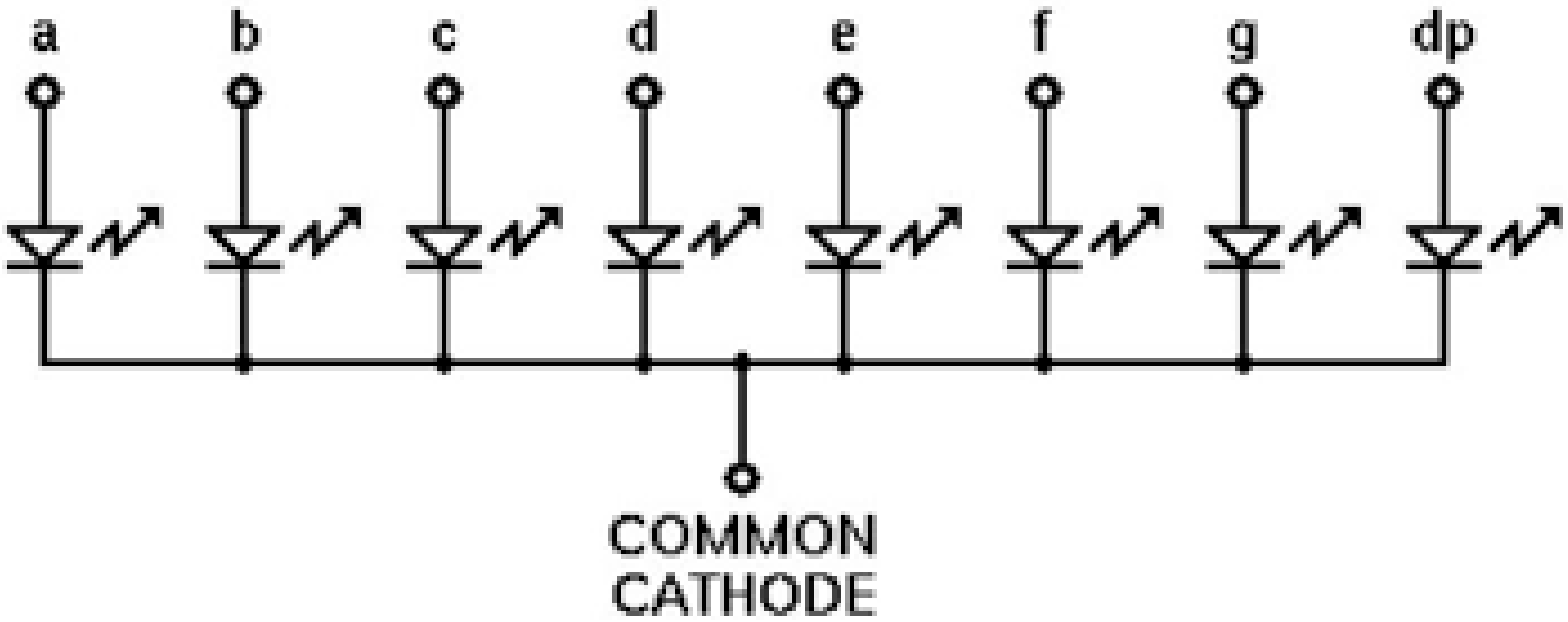


Photo Diode

- ❑ Silicon photodiode is a light-sensitive device, also called photo-detector, which converts light into electrical signals.
- ❑ The diode is made of a semiconductor PN junction kept in a sealed plastic or glass casing
- ❑ The cover is so designed that the light rays are allowed to fall on one surface across the junction
- ❑ When light falls on the **reverse-biased** PN photodiode junction, hole-electron pairs are created thereby resulting into a flow of current
- ❑ The magnitude of the photocurrent depends on the number of charge carrie rs generated and hence, on the illumination of the diode element.

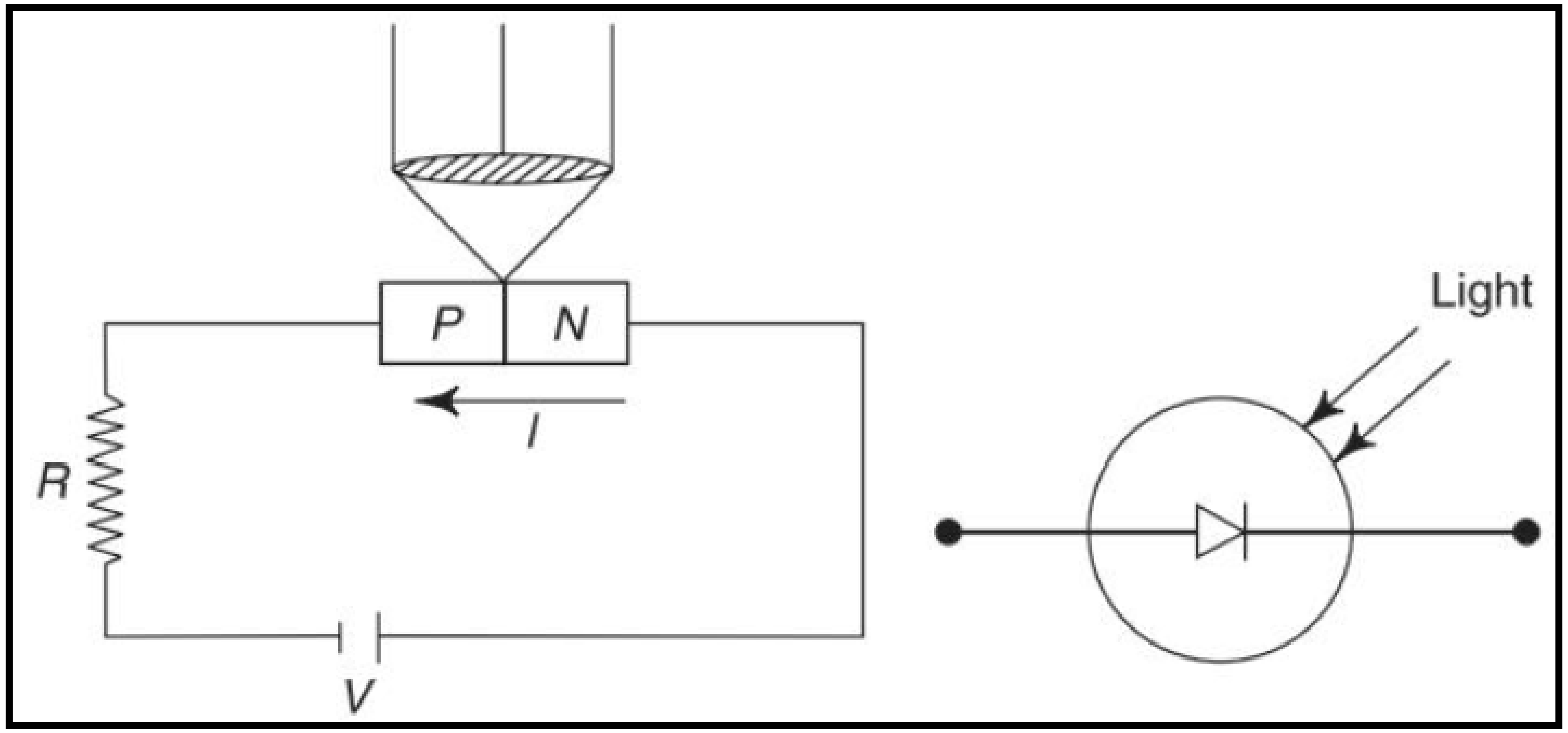
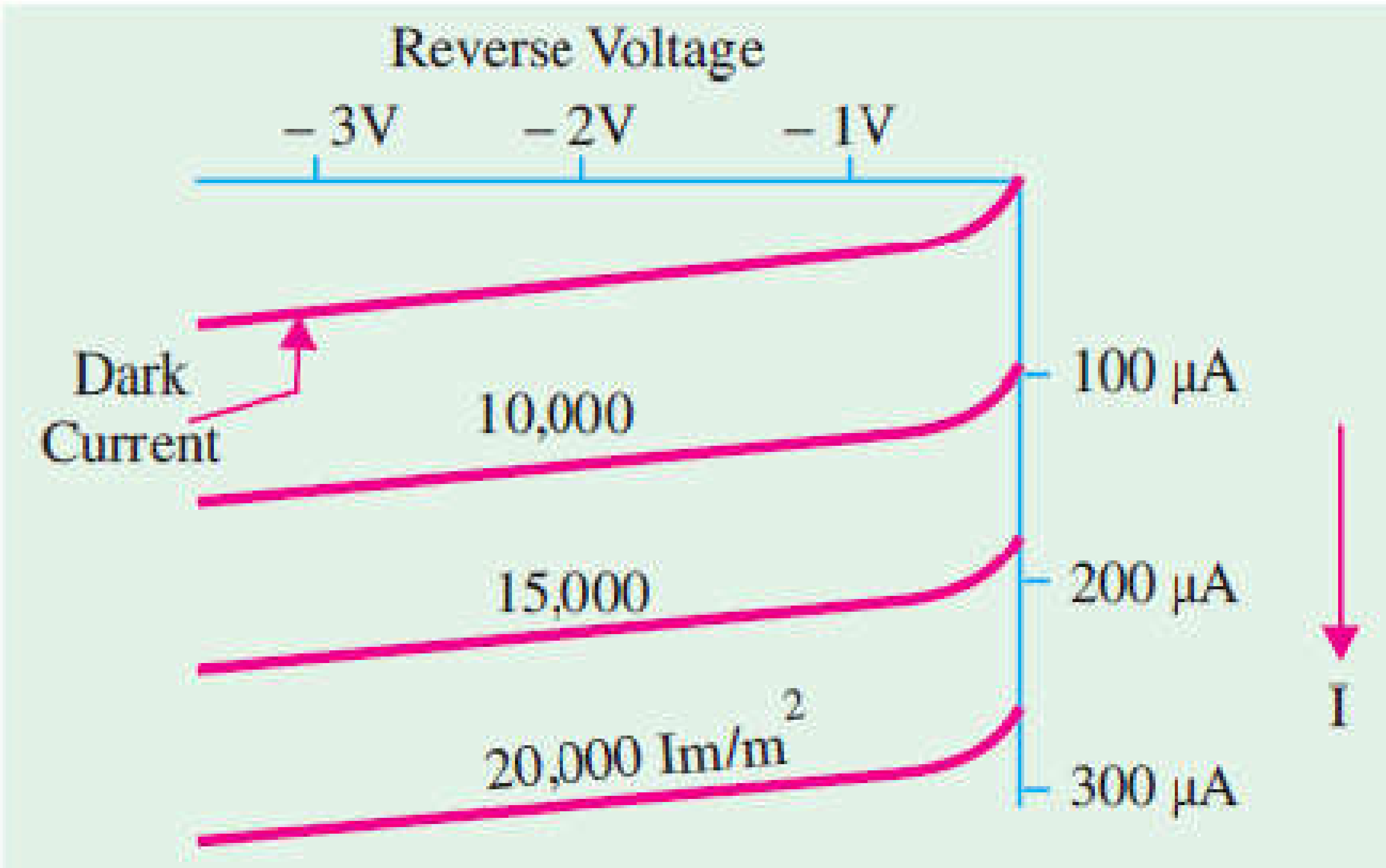


Photo Diode Cont…

- ❑ The characteristics of a photodiode is shown below. The reverse current increases in direct proportion to the level of illumination.
- ❑ Even when no light is applied, there is a minimum reverse leakage current called dark current, flowing through the device. Germanium has a higher dark current than silicon
- ❑ Resistance of Photo-diode when no light falls is called Dark Resistan ce and is given by



$$R_R = \frac{V_R}{\text{Dark current}}$$

Photo-Diode Applications

Alarm Circuit

- ❑ Light from a beam is allowed to fall on a photo-diode
- ❑ Reverse current will continue to flow till beam is not broken
- ❑ If a person passes, the beam breaks, the reverse current drops down to the dark current level
- ❑ This can be used to sound an alarm

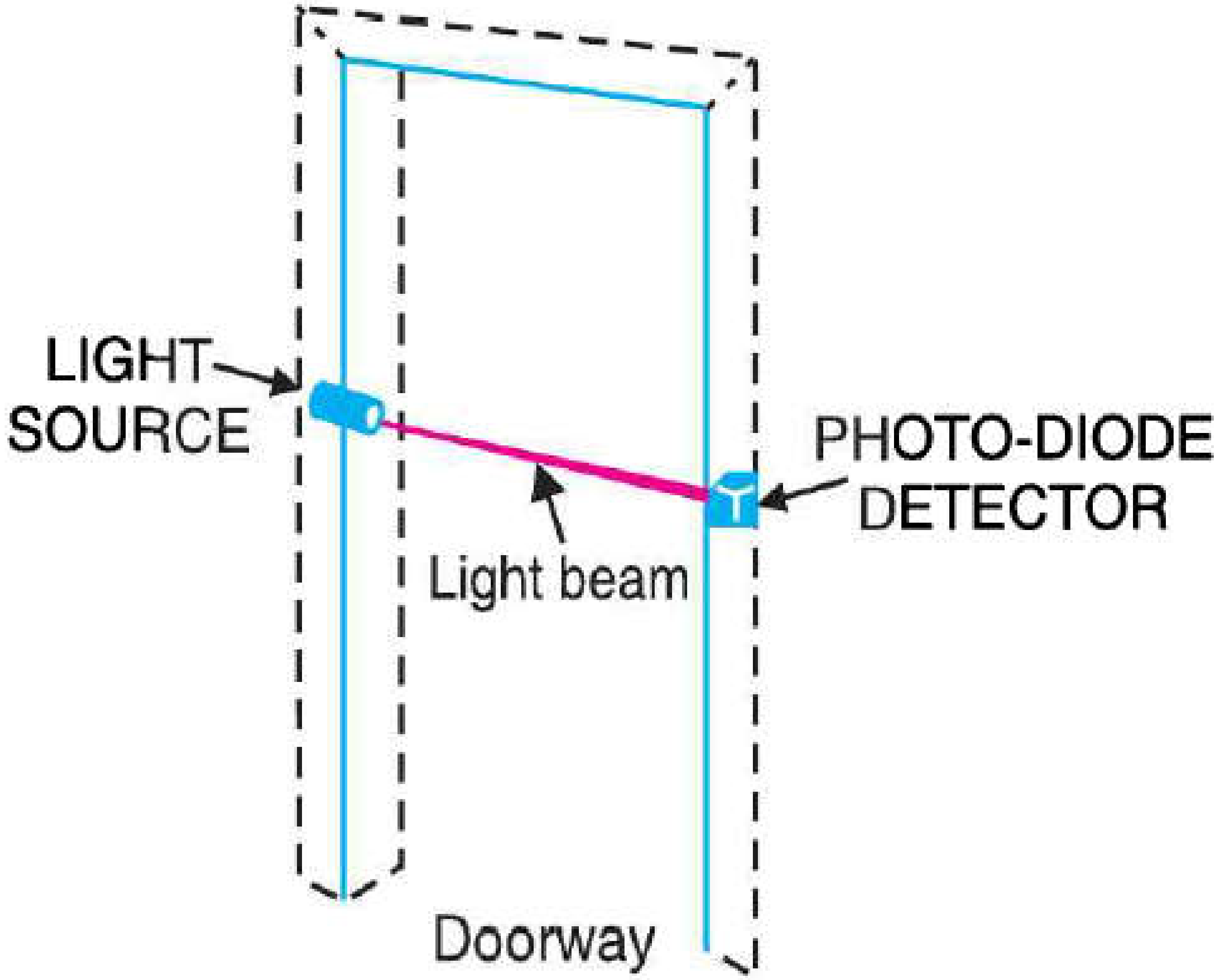
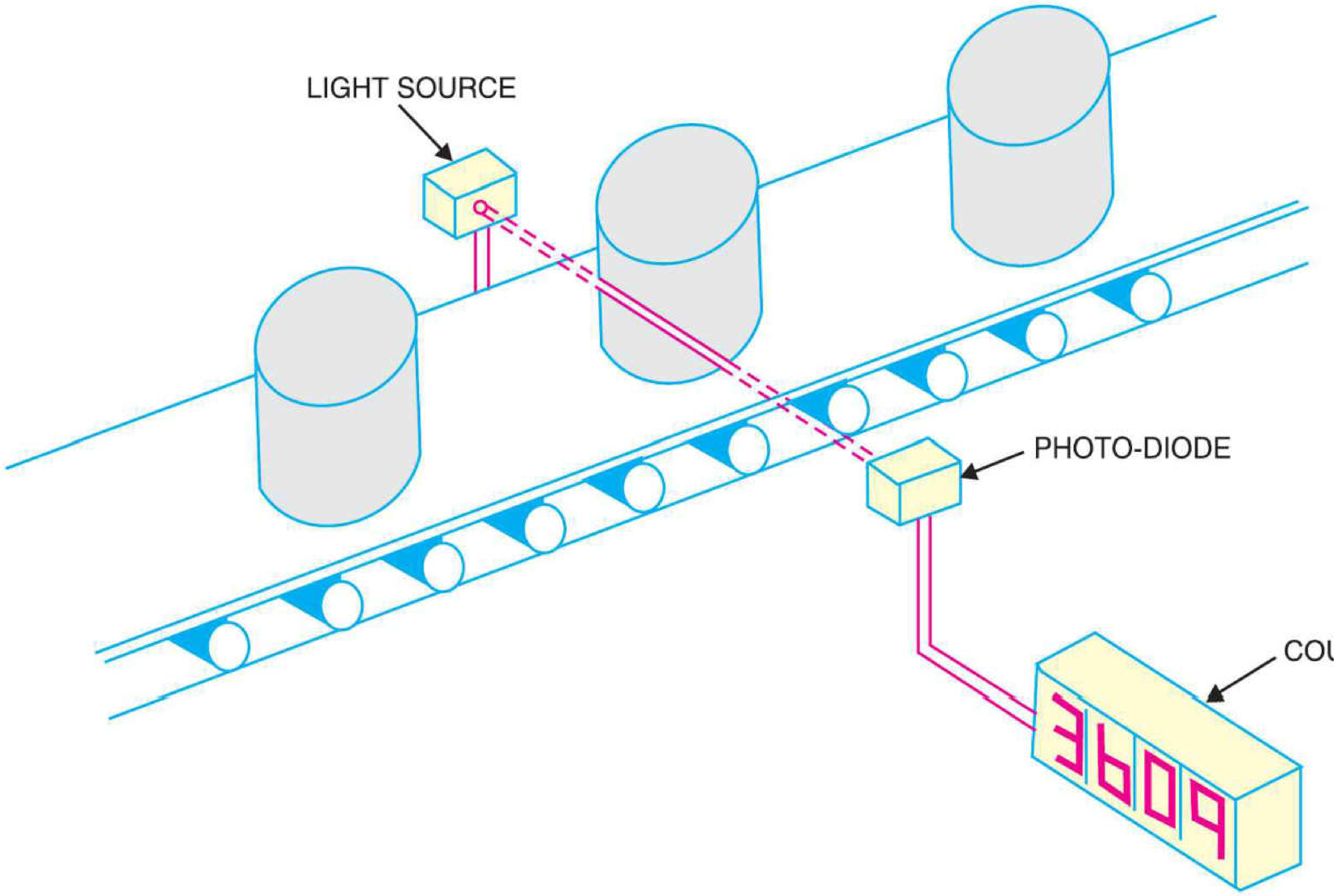


Photo-Diode Applications

Counter Circuit

❑ Source sends a concentrated beam to a photo-diode across a conveyor.

❑ As the object passes, the beam breaks, the reverse current drops down to the dark current level and the count increases by one.



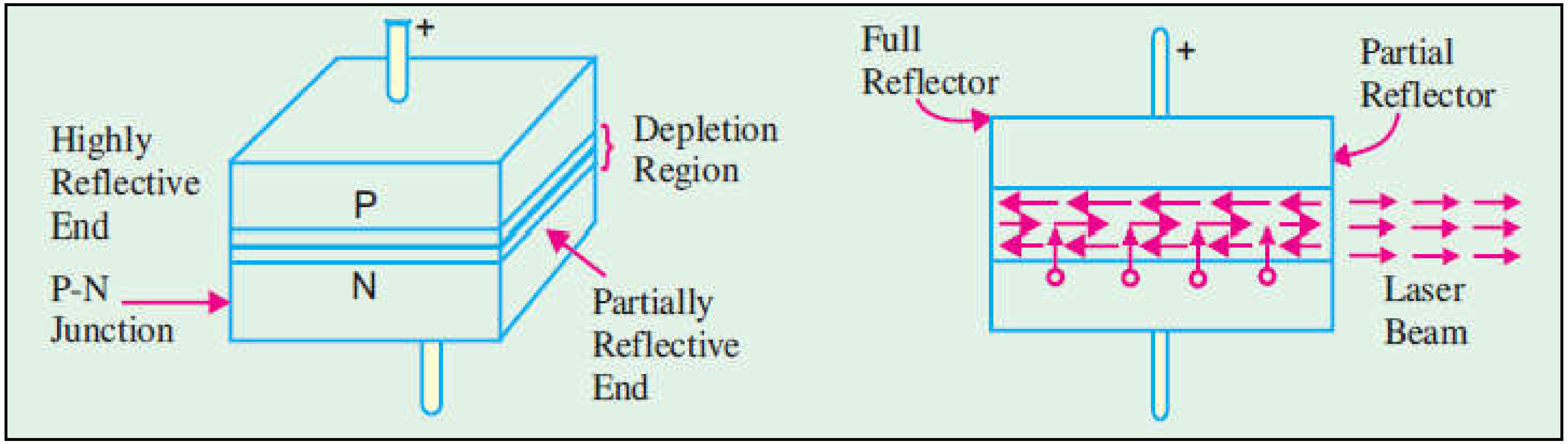
LASER Diode Features

Light Amplification (by) Stimulated Emission (of) Radiation

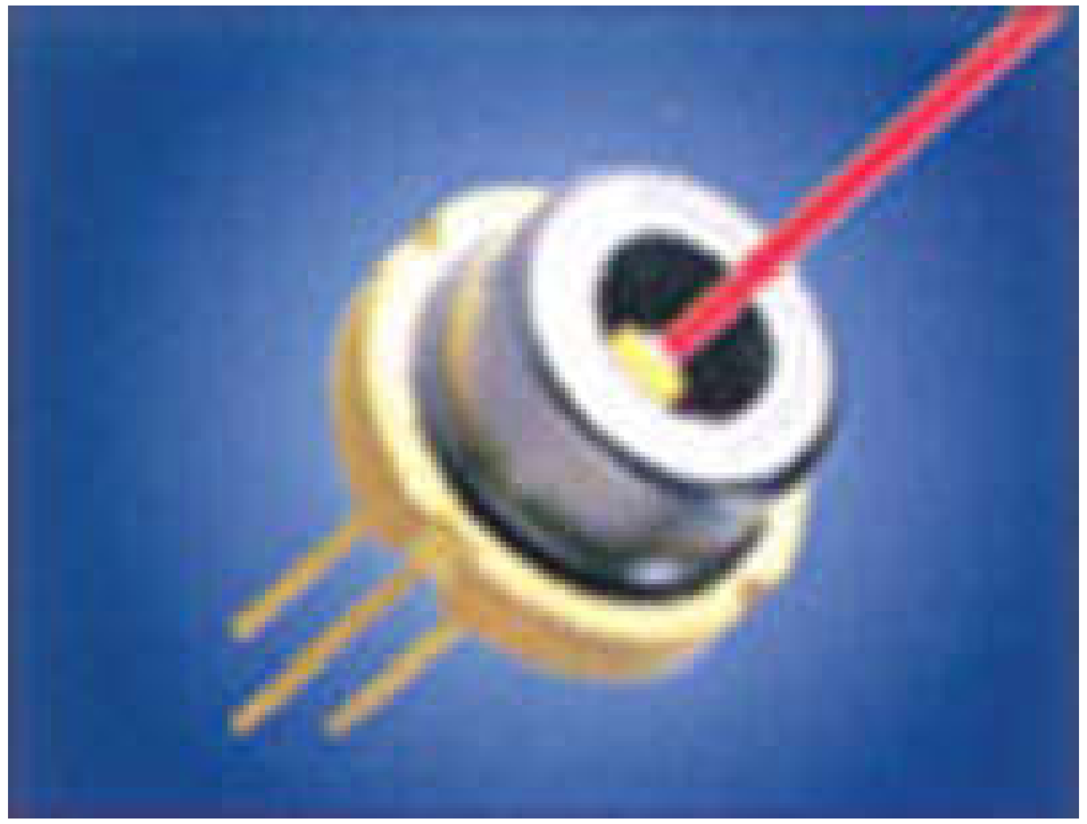
- ❑ Like LEDs, LASER diodes are PN Junction devices used under Forward Bias
- ❑ **Monochromatic :** Emits only one wavelength hence only color.
- ❑ **Collimated :** Emitted light waves travel parallel to each other.
- ❑ **Coherent Radiation :** Transmitted waves are of same frequency and phase in visible or infrared spectrum
- ❑ High Intensity (Can focus over small area of micrometers)
- ❑ Laser Diode is heavily doped
- ❑ Laser diodes are used in variety of applications ranging from medical equipment used in surgery to consumer products like optical disk equipment, laser printers, hologram scanners etc.
- ❑ Laser diodes emitting visible light are used as pointers. Those emitting visible and infrared light are used to measure range (or distance).

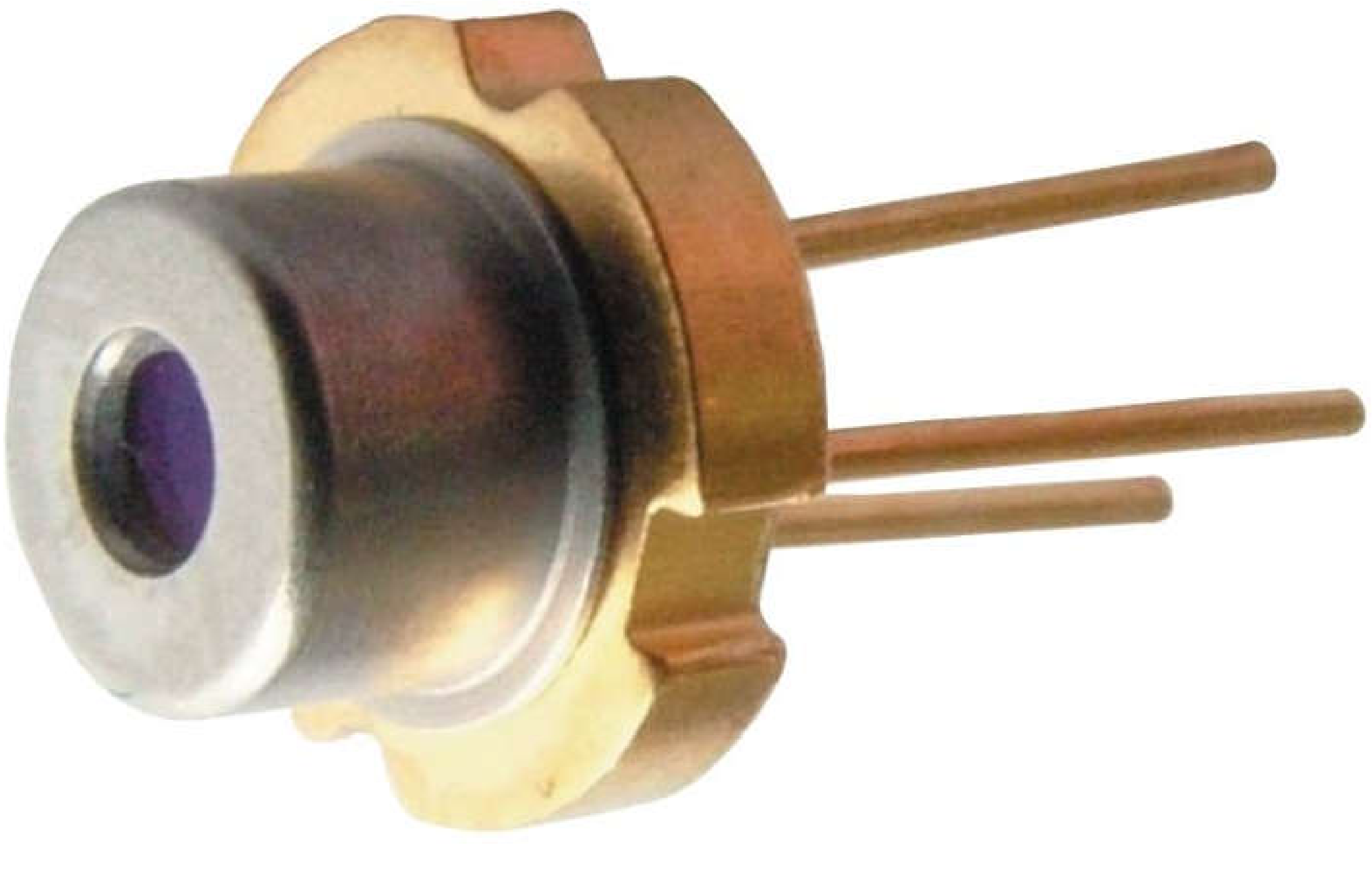
Working

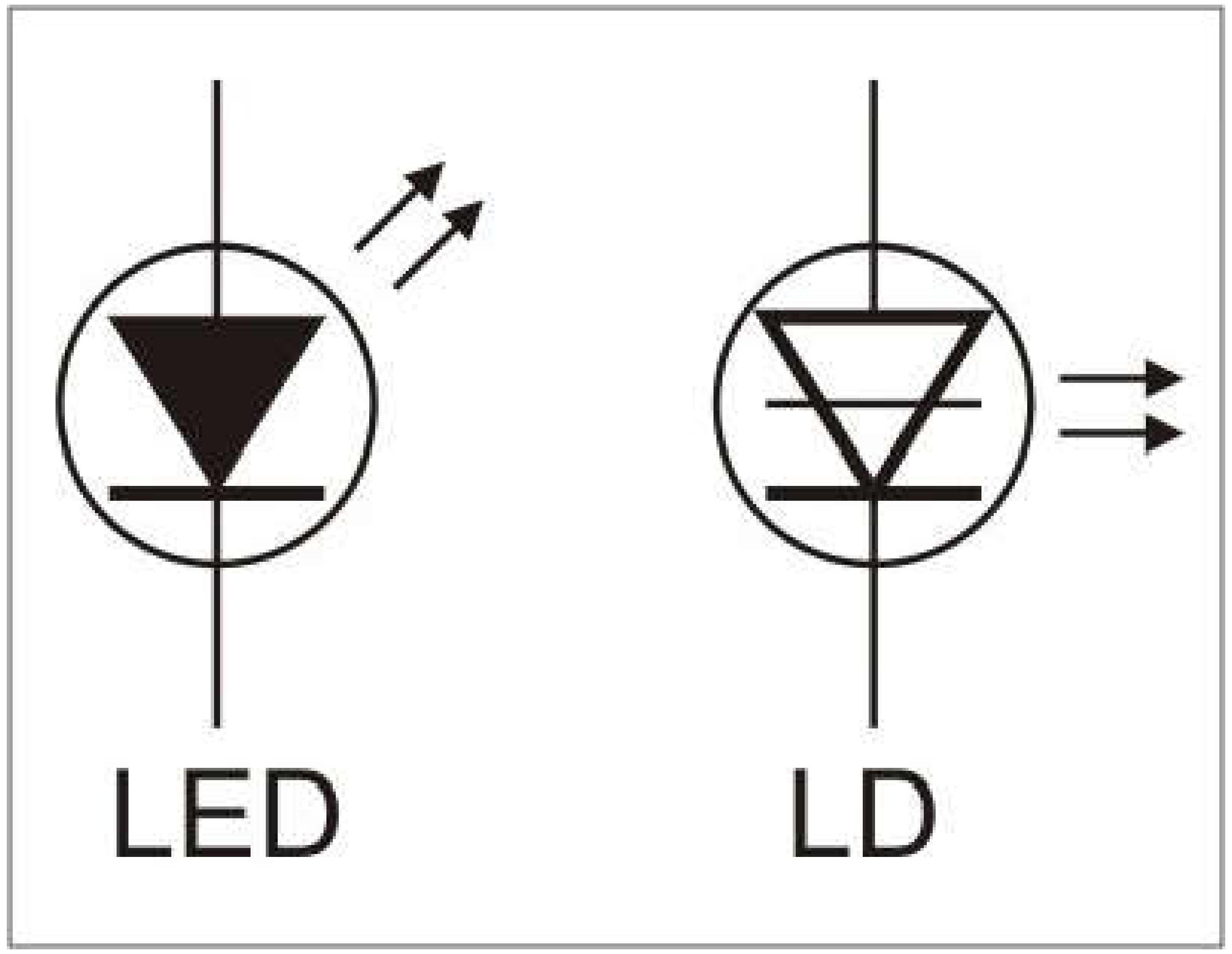
- Edge Emitting Laser: Emit light in a direction parallel to PN Junction Plane.
- When the P-N junction is forward-biased by an external voltage source,electrons move across the junction and usual recombination occurs in the depletion region which results in the production of photons.
- As forward current is increased, more photons are produced which drift at random in the depletion region. Some of these photons strike the reflective surface perpendicularly.
- These reflected photons enter the depletion region, strike other atoms and release more photons. All these photons move back and forth between the two ref lective surfaces.
- The photon activity becomes so intense that at some point, a strong beam of laser light comes out of the partially reflective surface of the diode.



LASER Symbol

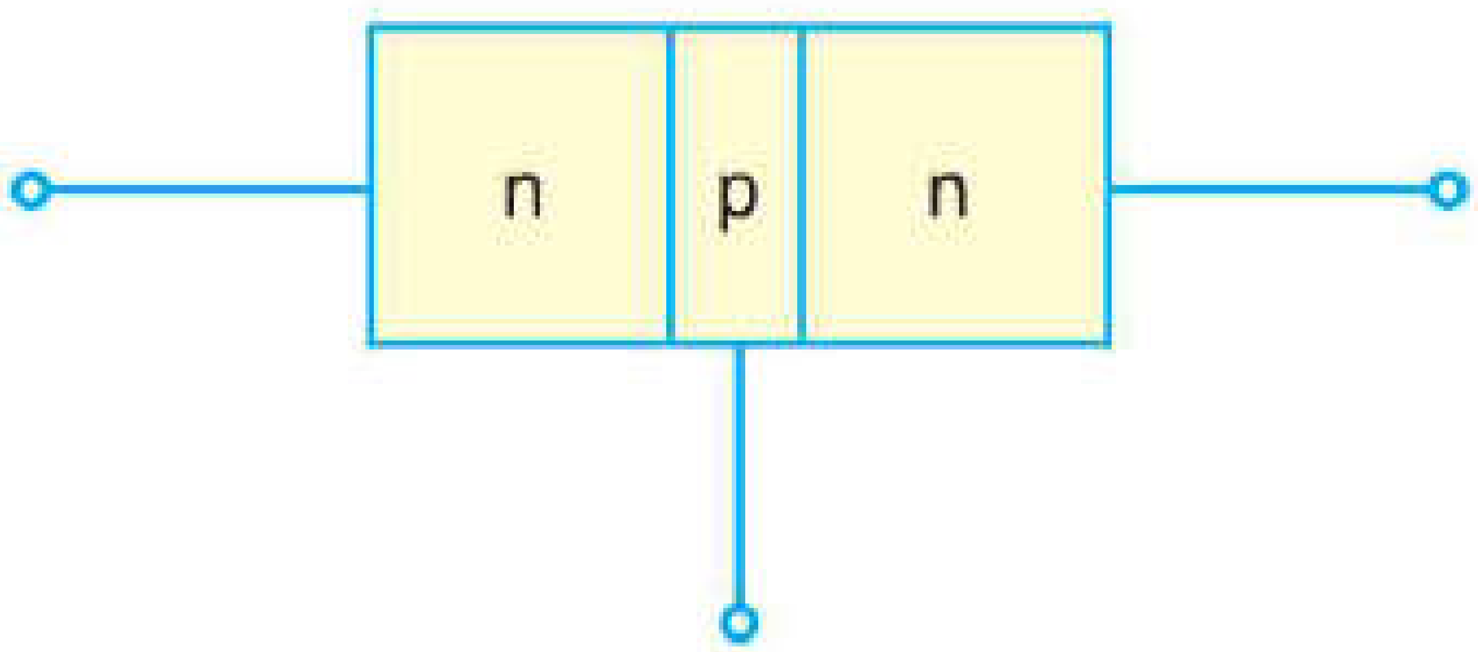


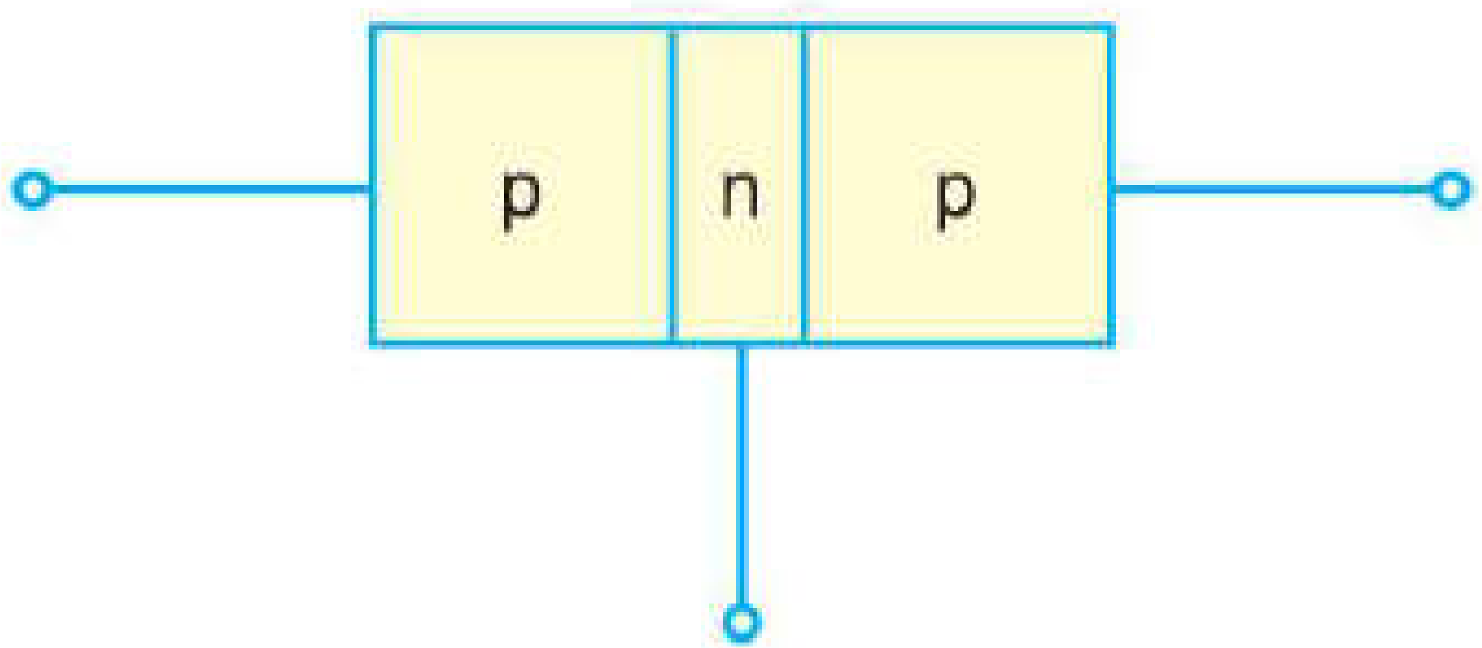




Transistors

- It's a three layer semiconductor device consisting of either two n and one p type material, or two p and one n type material.
- The former is called an npn transistor, while the latter is called the pnp.
- As shown in figure, it is a two junction device. Can be assumed as two diodes connected back to back.
- There are three terminals one taken from each semiconductor.
- The middle layer is thin compared to the other two. This is the most important factor in the functioning of transistor.

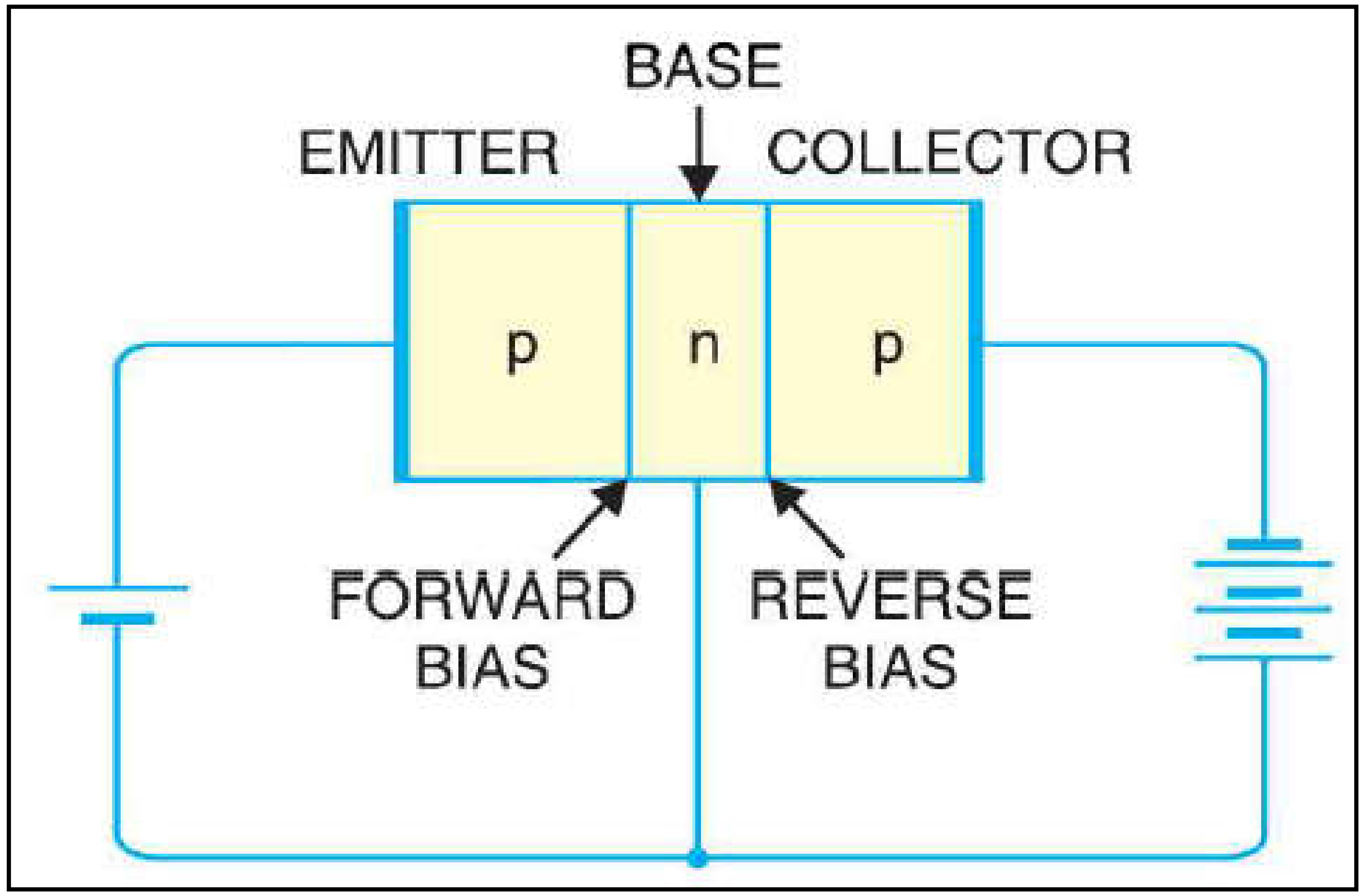


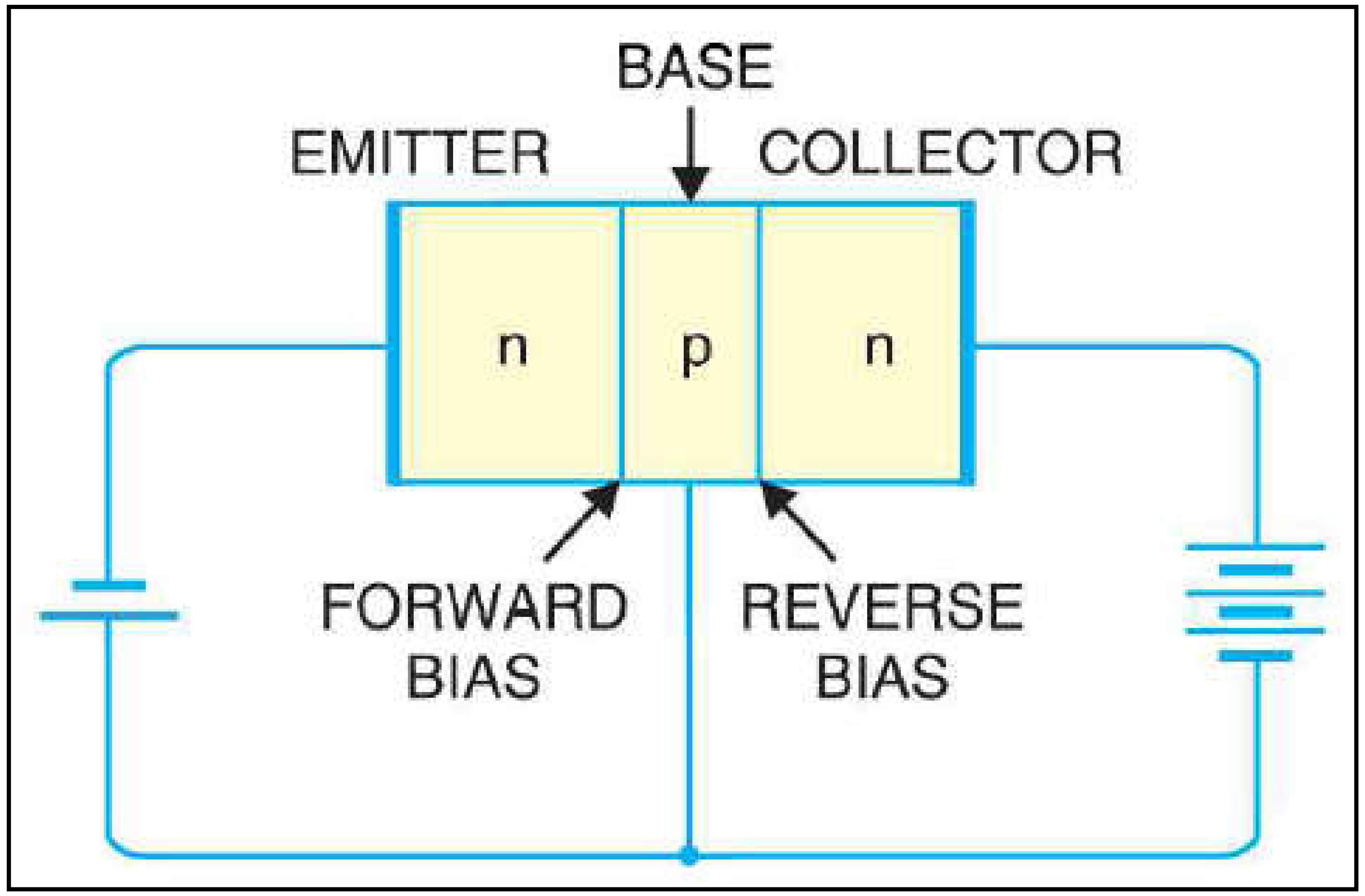


Naming Transistor Terminals

- A transistor has three sections. The section on one side is called emitter and the section on opposite side is called collector.
- The middle section is called base and forms two junctions between collector and emitter
- **Emitter:** Supplies charge carriers. Always forward biased w.r.t Base to supply large number of charge carriers. In PNP, emitter supplies large number of holes, whereas in NPN it supplies large number of electrons.
- **Collector:** Collector collects carriers. The collector is always reverse biased w.r.t Base. For an pnp transistor, collector receives holes from its junction, for npn it receives electrons.
- **Base:** The middle section which forms two pn junction between emitter and collector is called Base.

Junction Biasing





Few Important Points

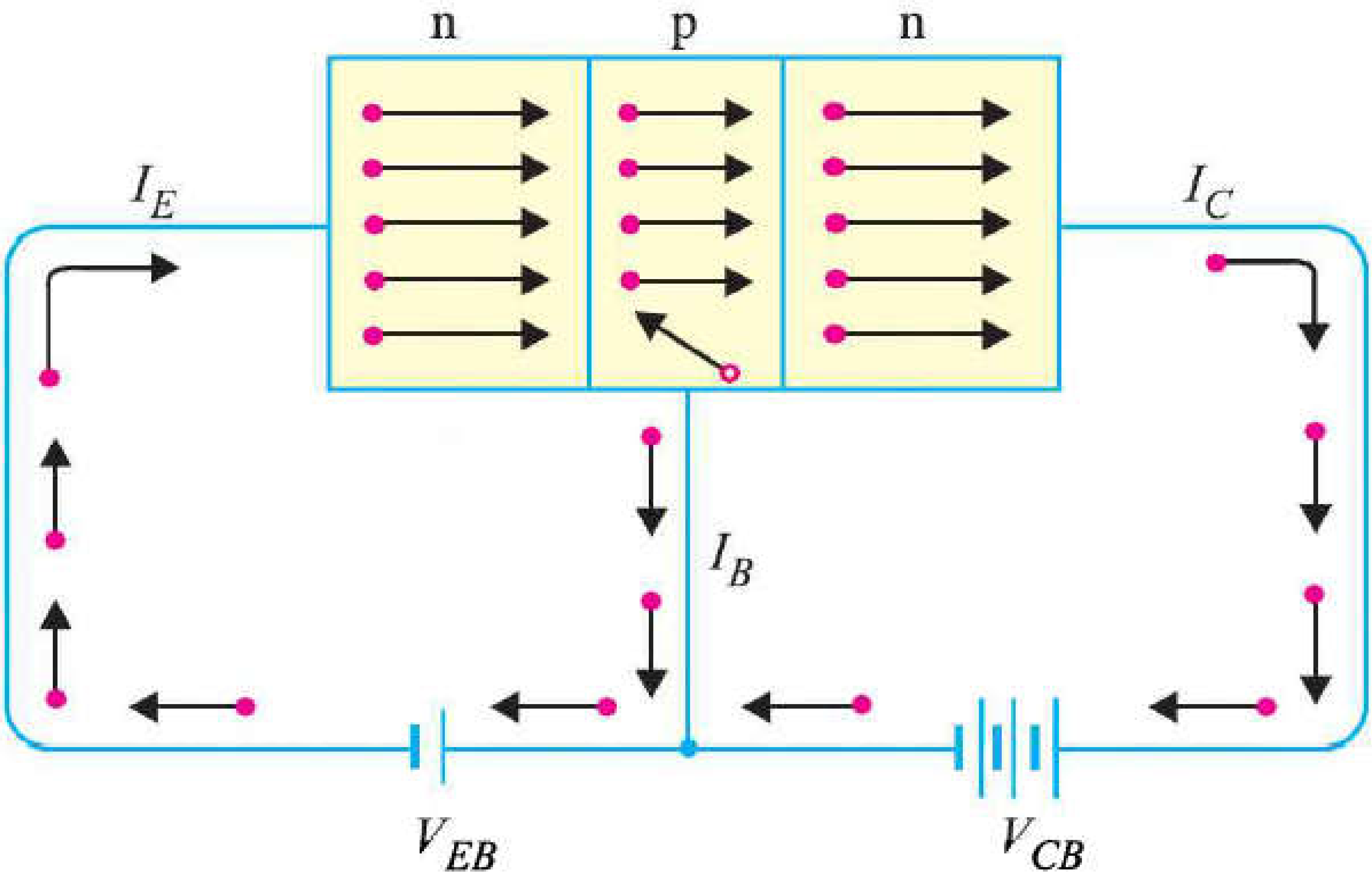
- Emitter is heavily doped so that it can inject large amount of carriers into the base
- Base is lightly doped so it can pass most of the carriers to collector
- Collector is moderately doped
- Junction between Emitter and Base is called Emitter-Base Junction (Emitter Diode) and the junction between Collector and Base is called Collector-Base Junction (Collector Diode).
- Emitter Diode is always Forward Biased and the Collector Diode is always reverse biased.
- The resistance of emitter diode is very small (Forward Biased), while the resistance of collector diode is very large (Reverse Biased).

Transistor Operation

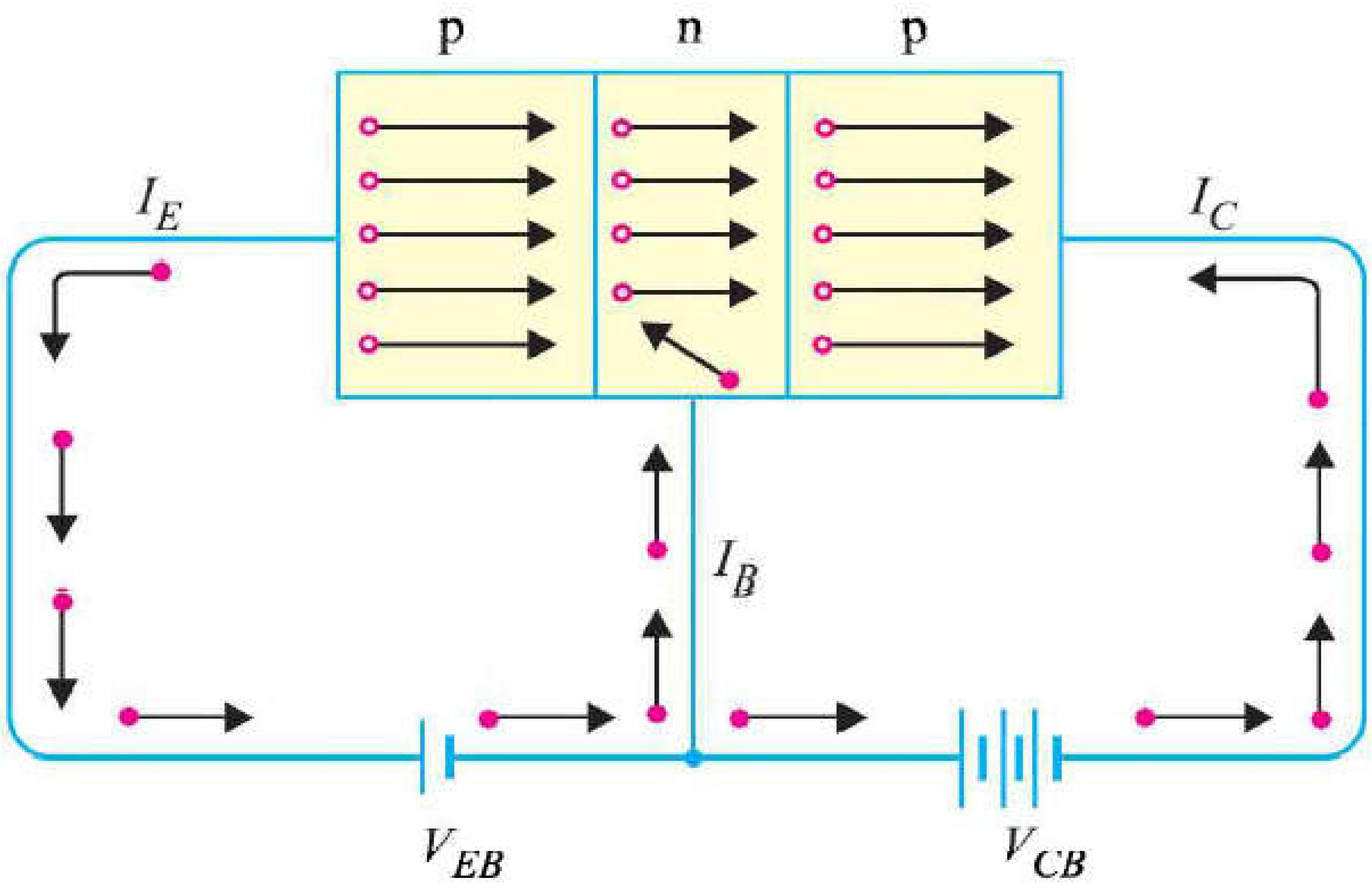
- The forward bias causes the electrons in the n-type emitter to flow towards the base
- This constitutes the emitter current Ie
- As these electrons flow through the p-type base they tend to combine with holes.
- Since base is very lightly doped and very thin, very few electrons (<5%) combine with holes to constitute base current Ib.
- The remainder electrons (>95%) cross the base collector junction to form collector current Ic.
- Almost entire emitter current flows in the collector circuit.
- The conduction in npn is due to electrons, where as in pnp it is due to holes.

$$I_E = I_B + I_C$$

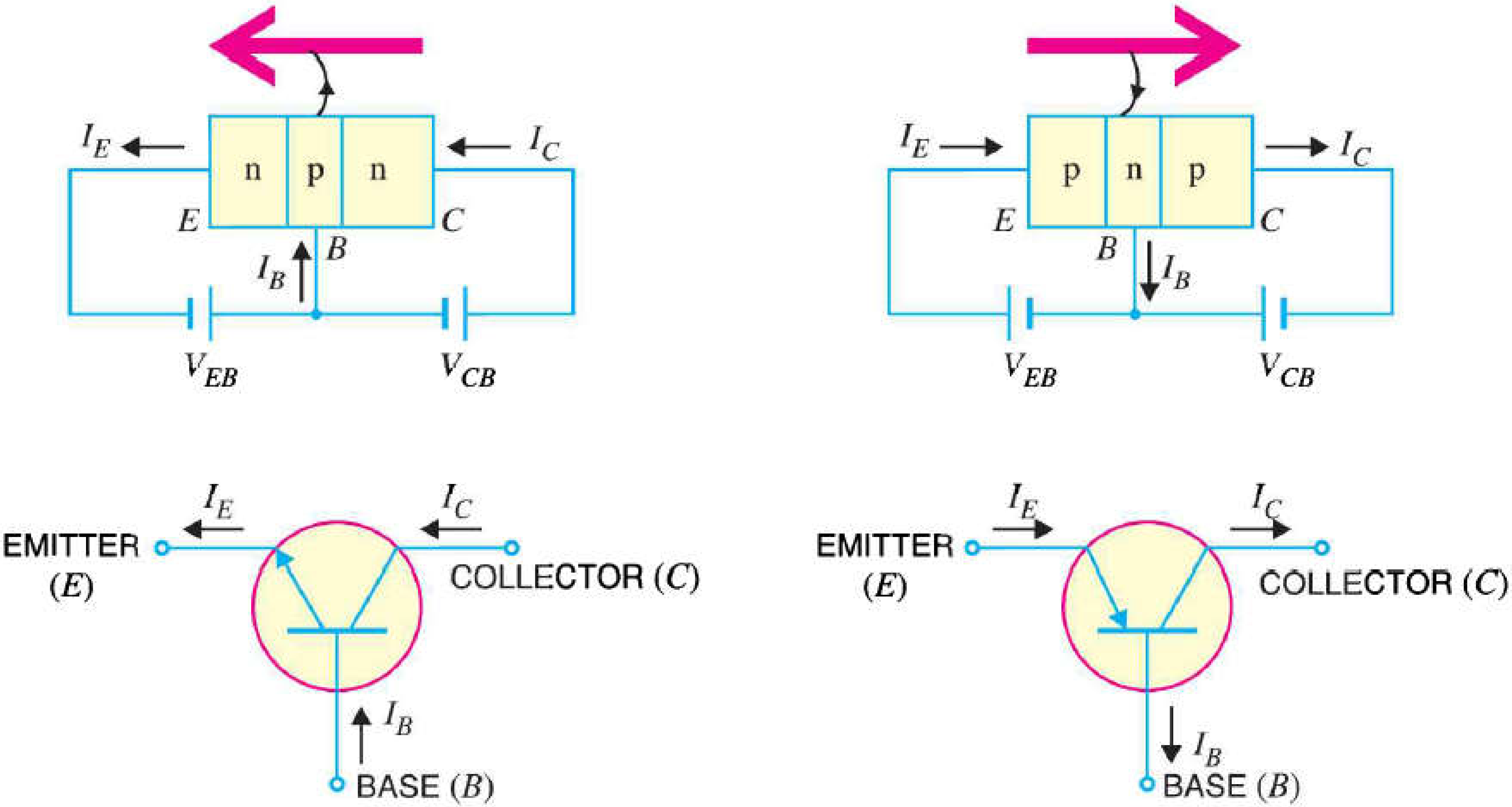
Transistor Current Flow (npn)



Transistor Current Flow (pnp)

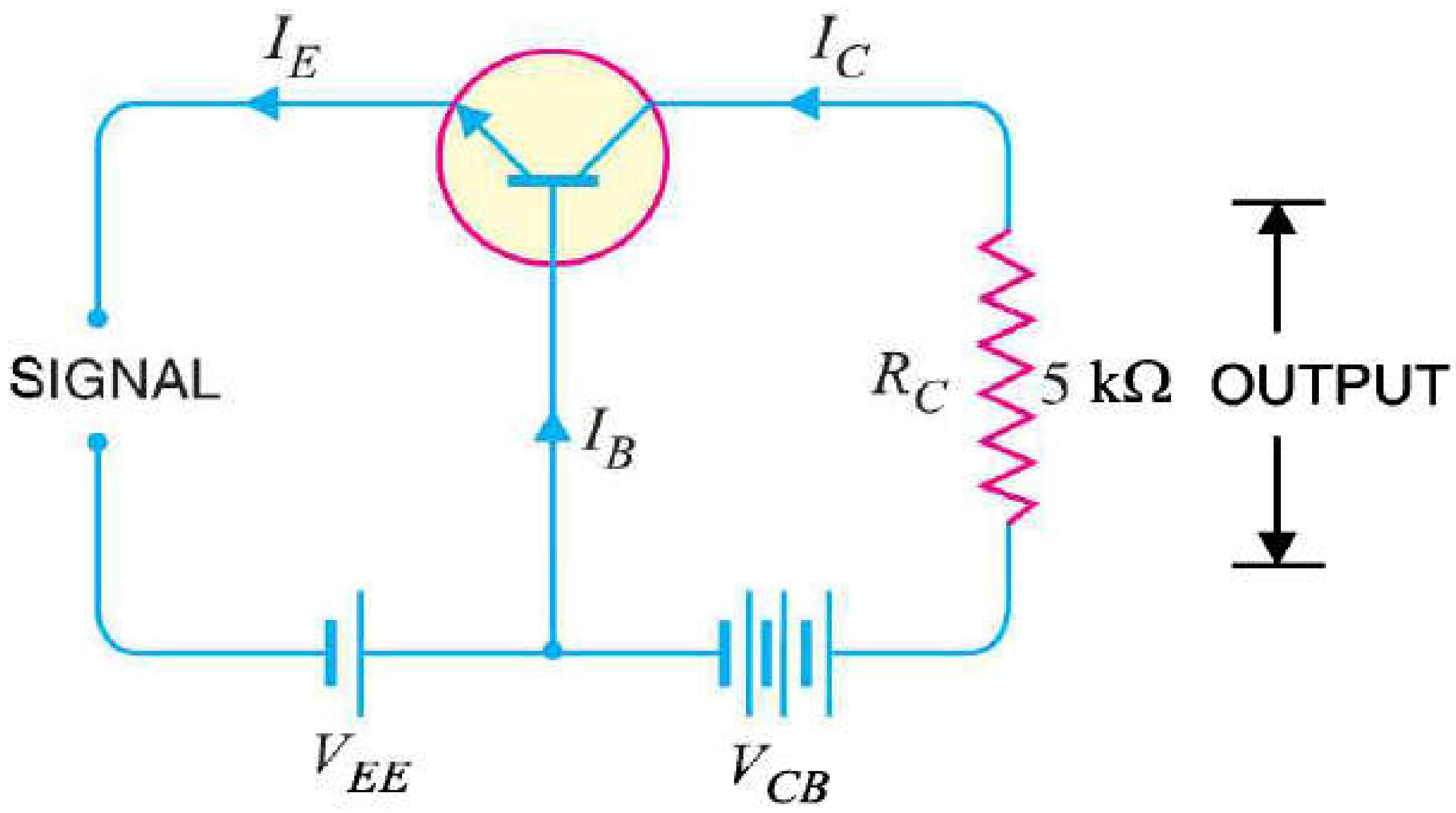


Transistor Symbols



Transistor as an Amplifier

- Raises the strength of weak signal.
- Weak signal is applied between emitter-base junction and the output is taken across load Rc connected in the collector circuit.
- For faithful amplification, the input circuit (Base-Emitter) should always remain forward biased.
- This is done using battery VEE. It's polarity and magnitude is such that it always keeps the input circuit forward biased regardless of the polarity of the signal.



Transistor as an Amplifier

- As the input circuit has small resistance, a small change in signal voltage causes an appreciable change in the emitter current.
- This causes almost same change in the collector current

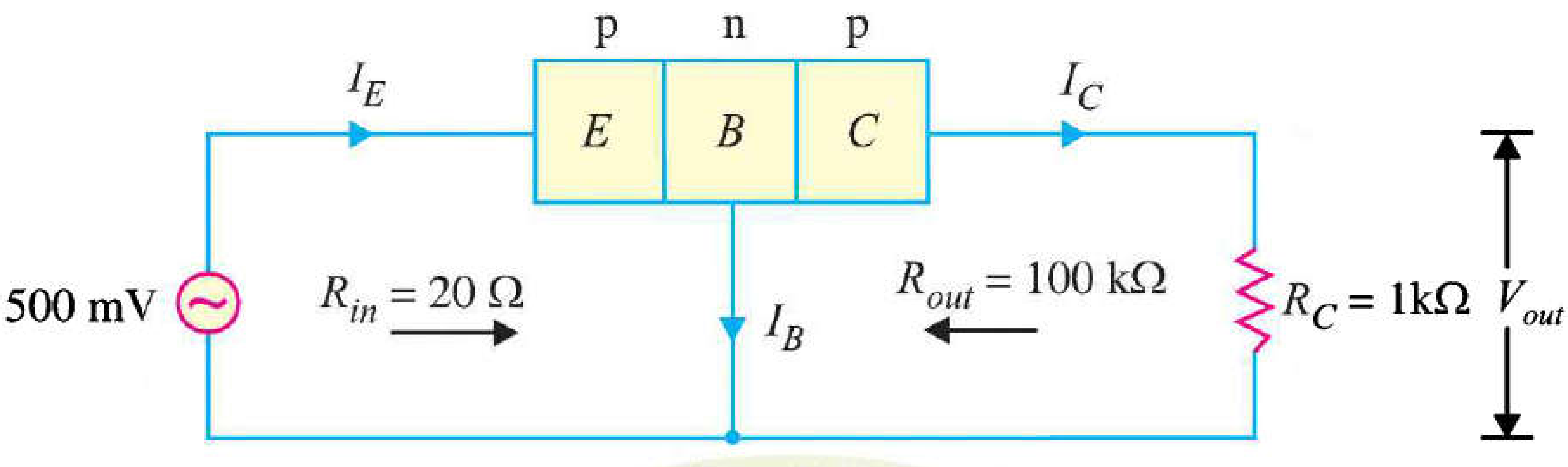
$$Ic=\beta.Ib$$

- The collector current flowing through a high load resistance Rc, produces a large voltage across it.
- Thus, a weak signal applied in the input circuit appears in the amplified form in the collector circuit.

Transfer + R**esistor** $\longrightarrow$ **Transistor**

Concept Check

Determine the Voltage Gain.

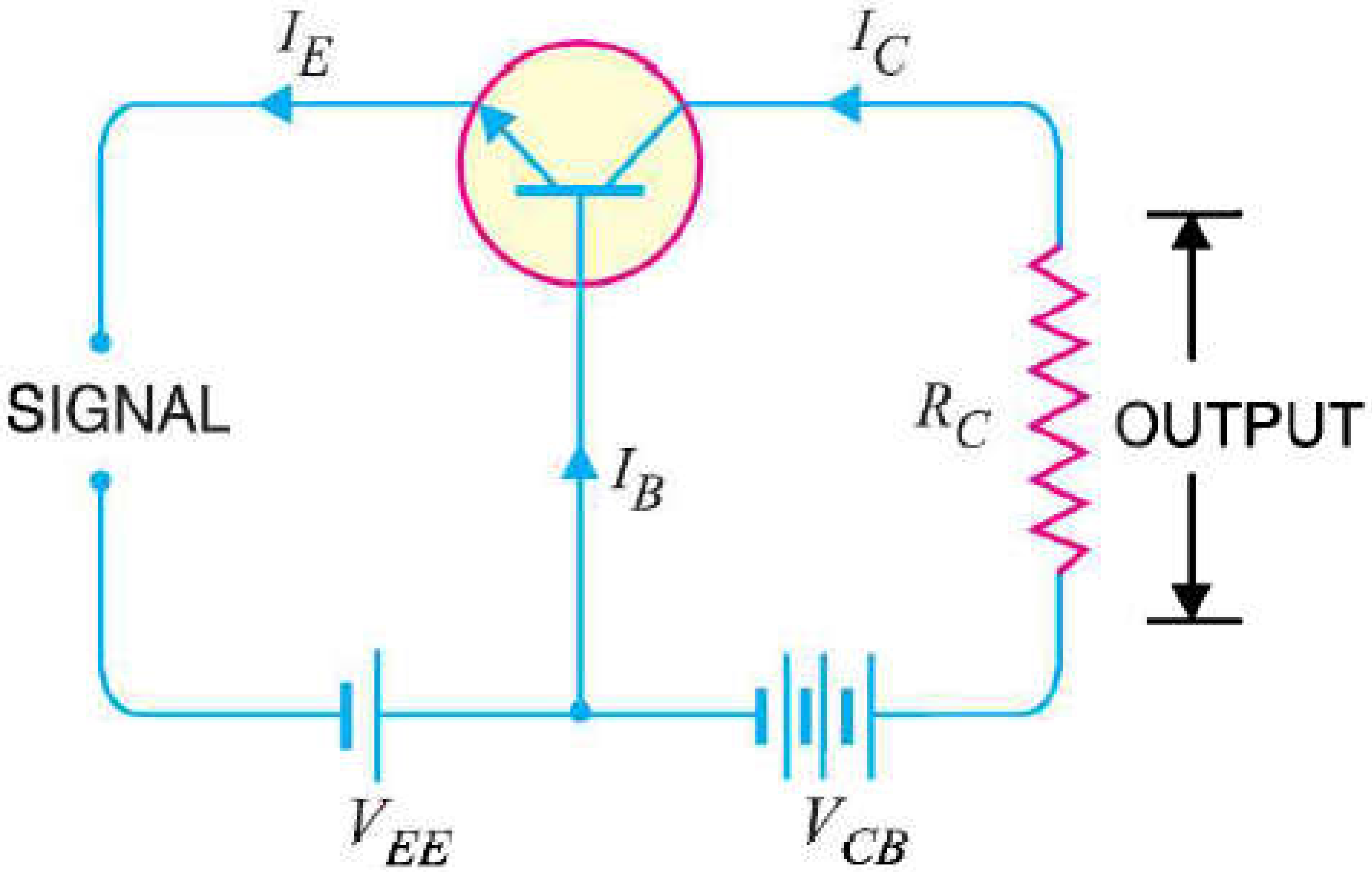


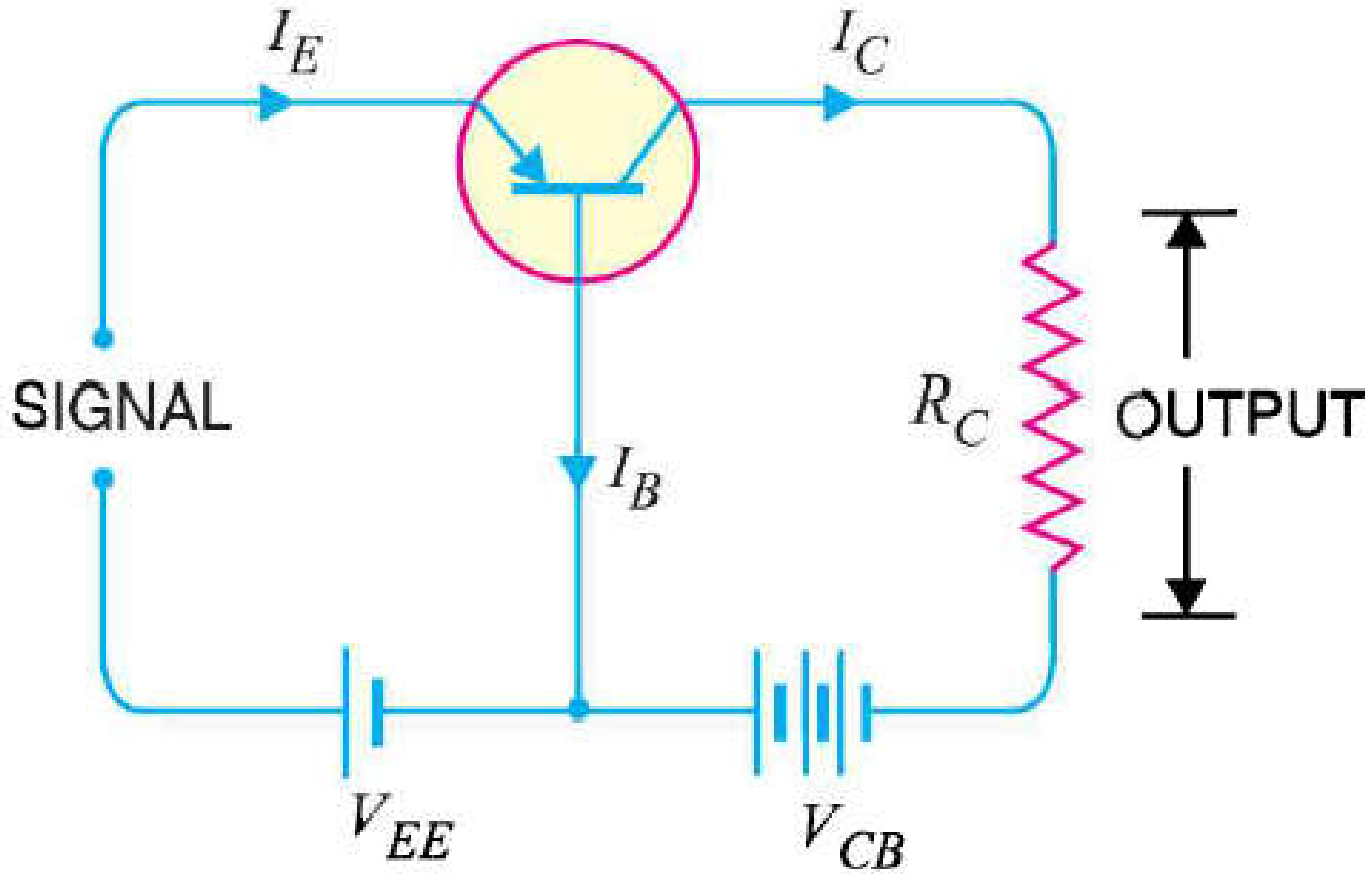
Transistor Connections

- ❑ **Common Base**
    - ❑ Base is common between Input and Output
- ❑ **Common Emitter**
    - ❑ Emitter is common between Input and Output
- ❑ **Common Collector**
    - ❑ Collector is common between Input and Output

Common Base

Input is applied between emitter and base and output is taken from collector and base





Features

- **Current amplification factor (α);** It is the ratio of output current to the input current.

α=Ic/Ie

- It will always be less than unity because collector current will always be less than the emitter current
- This value can be increased but not greater than unity by making base thin and doping it lightly
- Practical values of α in commercial transistors range from 0 to 0.99
- The whole emitter current does not reaches the collector because there will always be some combination in base.
- Also since collector base junction is reverse biased, there will always be a small leakage current due to flow of minority charge carriers.
- The collector current thus comprises of two currents: 1) the part of the emitter current which reaches the collector (α.Ie) and 2) the leakage current

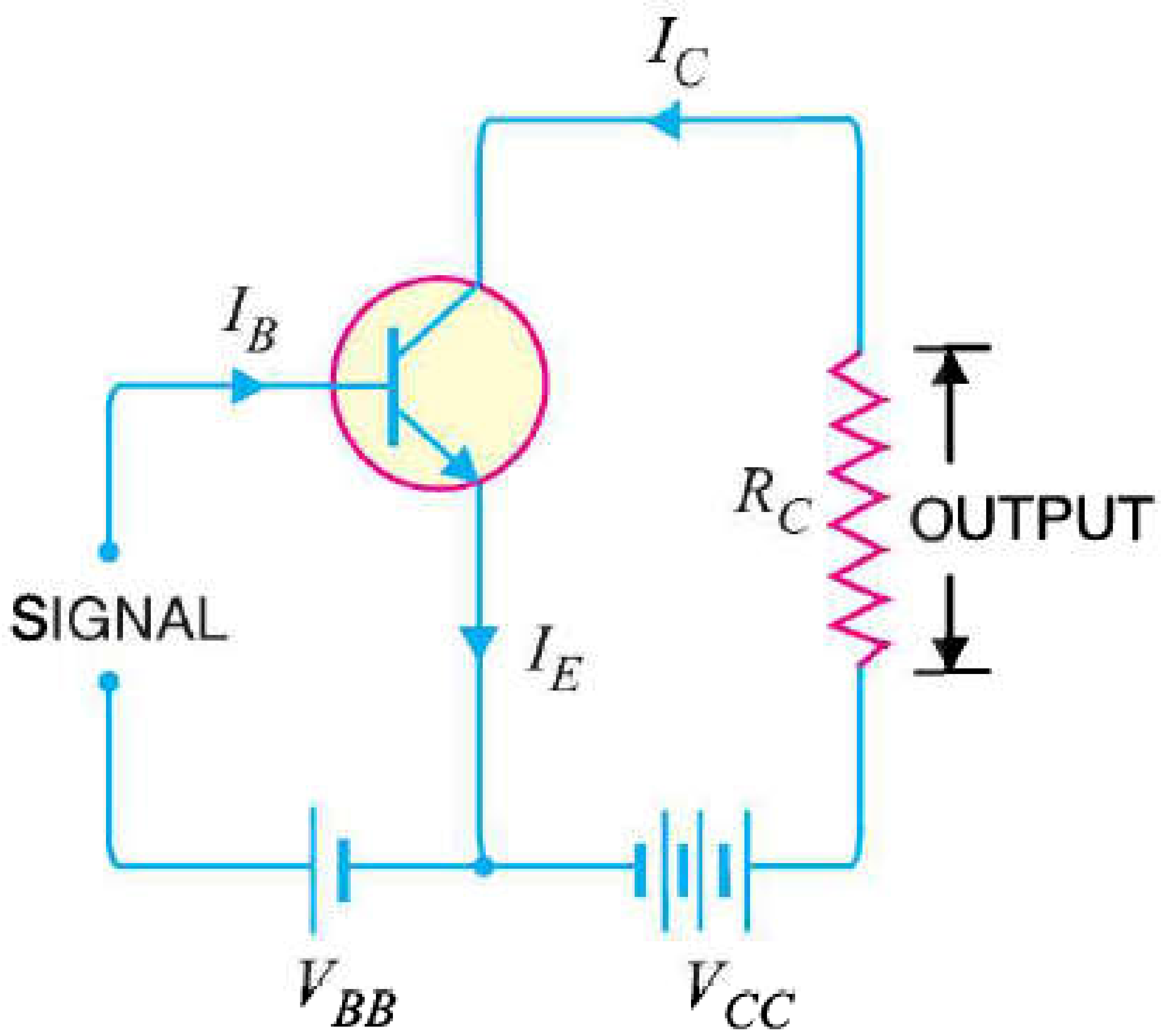
$$I_C = \alpha I_E + I_{leakage}$$

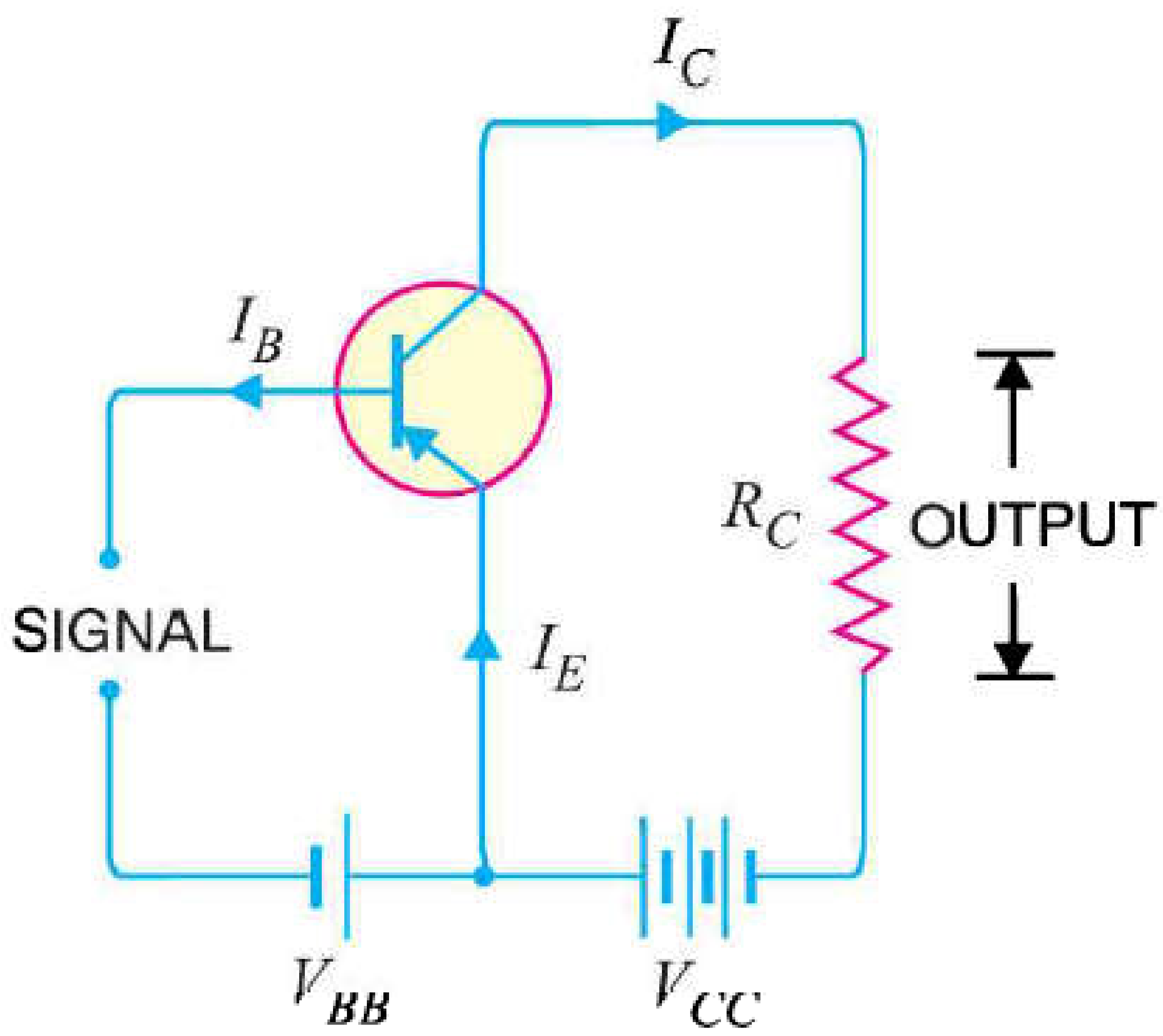
Current Equations

$$
\begin{aligned}
I_C &= \alpha\, I_E + I_{CBO} \\
I_E &= I_C + I_B \\
I_C &= \alpha\,(I_C + I_B) + I_{CBO} \\
I_C\,(1-\alpha) &= \alpha\, I_B + I_{CBO} \\
I_C &= \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}
\end{aligned}
$$

Common Emitter Configuration

Input is applied between base and emitter and output is taken from collector and emitter





Features

- Input is applied between base and emitter and output is taken between collector and emitter
- Ib is the input current and Ic is the output current
- **Base current amplification factor (β):**

$$\beta = Ic/Ib$$

- In any transistor, base current comprises of <5% of emitter current.
- Hence the value of β will always be greater than 20. Usually the range is between 20 – 500
- **Relation between α and β**

$$\alpha = \beta/\beta+1 \quad \text{or} \quad \beta=\alpha/1-\alpha$$

- As α approaches unity, β will tend to become infinity.
- Thus the current gain in common emitter configuration is very high.
- It is due to this reason this configuration is used in almost 90 to 95 percent of all transistor applications

Current Equations

$$\text{We know } I_E = I_B + I_C \qquad \ldots(i)$$

and

$$I_C = \alpha I_E + I_{CBO} \qquad \ldots(ii)$$

From exp. (*ii*), we get,

$$I_C = \alpha I_E + I_{CBO} = \alpha (I_B + I_C) + I_{CBO}$$

or

$$I_C (1 - \alpha) = \alpha I_B + I_{CBO}$$

or

$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \qquad \ldots(iii)$$

From exp. (*iii*), it is apparent that if $I_B = 0$ (*i.e.* base circuit is open), the collector current will be current to the emitter. This is abbreviated as I_{CEO}, meaning collector-emitter current with base open.

$\therefore$

$$I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$$

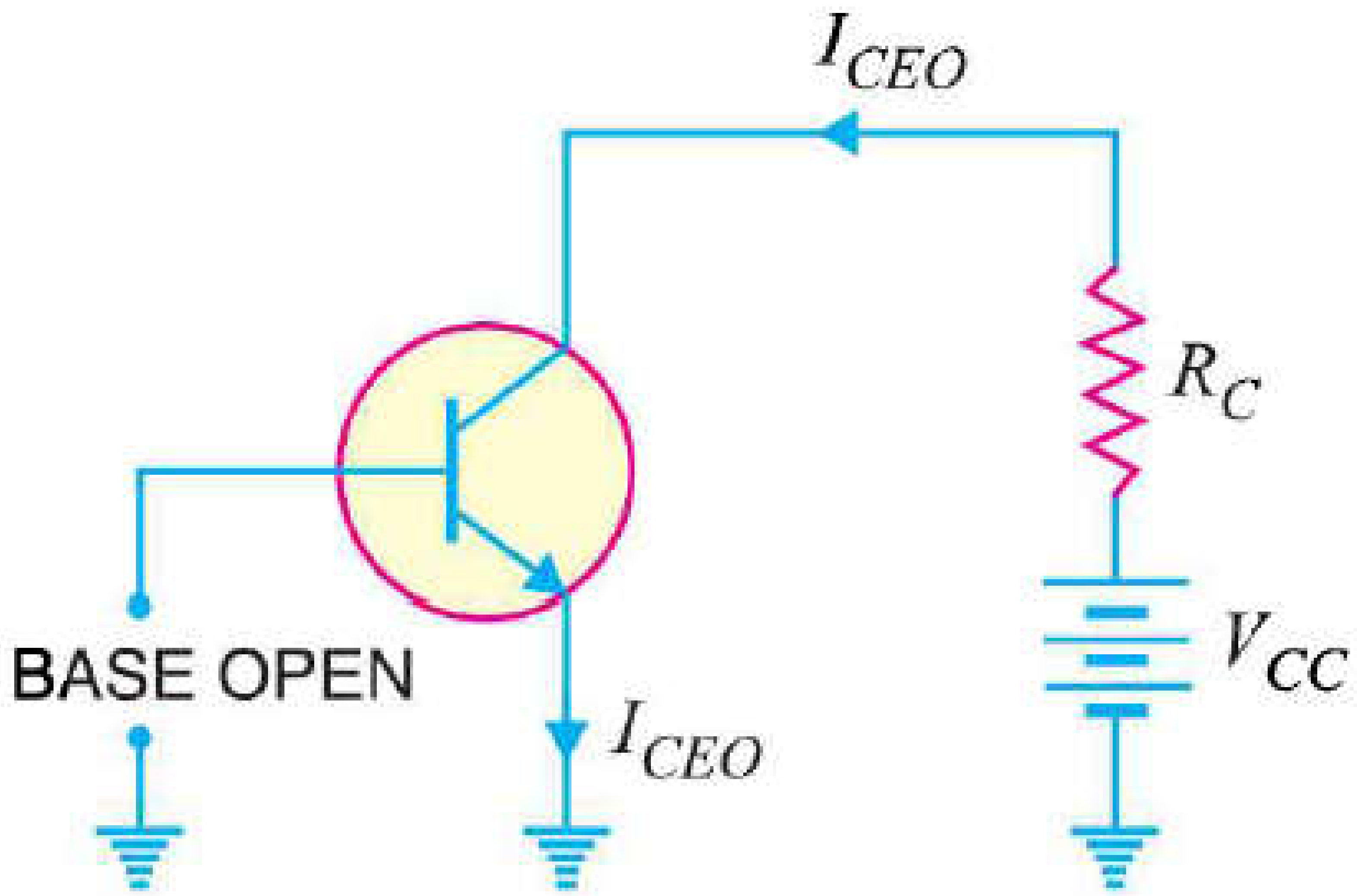
Substituting the value of $\frac{1}{1-\alpha} I_{CBO} = I_{CEO}$ in exp. (*iii*), we get,

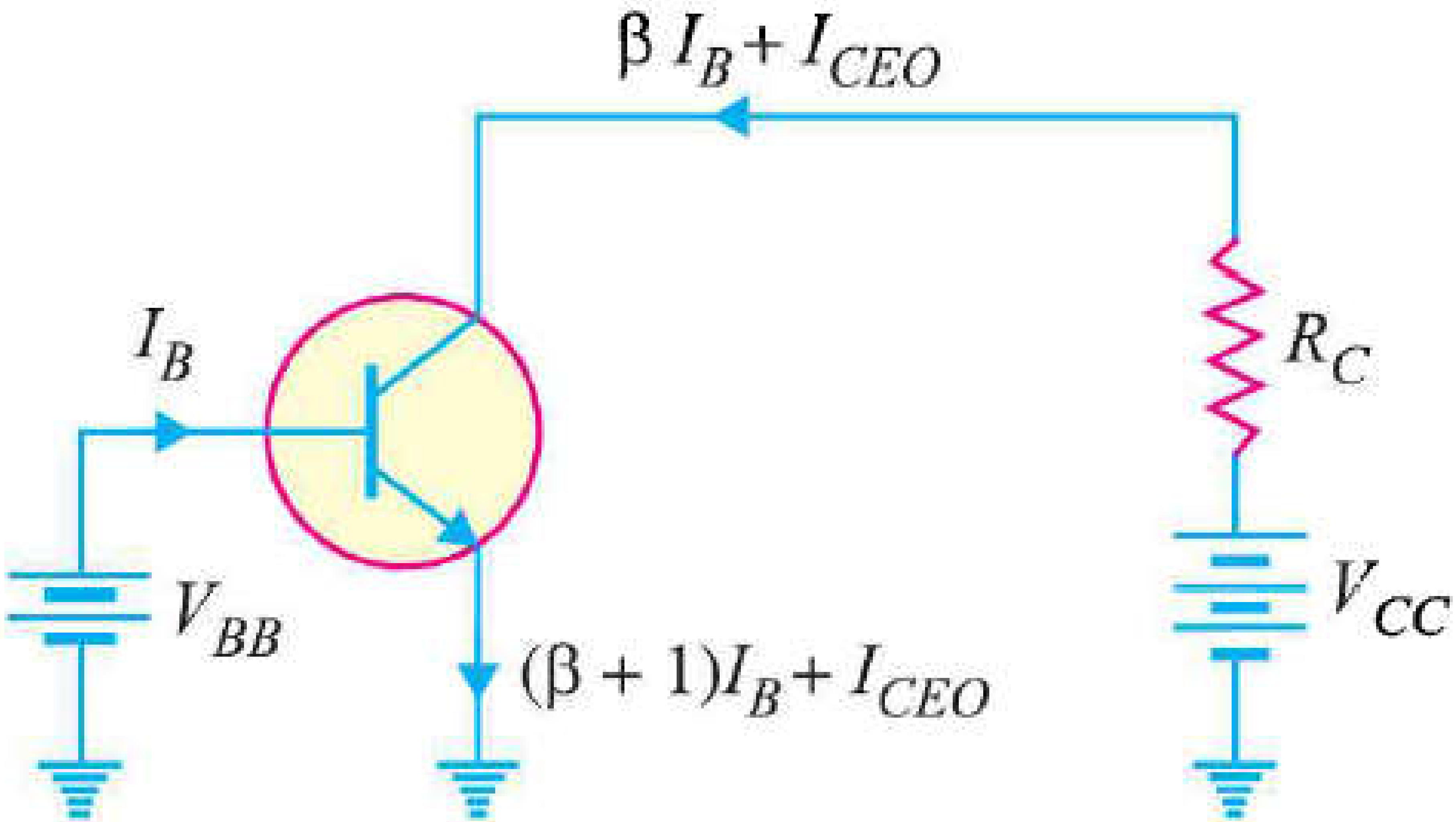
$$I_C = \frac{\alpha}{1-\alpha} I_B + I_{CEO}$$

or

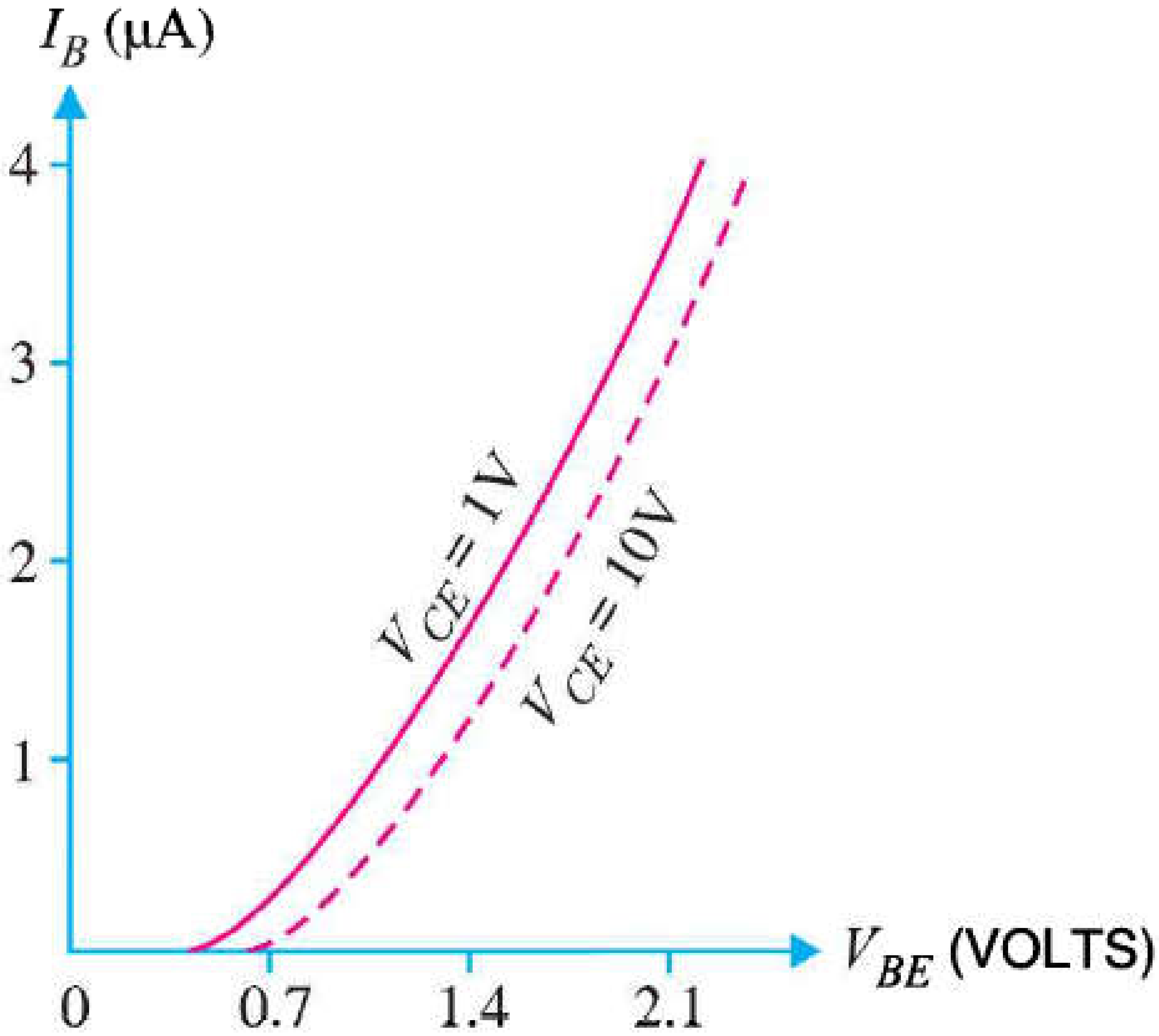
$$I_C = \beta I_B + I_{CEO} \qquad \left(\because \beta = \frac{\alpha}{1-\alpha}\right)$$

Concept of Iceo

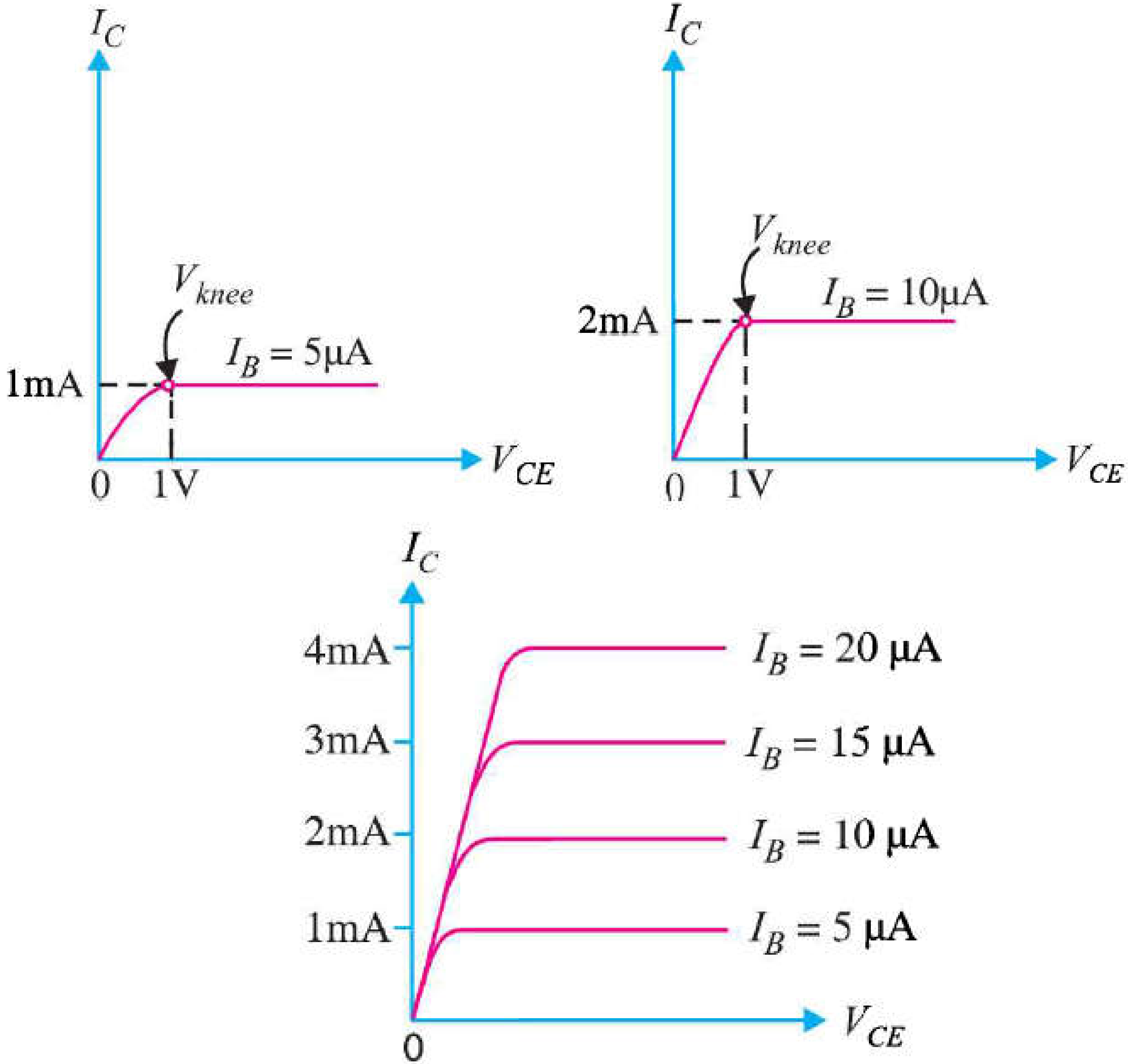




CE – Characteristics (Input)

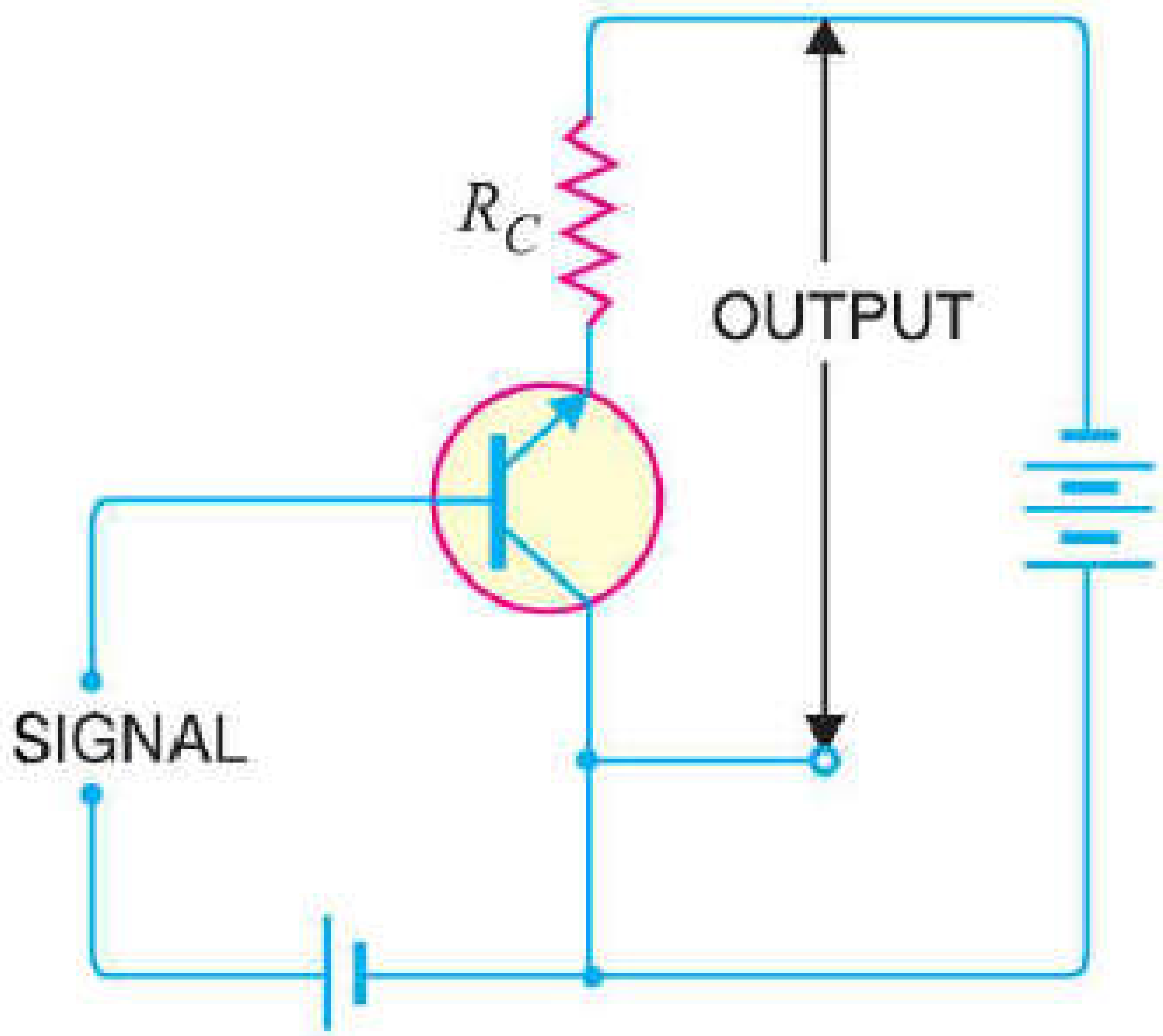


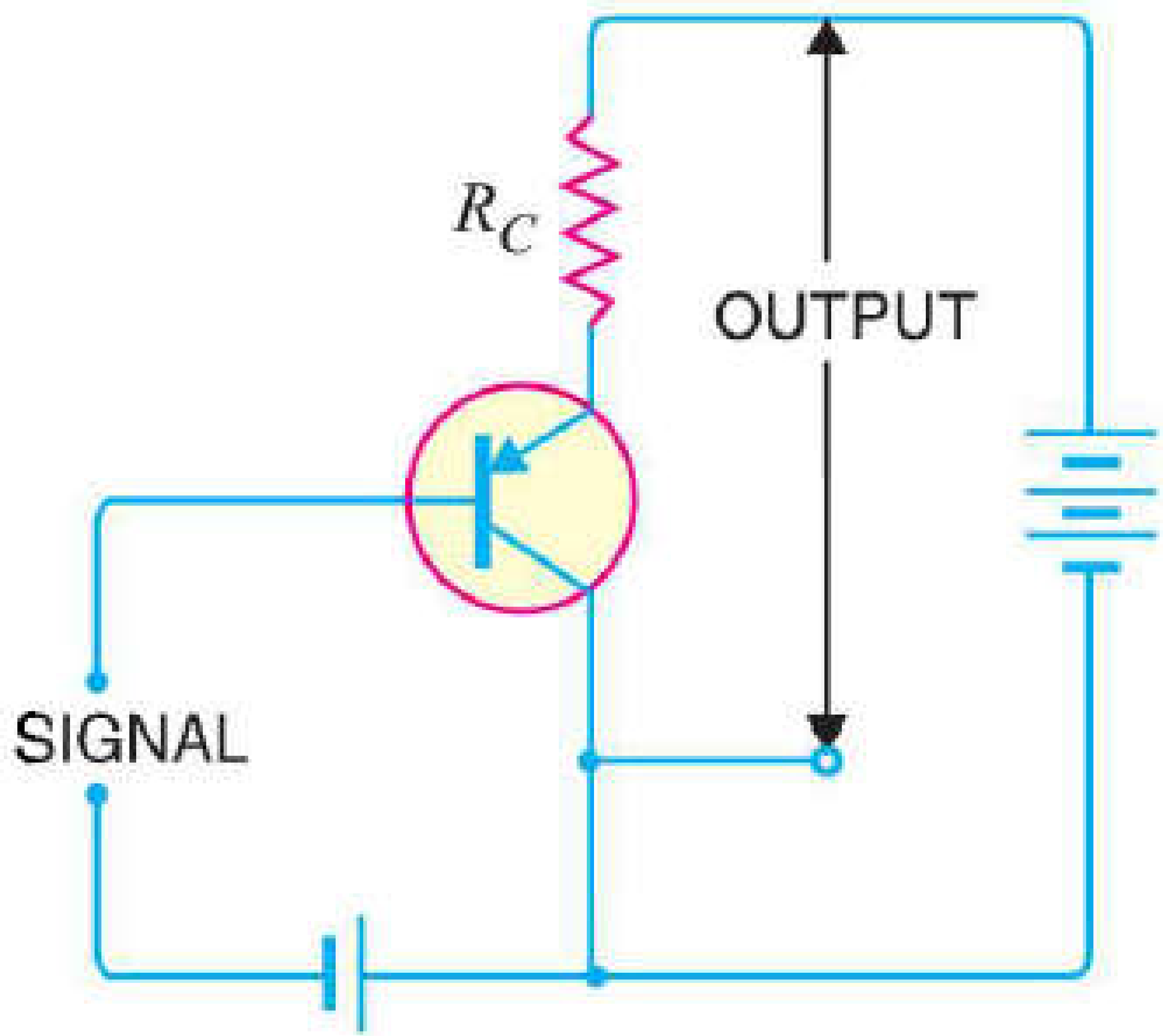
CE – Characteristics (Output)



Common Collector Configuration

Input is applied between Base and Collector, and output is taken bet ween Emitter and Collector





Features and Current Equations

- Input current is Base current (Ib) and the output current is Emitter current (Ie)
- Current amplification factor γ = Ie/Ib

$$\gamma = \frac{1}{1-\alpha}$$

$$I_C = \alpha I_E + I_{CBO}$$

$$I_E = I_B + I_C = I_B + (\alpha I_E + I_{CBO})$$

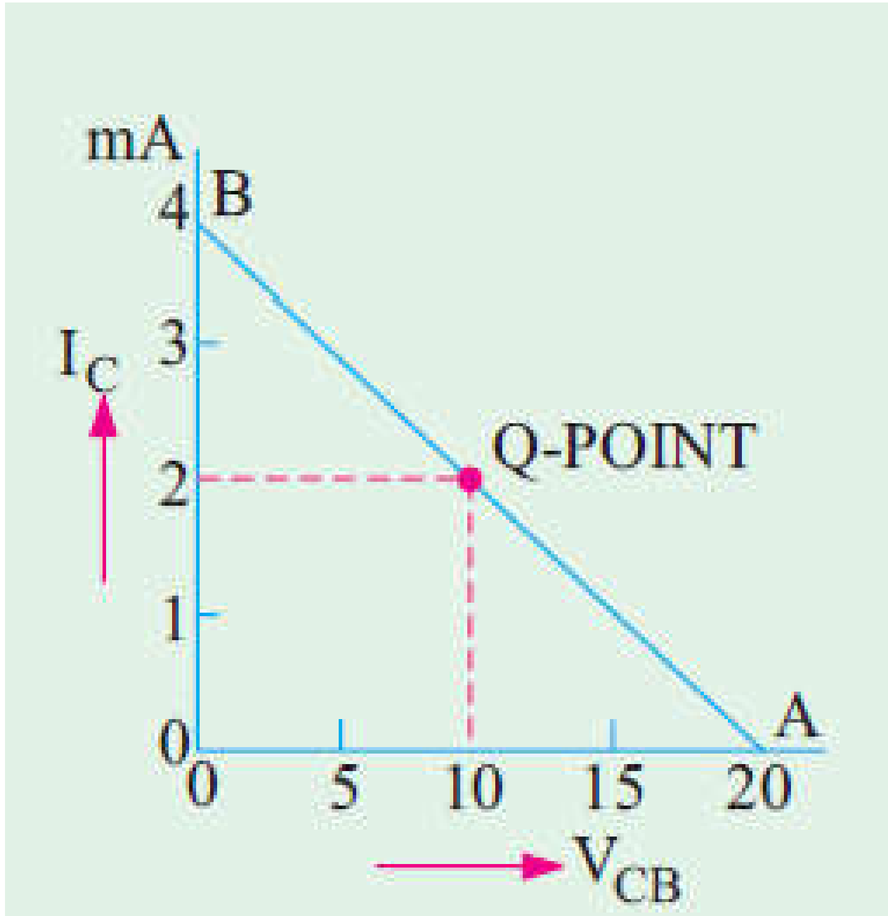
$$I_E(1-\alpha) = I_B + I_{CBO}$$

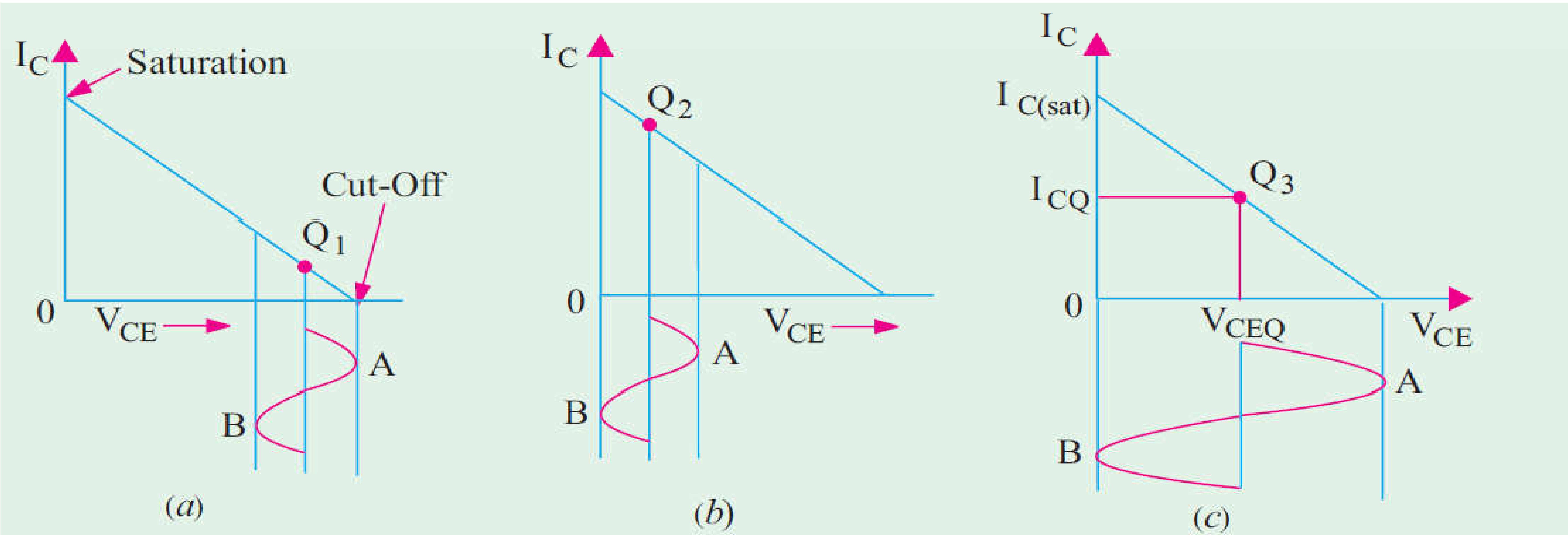
$$I_E = \frac{I_B}{1-\alpha} + \frac{I_{CBO}}{1-\alpha}$$

Transistor Connection Comparison

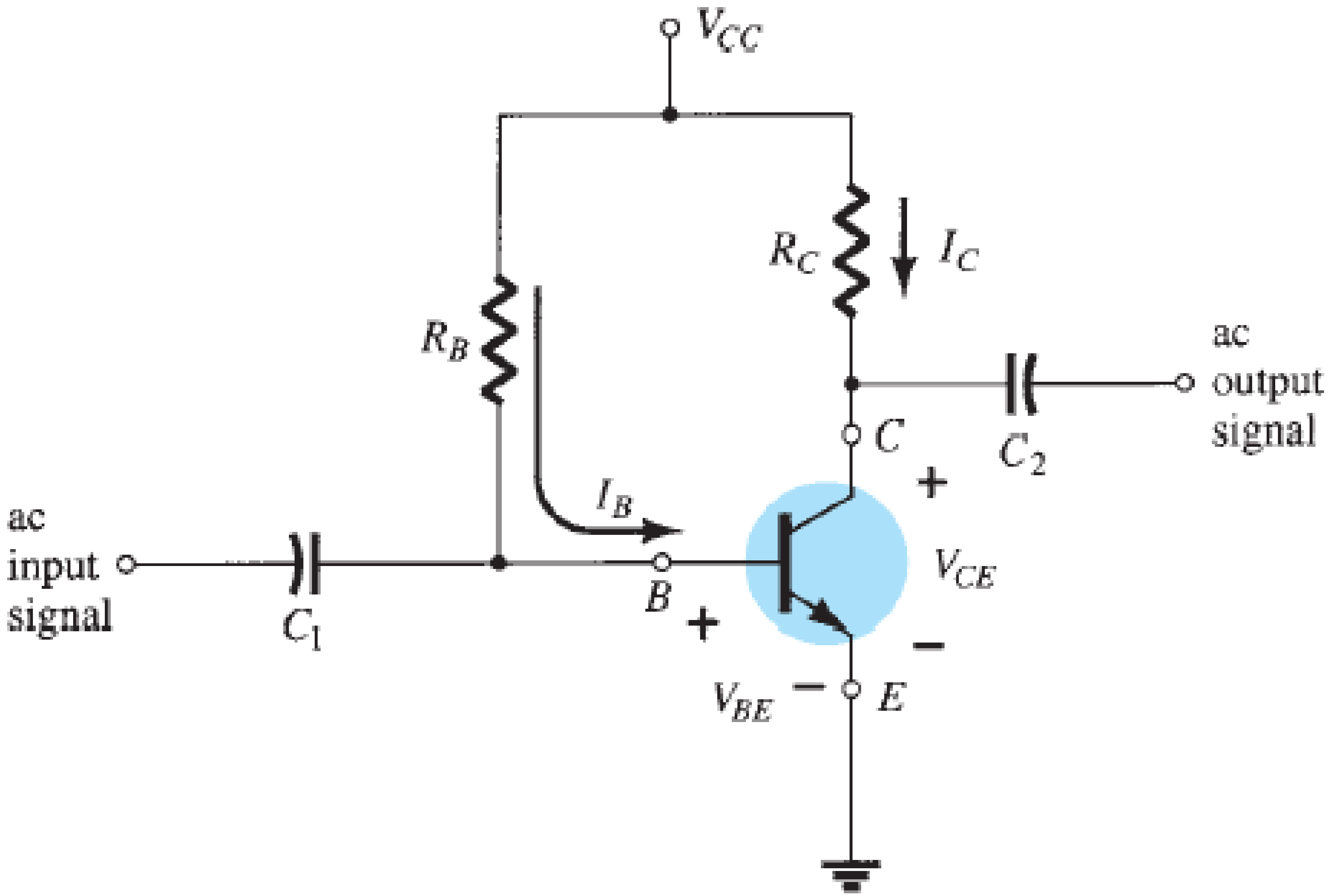
S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

Transistor Biasing



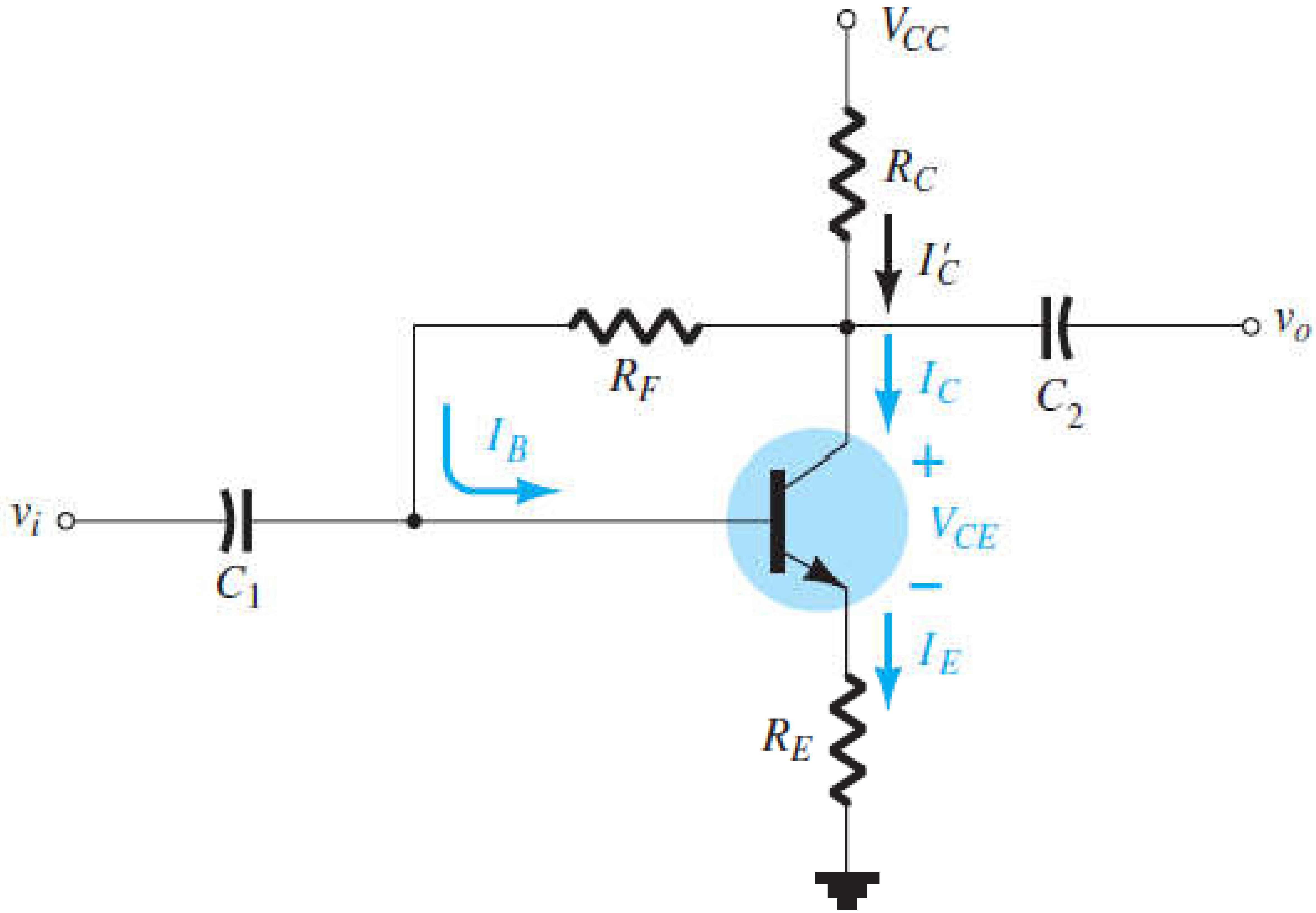


Fixed Bias

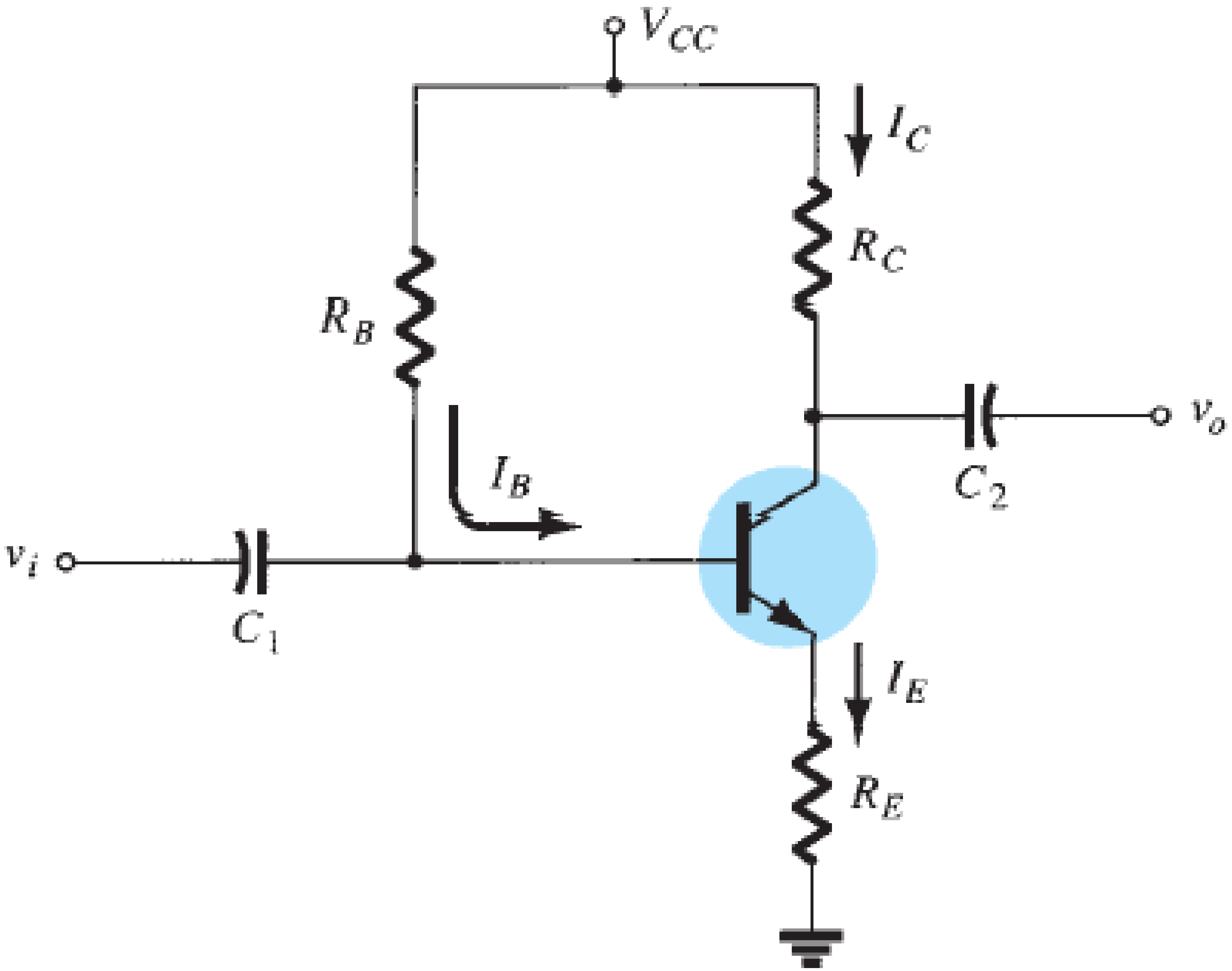


V_{CC}
R_B
R_C
I_C
I_B
ac
input
signal
C_1
ac
output
signal
C_2
C
B
E
V_{CE}
V_{BE}
+
−
+
−

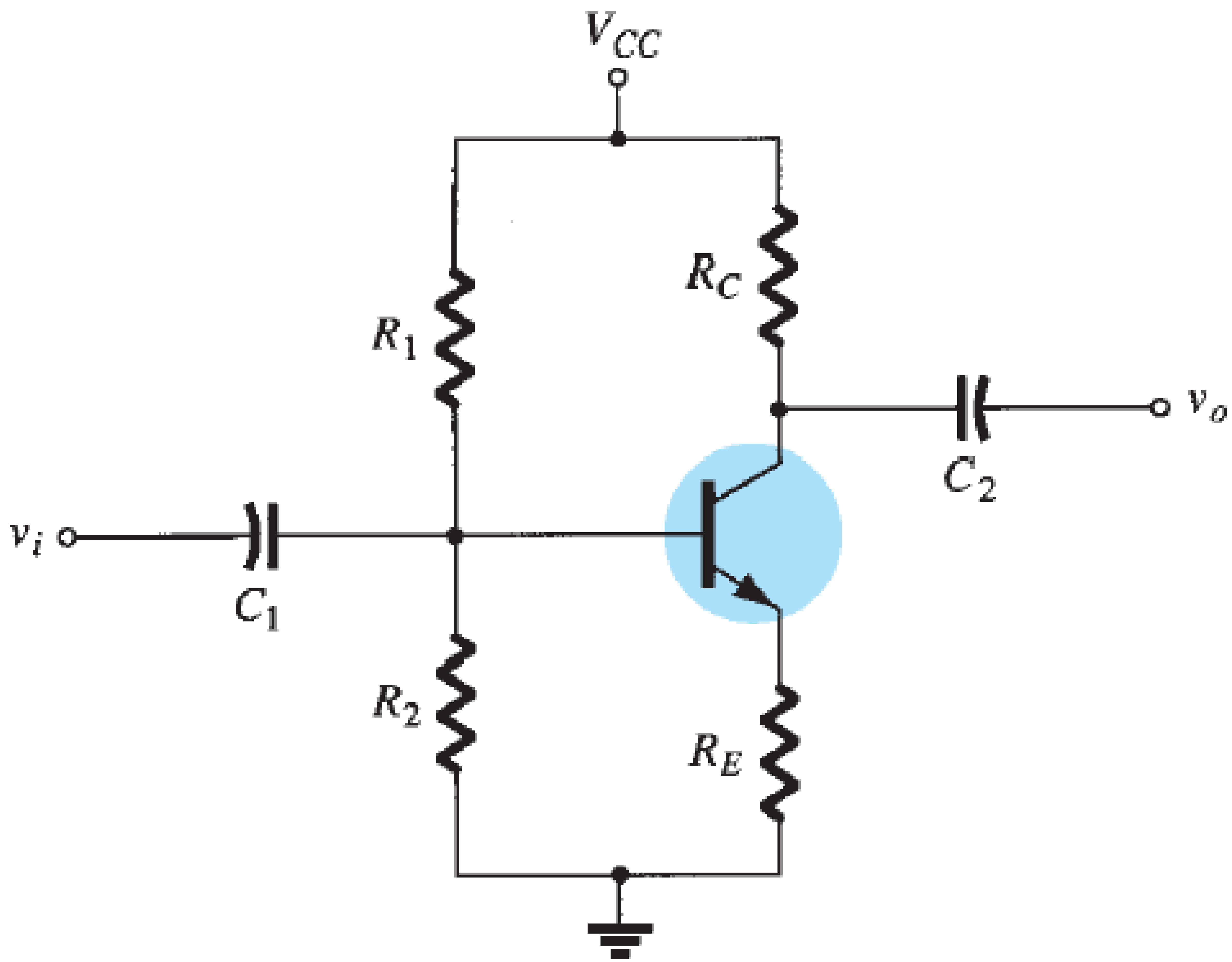
Collector Feedback Configuration



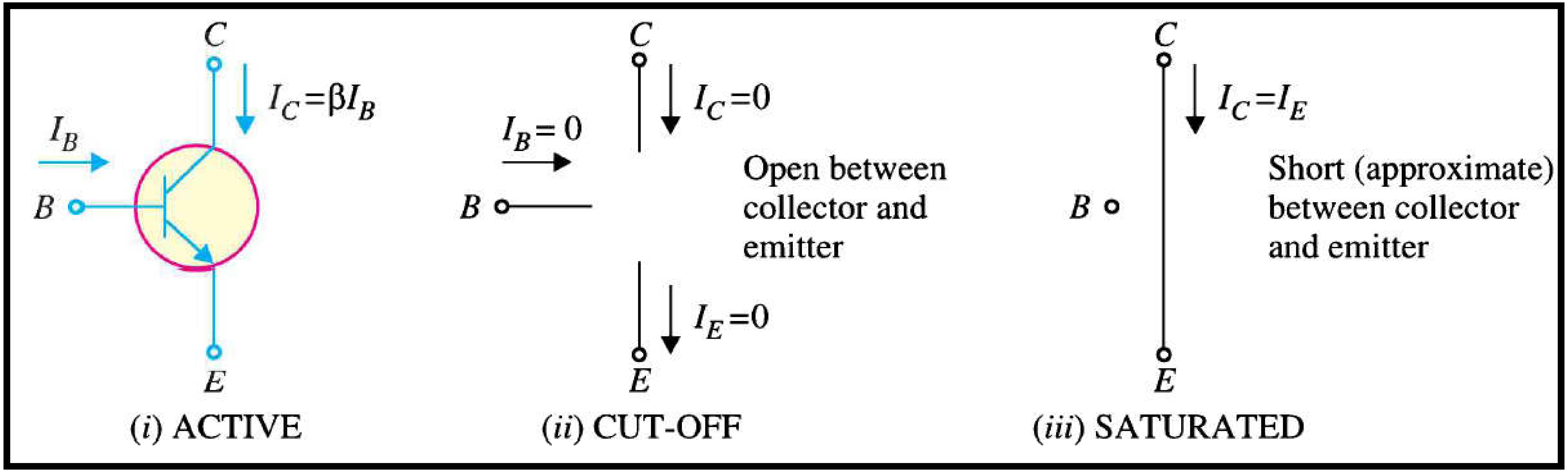
Emitter Bias



Voltage Divider Bias



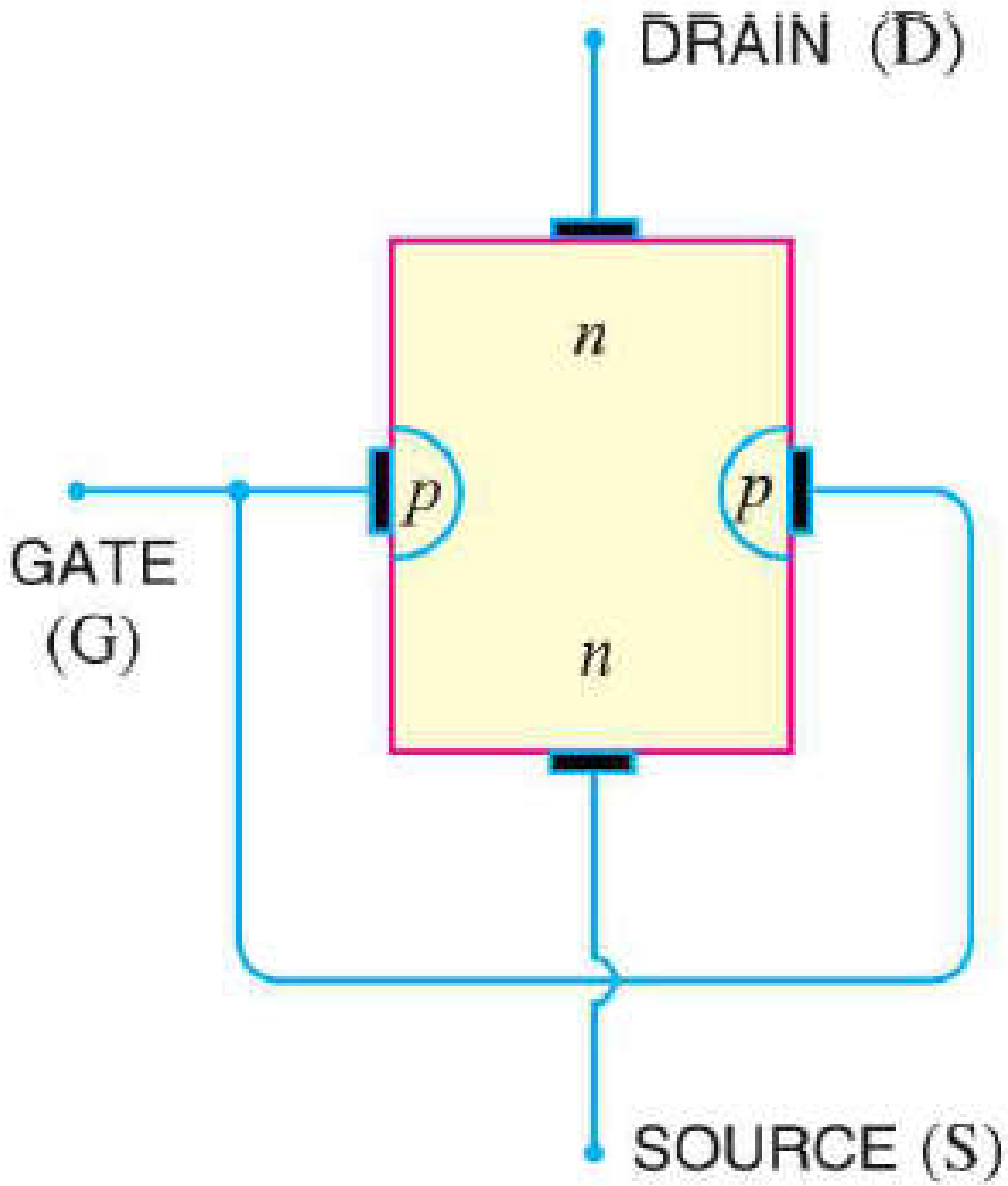
Transistor in Applications



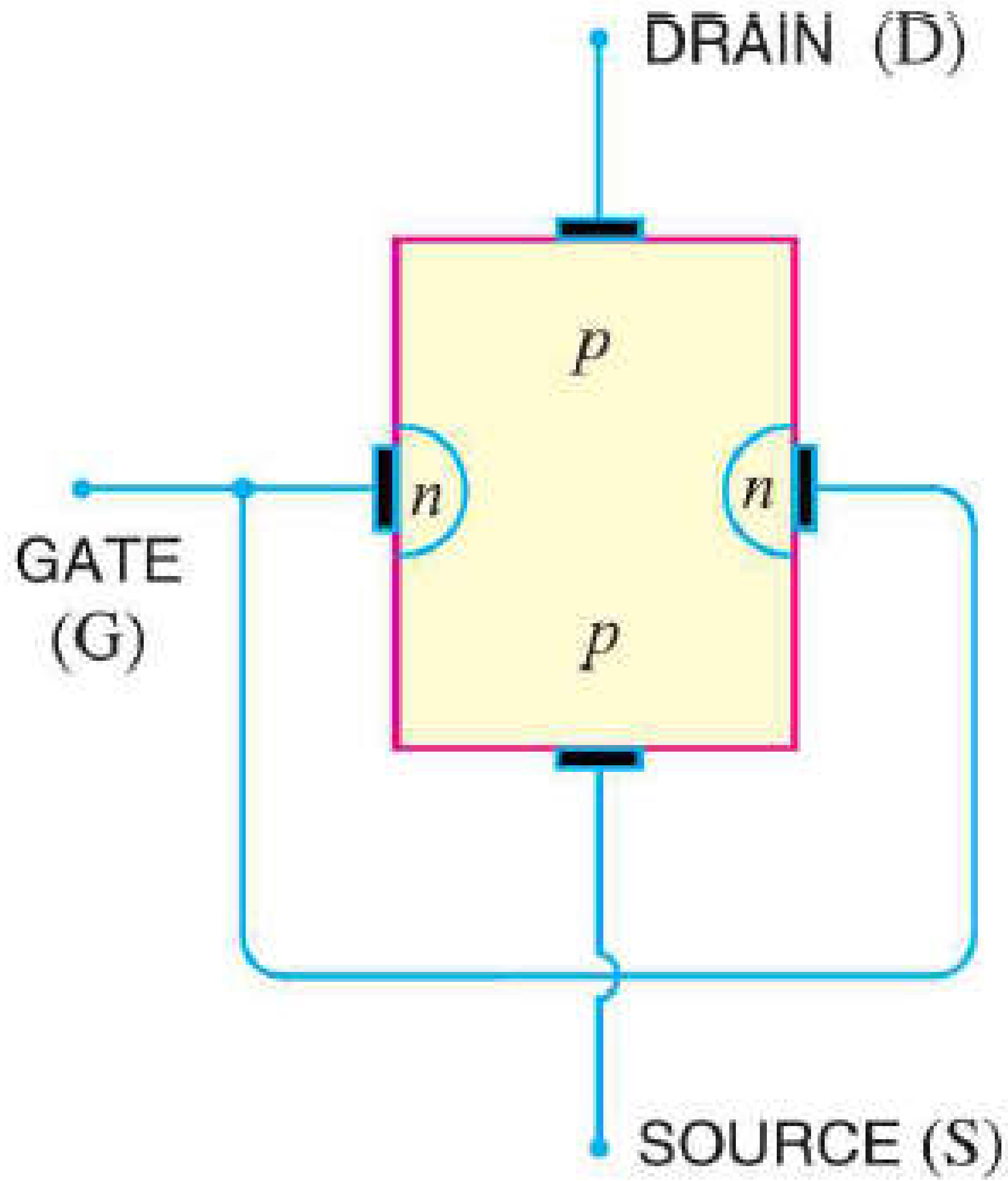
Introduction to FET

Field Effect Transistor

- ❑ It consists of a p-type or n-type silicon bar comprising of two pn-junctions
- ❑ Bar forms the conducting channel for the charge carriers
- ❑ If the bar is n-type: N-Channel JFET, if it is p-type: P-Channel JFET

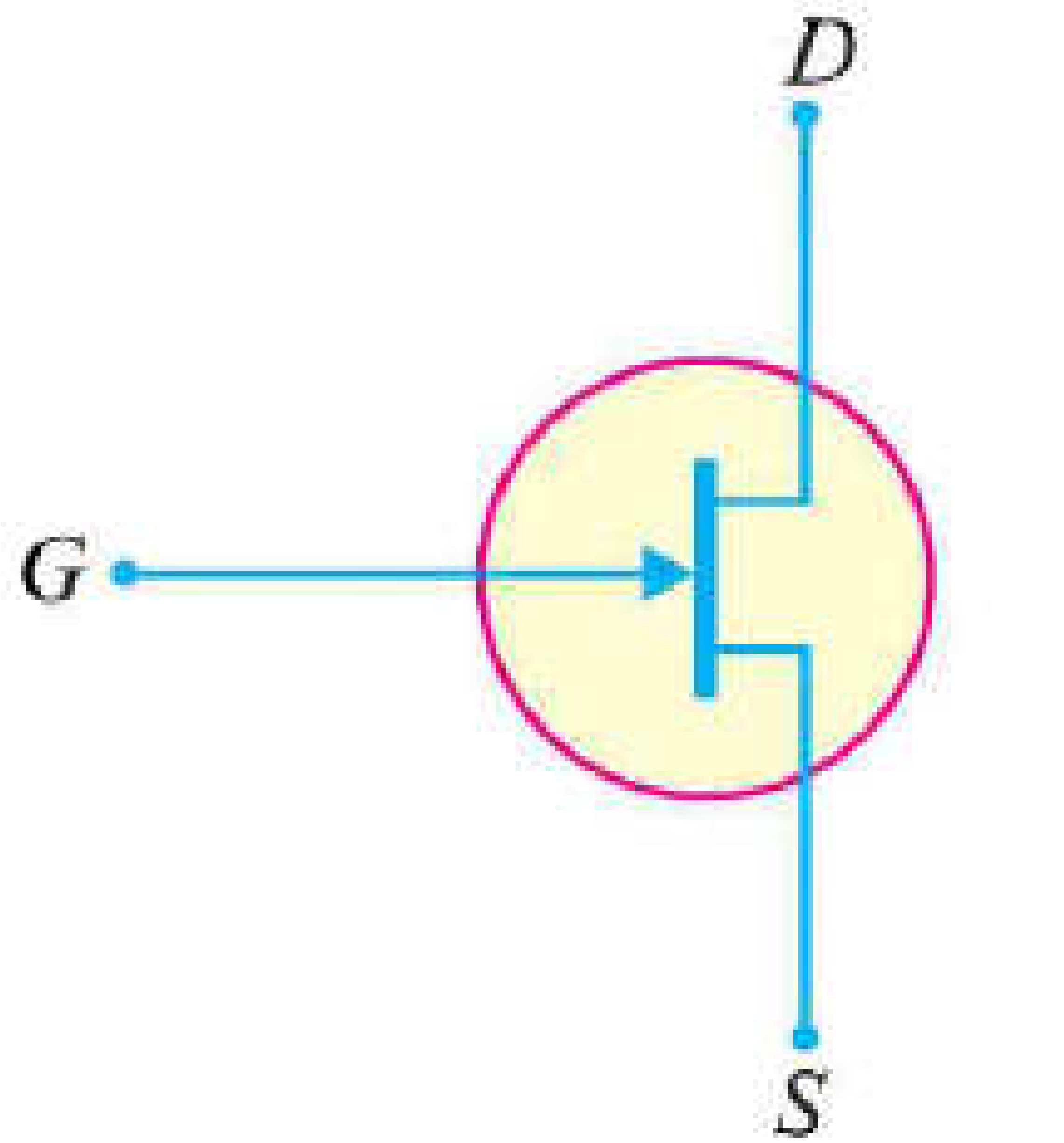


n-Channel JFET

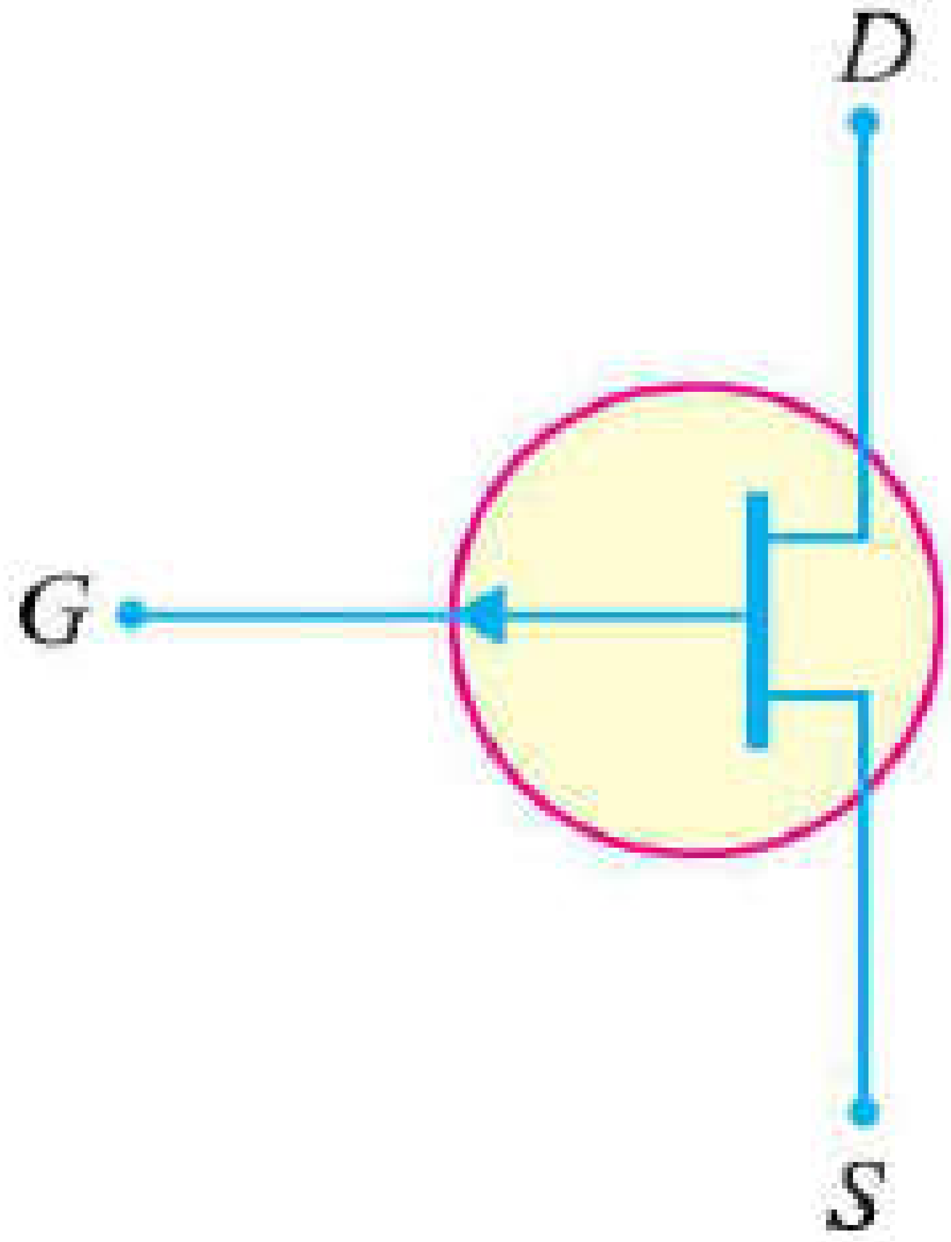


p-Channel JFET

FET Symbols

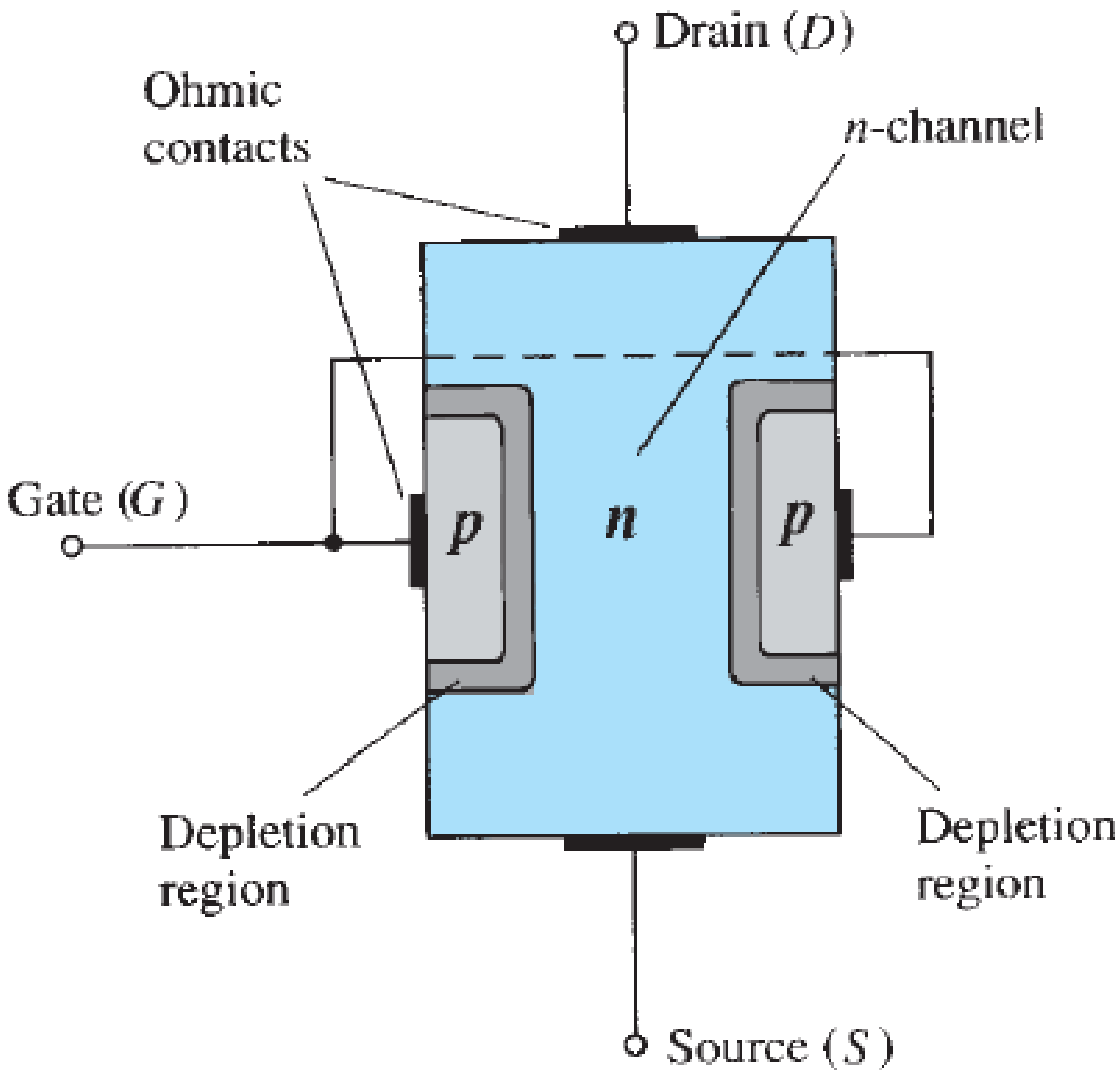


n-Channel *JFET*

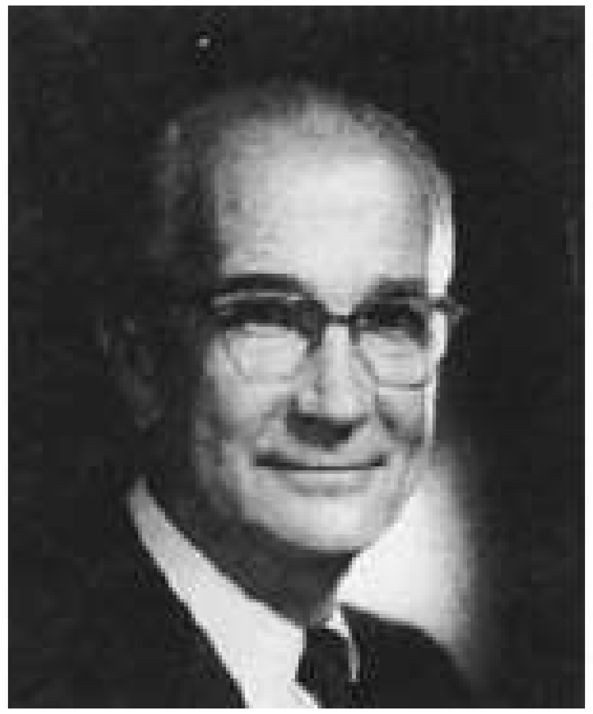


p-Channel *JFET*

FET Terminals, Region and Channel



FET's & BJT's Current Equation Comparison



William Bradford Shockley (1910–1989), co-inventor of the first transistor and formulator of the "field-effect" theory employed in the development of the transistor and the FET.

Shockley Born: London, England; PhD, Harvard, 1936; Head, Transistor Physics Department, Bell Laboratories; President, Shockley Transistor Corp.; Poniatoff Professor

For the BJT transistor the output current I_C and the input controlling current I_B are related by beta, which was considered constant for the analysis to be performed. In equation form,

control variable

$$\boxed{I_C = f(I_B) = \beta I_B}$$

constant

a linear relationship exists between I_C and I_B. Double the level of I_B and I_C will increase by a factor of two also.

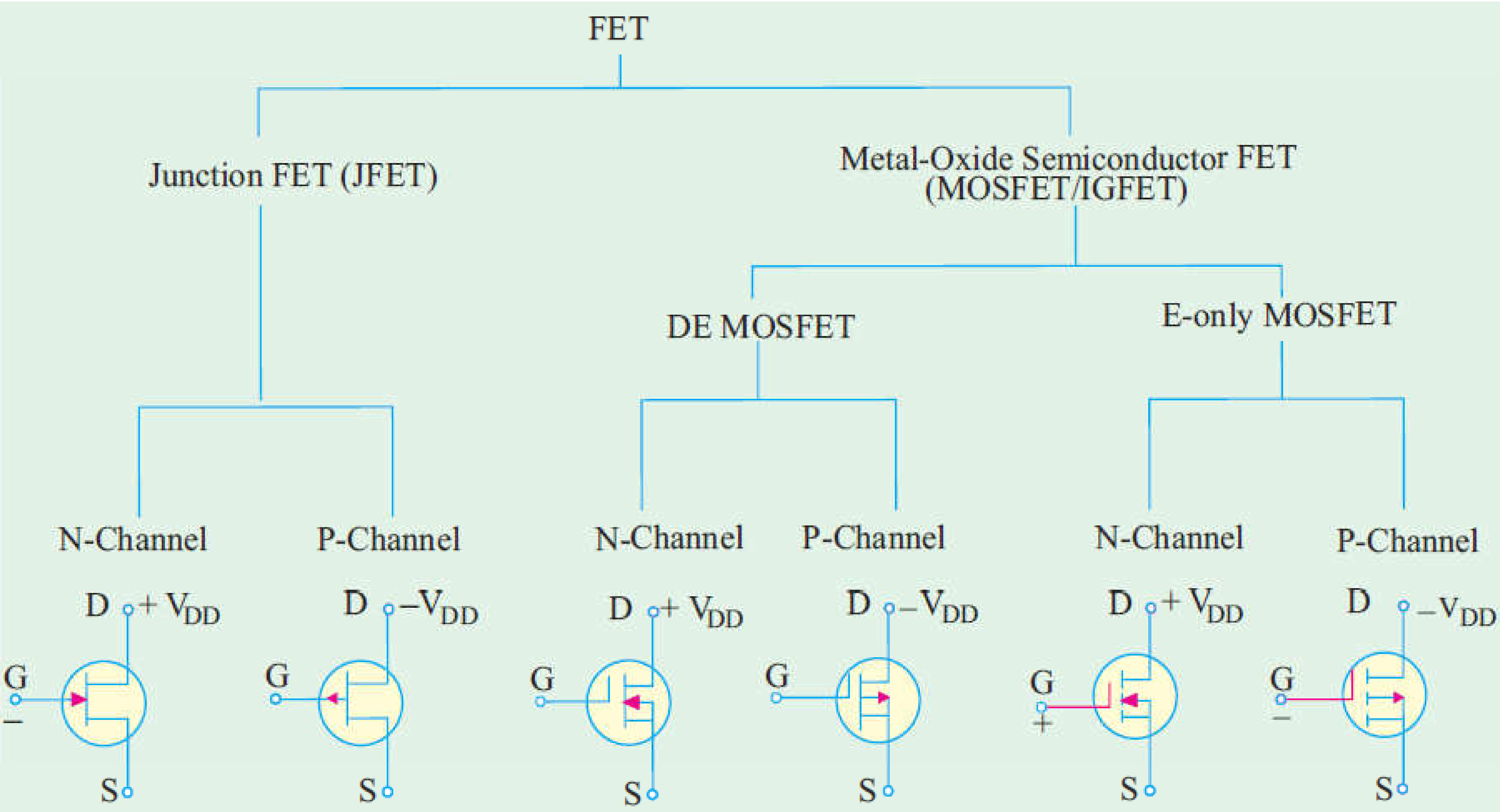
Unfortunately, this linear relationship does not exist between the output and input quantities of a JFET. The relationship between I_D and V_{GS} is defined by *Shockley's equation*

control variable

$$\boxed{I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2}$$

constants

FET Types

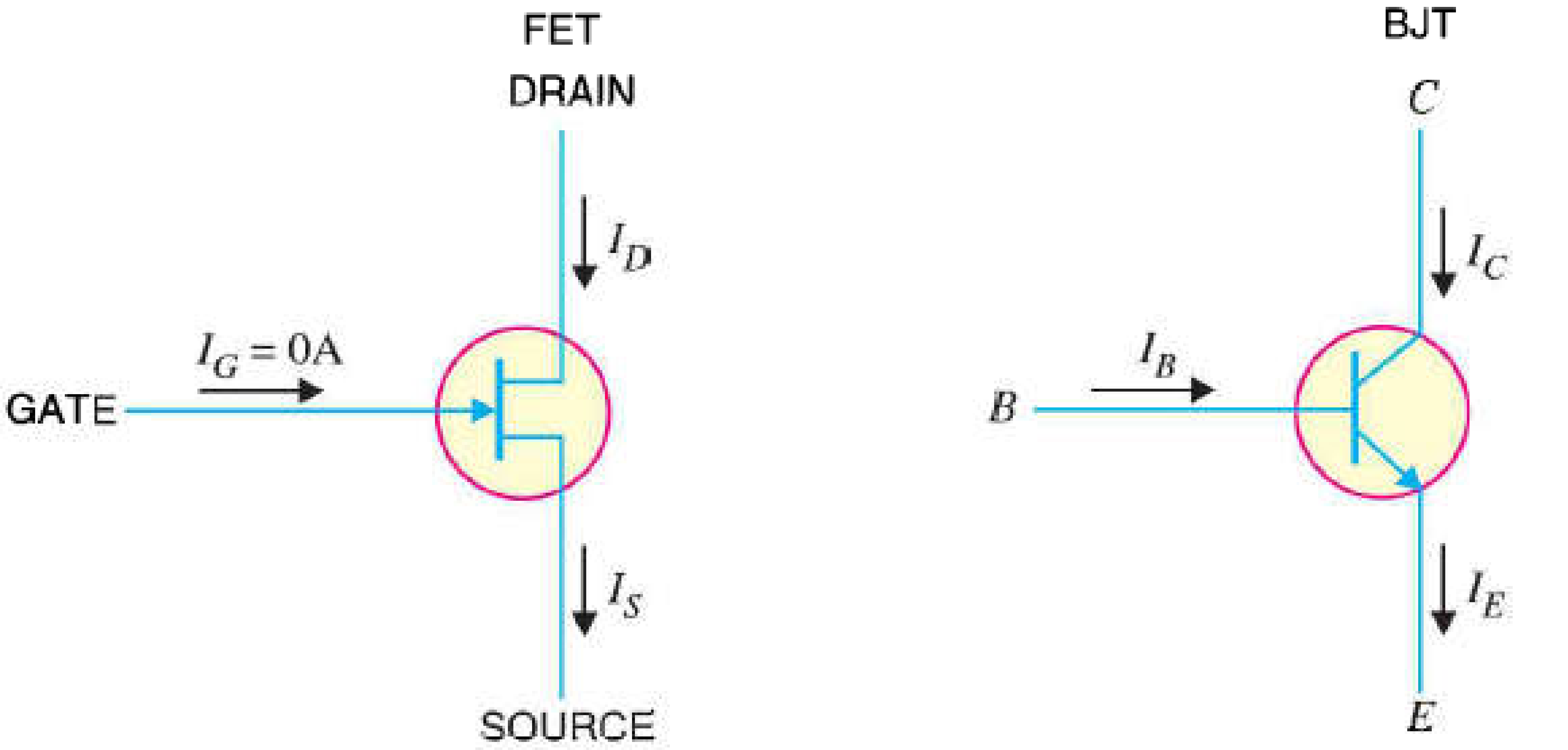

FET
Junction FET (JFET)
Metal-Oxide Semiconductor FET
(MOSFET/IGFET)
DE MOSFET
E-only MOSFET
N-Channel
P-Channel
N-Channel
P-Channel
N-Channel
P-Channel
D + V_DD
D –V_DD
D + V_DD
D – V_DD
D + V_DD
D – V_DD
G
S

Important Features of FET

- It's a three terminal voltage controlled device.
- It has very high input impedance
- Gate current is always zero
- Since there is no gate current, Id = Is
- Drain and Source terminals can be interchanged

FET & BJT Comparison

- FET is an unipolar device, while BJT is a bipolar device
- It has very high input impedance
- FET is voltage controlled device, BJT is current controlled device
- For amplification, BJT is operated in active region, while FET should be operated in saturation region



End of Unit -1