Chapter 1:
Semiconductor Diodes

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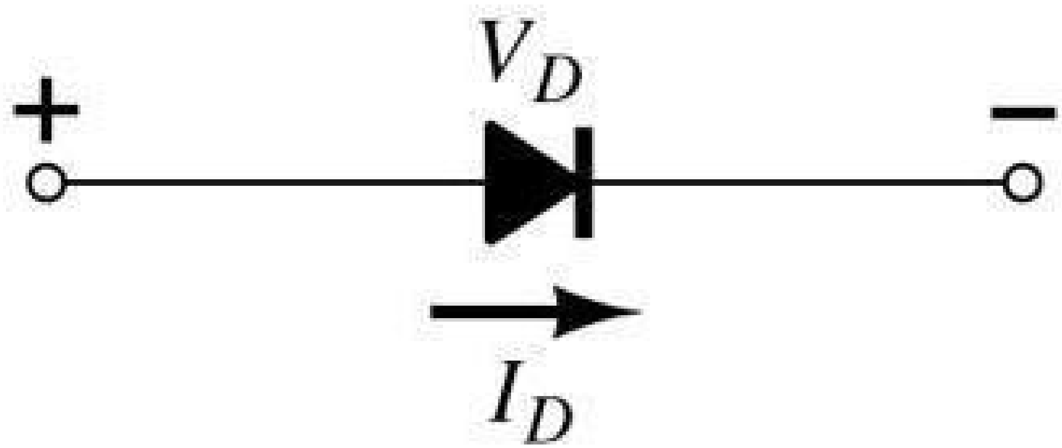
Diodes

Simplest Semiconductor Device



(a)

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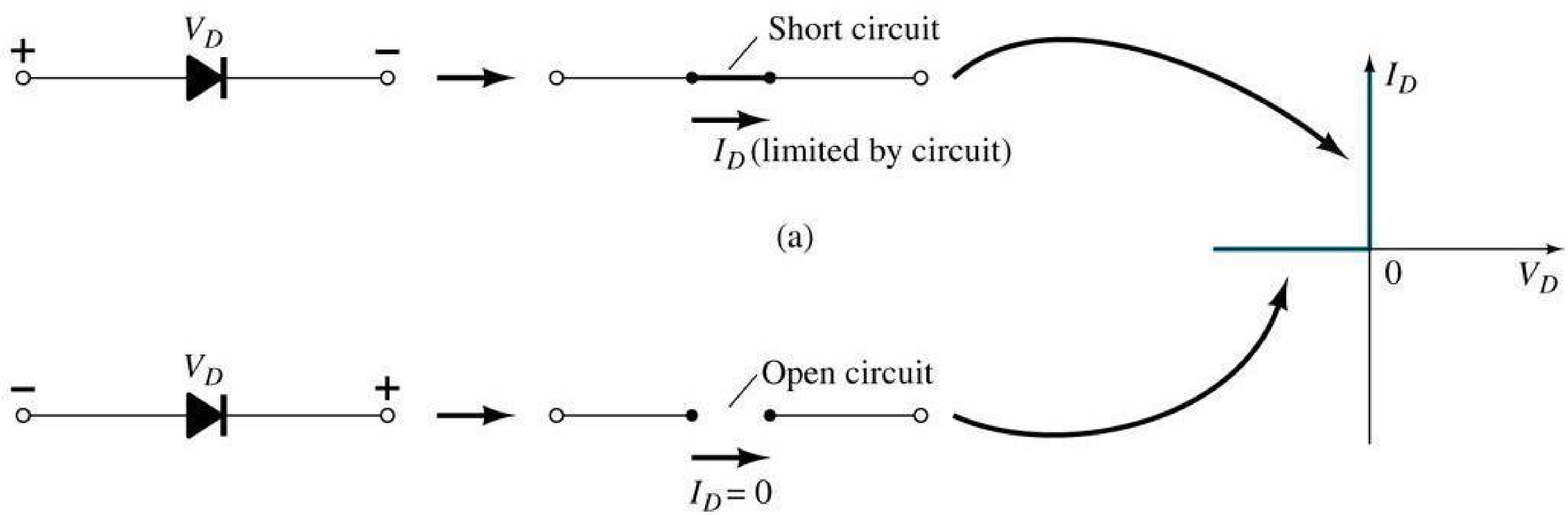
Basic operation

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



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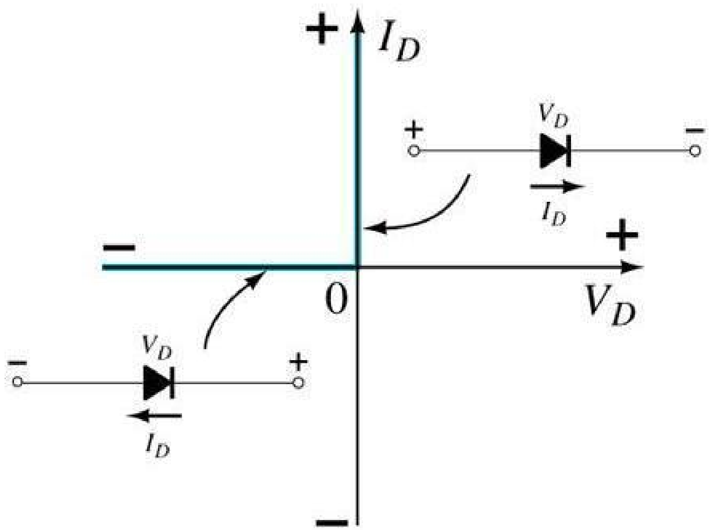
Characteristics of an ideal diode: Conduction Region



(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.

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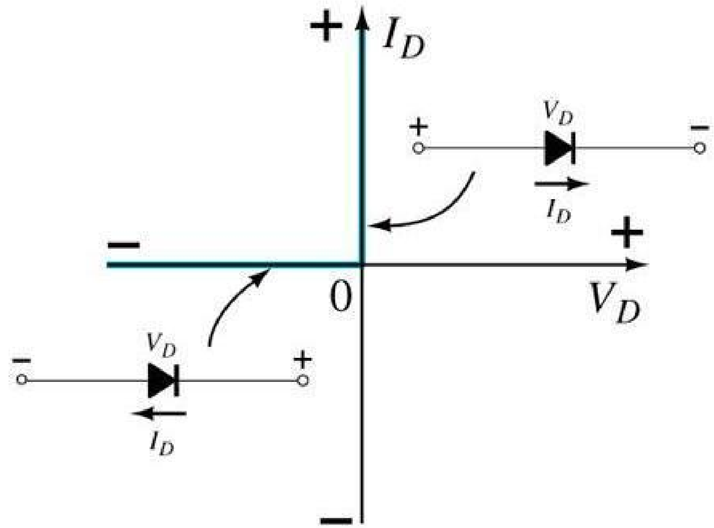
Characteristics of an ideal diode: Non-Conduction Region



(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.

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Semiconductor Materials

Common materials used in the development of semiconductor devices:

- Silicon (Si)
- Germanium (Ge)

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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
- p-type

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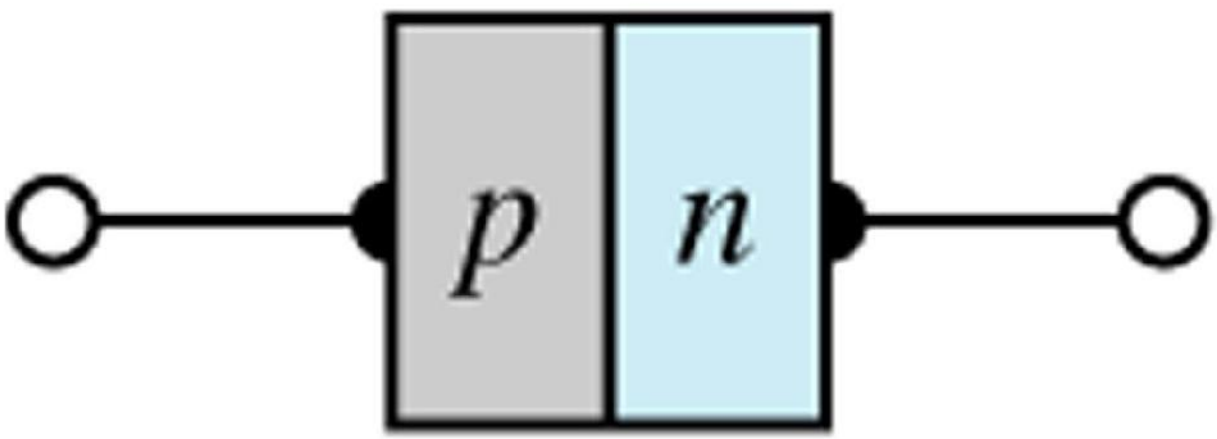
n-type versus p-type

n-type materials make the Silicon (or Germanium) atoms more negative.**p-type** materials make the Silicon (or Germanium) atoms more positive.

Join n-type and p-type doped Silicon (or Germanium) to form a **p-n junction.**



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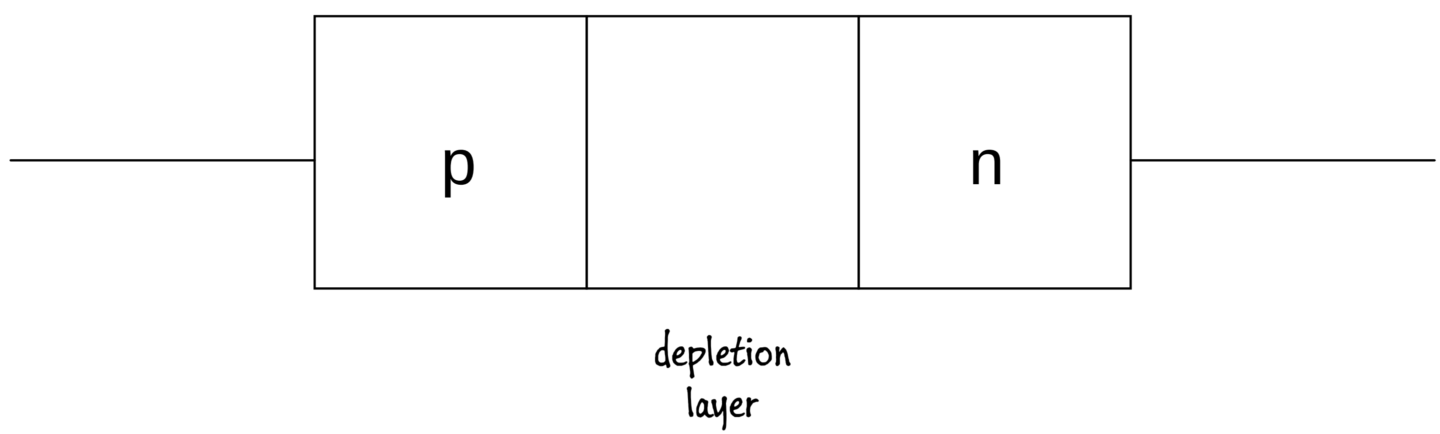
p-n junction

When the materials are joined, the negatively charged atoms of the n-type doped side are attracted to the positively charged atoms of the p-type doped side.

The electrons in the n-type material migrate across the junction to the p-type material (electron flow). Or you could say the 'holes' in the p-type material migrate across the junction to the n-type material (conventional current flow).

The result is the formation of a **depletion layer** around the junction.



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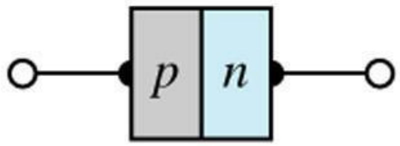
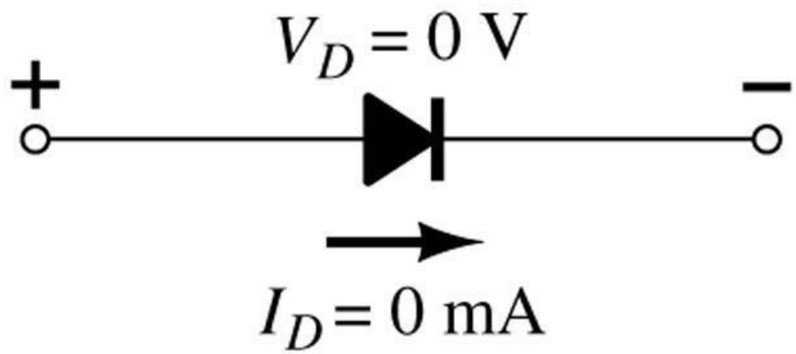
Operating Conditions

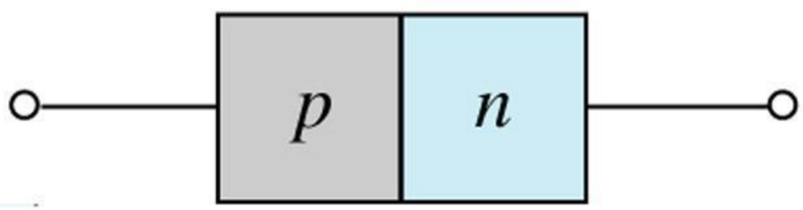
- No Bias
- Forward Bias
- Reverse Bias

No Bias Condition

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







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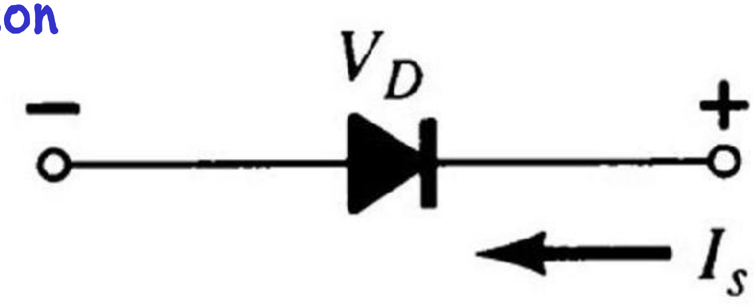
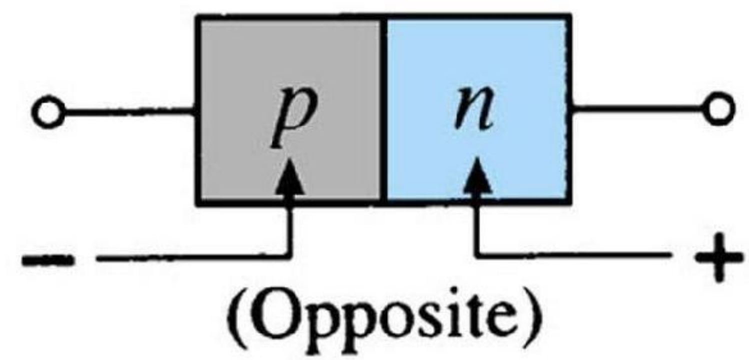
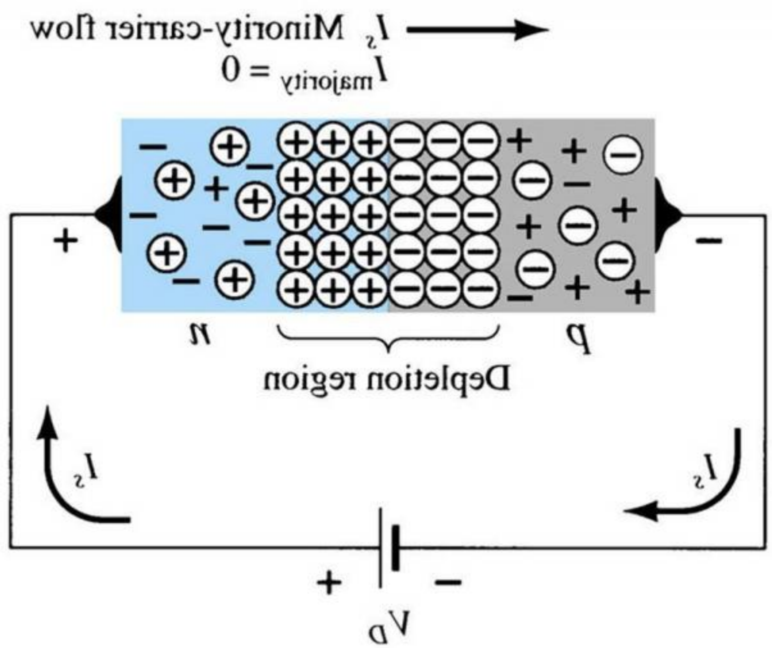
Reverse Bias Condition



External voltage is applied across the p-n junction
in the opposite polarity of the p- and n-type materials.





This causes the depletion layer to widen.
The electrons in the n-type material are attracted towards the positive terminal and the 'holes' in the p-type material are attracted towards the negative terminal.

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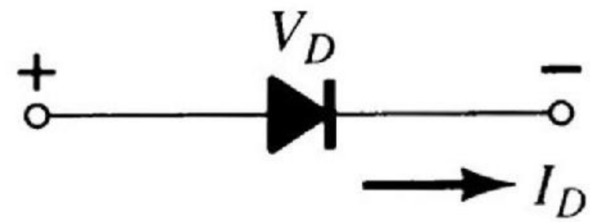
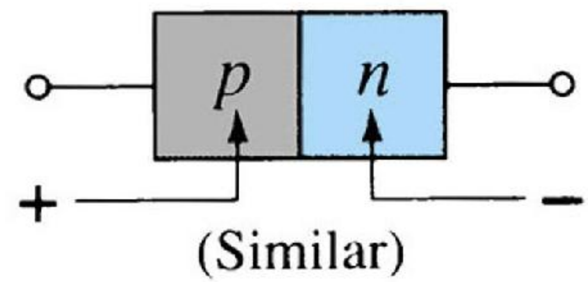
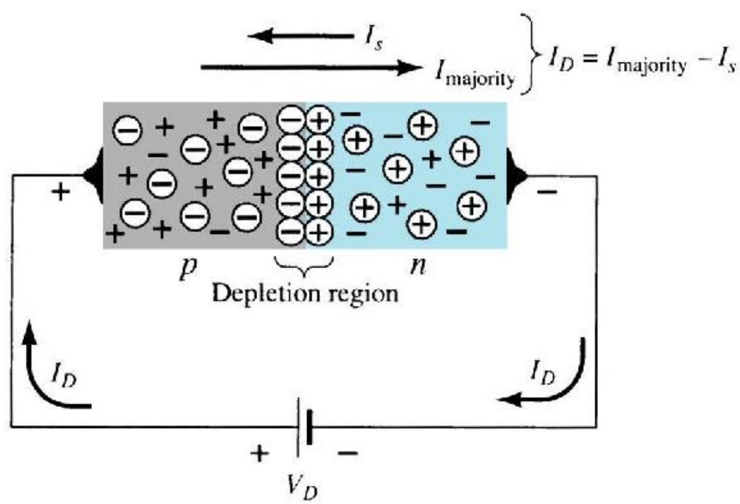
Forward Bias Condition

External voltage is applied across the p-n junction in the same polarity of the p- and n-type materials.



The depletion layer is narrow. The electrons from the n-type material and 'holes' from the p-type material have sufficient energy to cross the junction.





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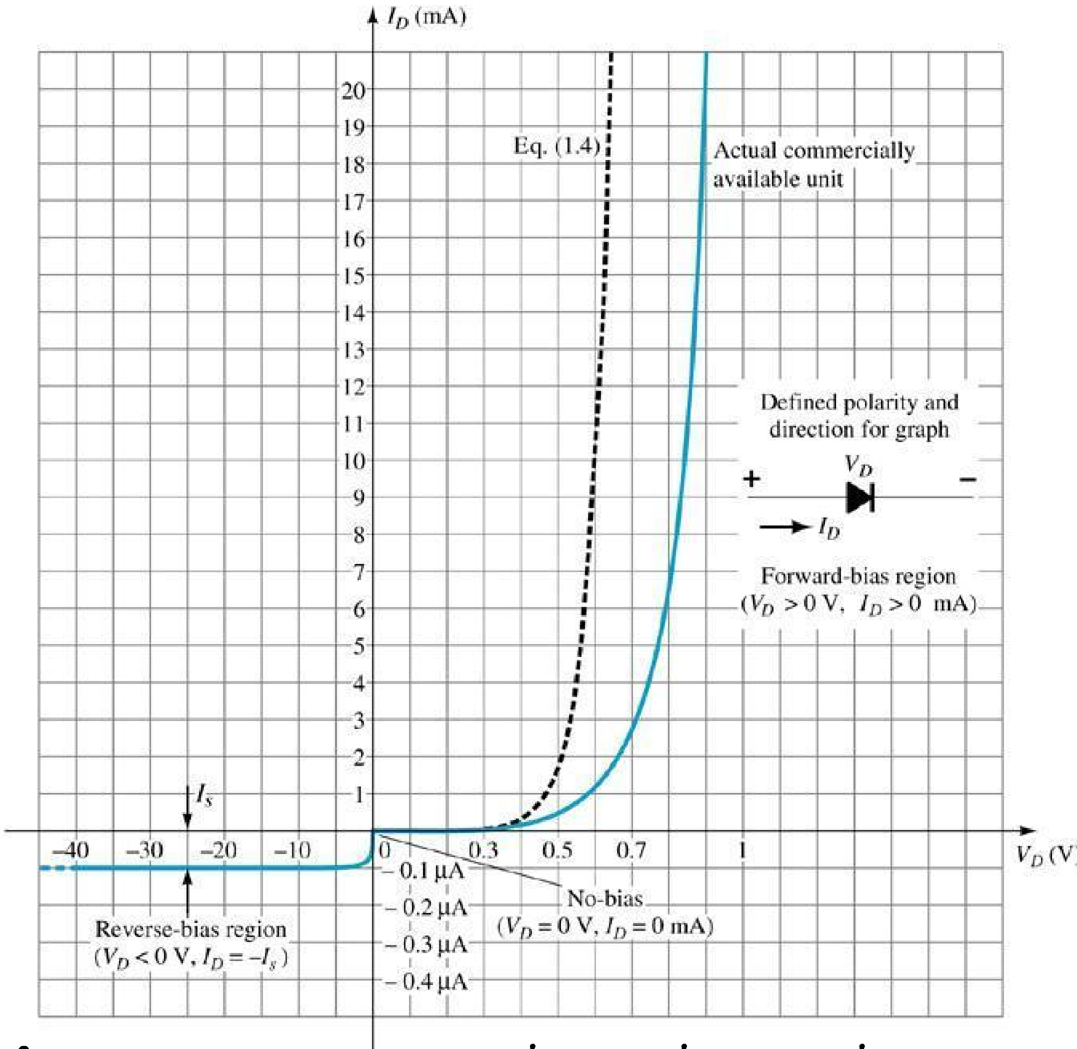
Actual Diode Characteristics



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

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Majority and Minority Carriers in Diode

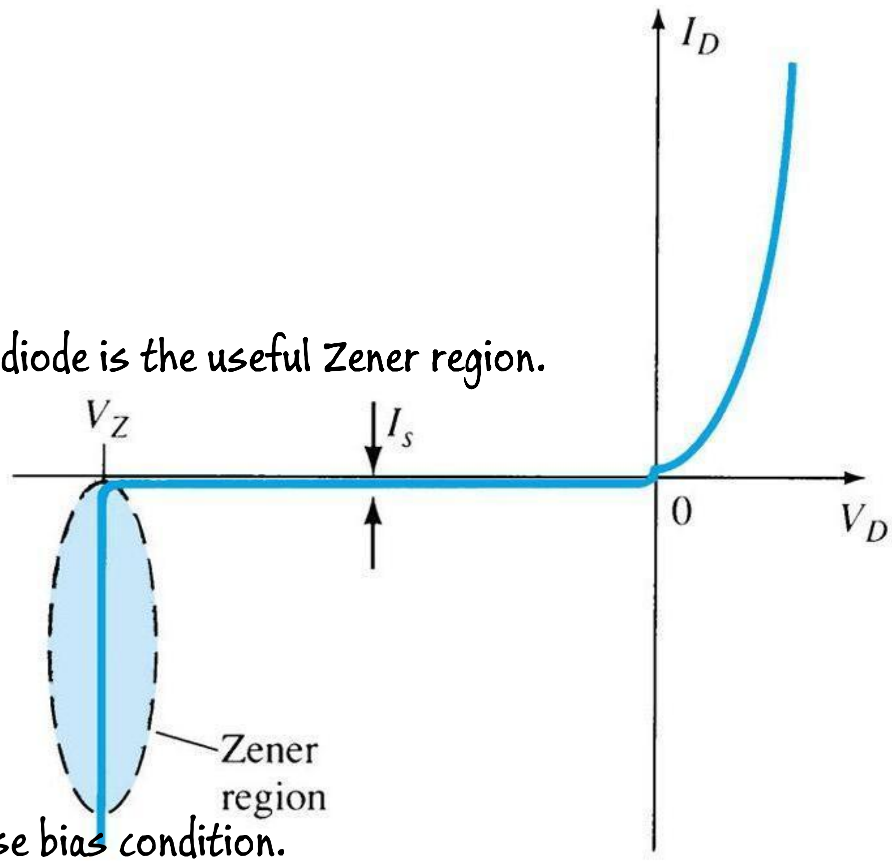
A diode, as any semiconductor device is not perfect!
There are two sets of currents:

- ***Majority Carriers***The electrons in the n-type and 'holes' in the p-type material are the source of the majority of the current flow in a diode.

- ***Minority Carriers***Electrons in the p-type and 'holes' in the n-type material are rebel currents. They produce a small amount of opposing current.

Zener Region

Another detail about the diode is the useful Zener region.



The diode is in the reverse bias condition.
At some point the reverse bias voltage is so large the diode breaks down.
The reverse current increases dramatically.
This maximum voltage is called ***avalanche breakdown voltage*** and the current is called ***avalanche current.***

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Forward Bias Voltage

The point at which the diode changes from No Bias condition to Forward Bias condition happens when the electron and 'holes' are given sufficient energy to cross the p-n junction. This energy comes from the external voltage applied across the diode.

The Forward bias voltage required for a

- Silicon diode V_T approximately equal to 0.7V
- Germanium diode V_T approximately equal to 0.3V

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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.
It increases maximum Reverse Bias Avalanche Voltage.

Germanium diodes are more sensitive to temperature variations than Silicon Diodes.

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Resistance Levels

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

- DC or Static Resistance
- AC or Dynamic Resistance
- Average AC Resistance

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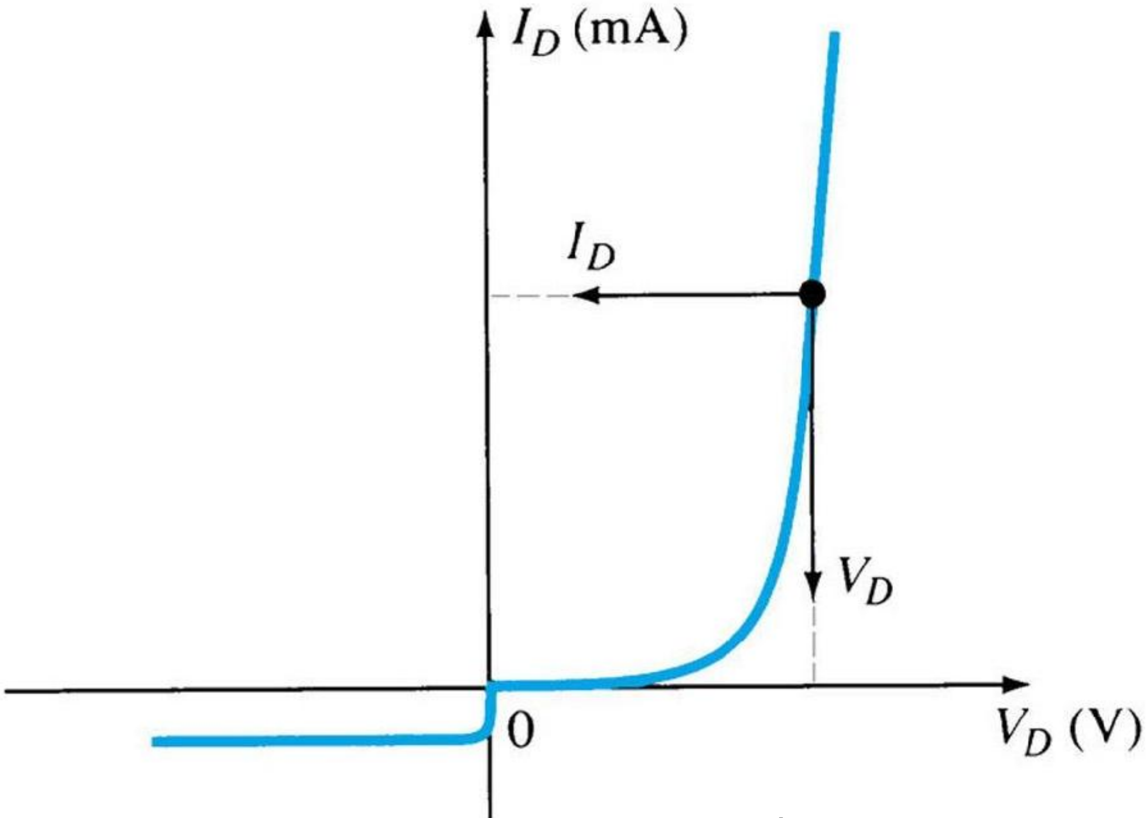
DC or Static Resistance



$R_D = V_D/I_D$

For a specific applied DC voltage V_D, the diode will have a specific current I_D, and a specific resistance R_D. The amount of resistance R_D, depends on the applied DC voltage.

AC or Dynamic Resistance

Forward Bias region:

- The resistance depends on the amount of current (I_D) in the diode.
- The voltage across the diode is fairly constant (26mV for 25 deg C).

Reverse Bias region:

The resistance is essentially infinite. The diode acts like an open.

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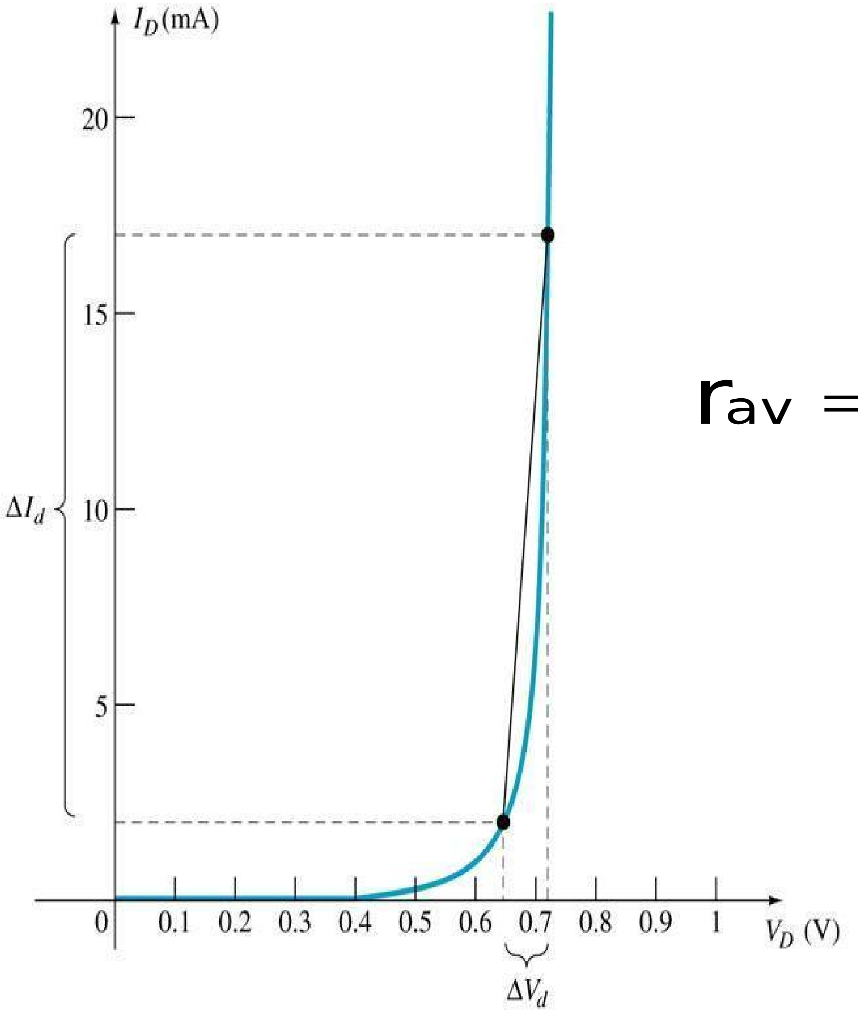
Average AC Resistance



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

AC resistance can be determined by picking 2 points on the characteristic curve developed for a particular circuit.

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Diode Specification Sheets

Data about a diode is presented uniformly for many different diodes. This makes cross-matching of diodes for replacement or design easier.

1. V_F, forward voltage at a specific current and temperature
2. I_F, maximum forward current at a specific temperature
3. I_R, maximum reverse current at a specific temperature
4. PIV or PRV or $V_{(BR)}$, maximum reverse voltage at a specific temperature
5. Power Dissipation, maximum power dissipated at a specific temperature6.
6. C, Capacitance levels in reverse bias
7. trr, reverse recovery time
8. Temperatures, operating and storage temperature ranges

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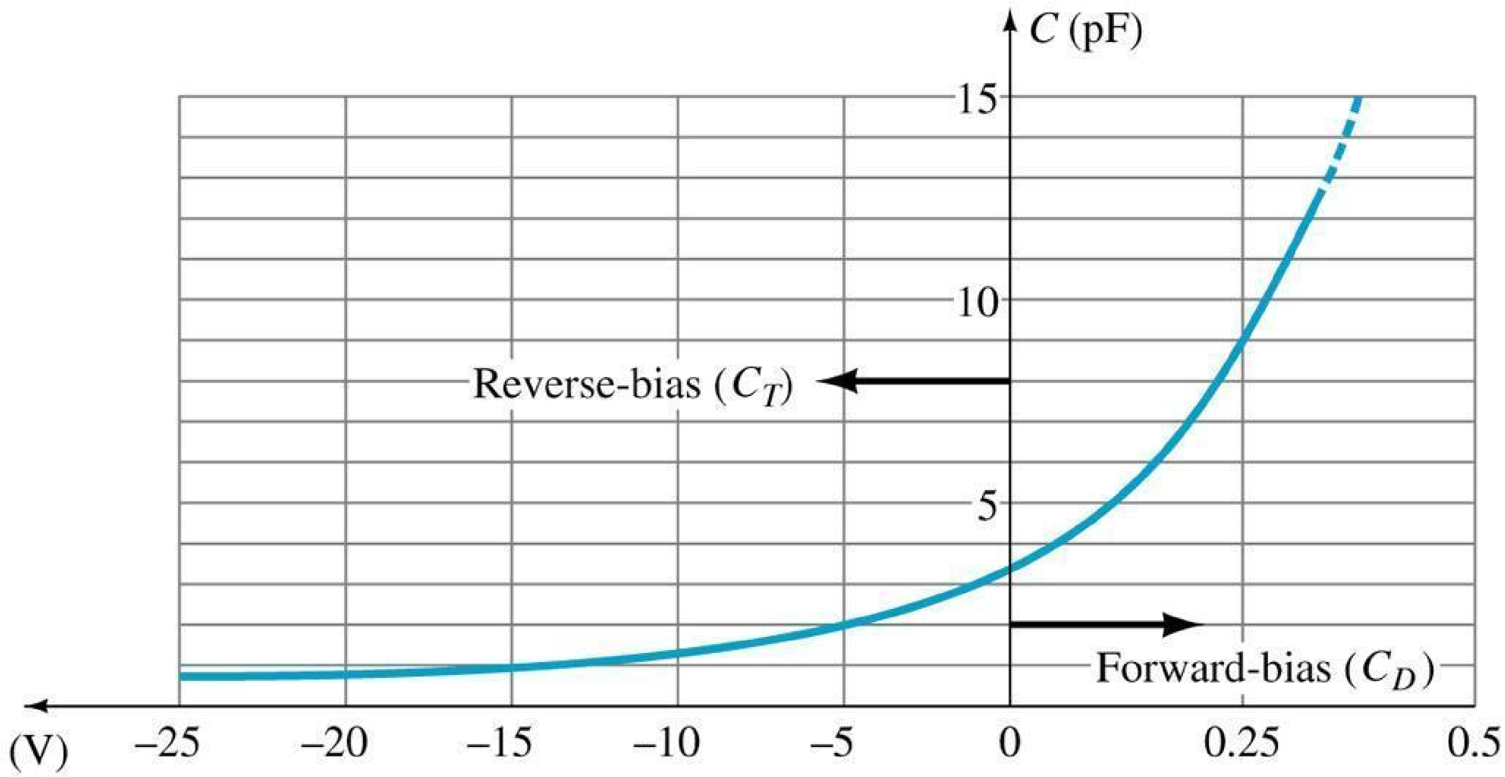
Capacitance



In Reverse Bias the depletion layer is very large. The diode's strong positive and negative polarities create capacitance, C_T. The amount of capacitance depends on the reverse voltage applied.

In Forward Bias storage capacitance or diffusion capacitance (C_D) exists as the diode voltage increases.

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Reverse Recovery Time (trr)

This is the amount of time it takes for the diode to stop conducting once the diode is switched from Forward Bias to Reverse Bias.

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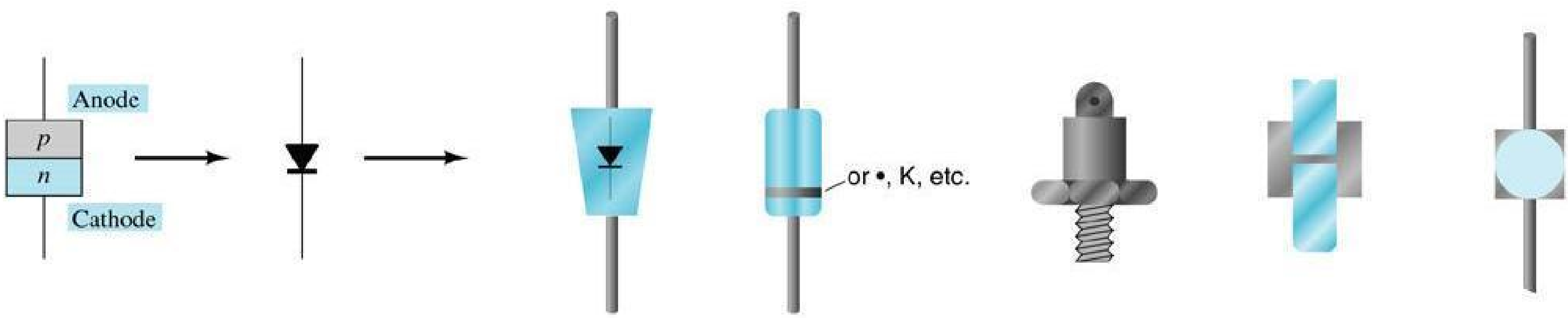
Diode Symbol and Notation



Cathode is abbreviated – K

(because the Cathode end of the diode symbol looks like a backwards K)

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Diode Testing

A. Diode Checker

B. Ohmmeter

C. Curve Tracer

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A. Diode Checker

Many DMM's have a diode checking function.
A normal diode will exhibit its Forward Bias voltage (V_F).
The diode should be tested out of circuit.

Silicon diode approximately equal to 0.7V
Germanium diode approximately equal to 0.3V

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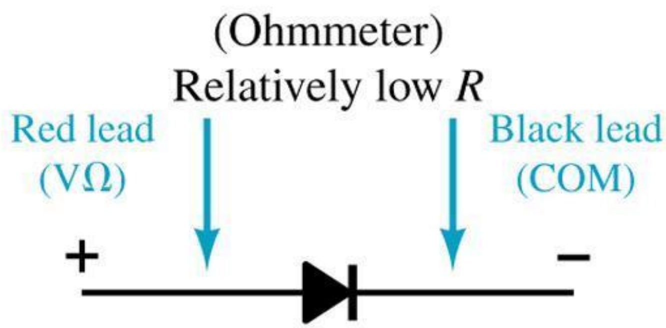
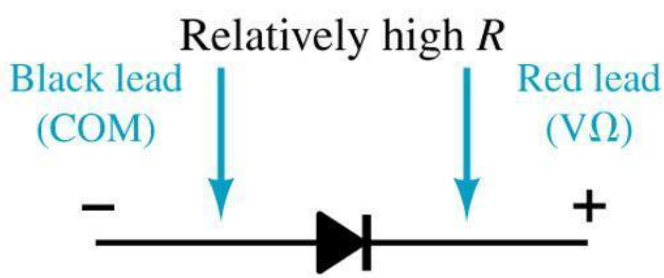
B. Ohmmeter

An ohmmeter set on a low ohms scale can be used to test a diode.
A normal diode will have the following readings.
The diode should be tested out of circuit.



(a)



(b)

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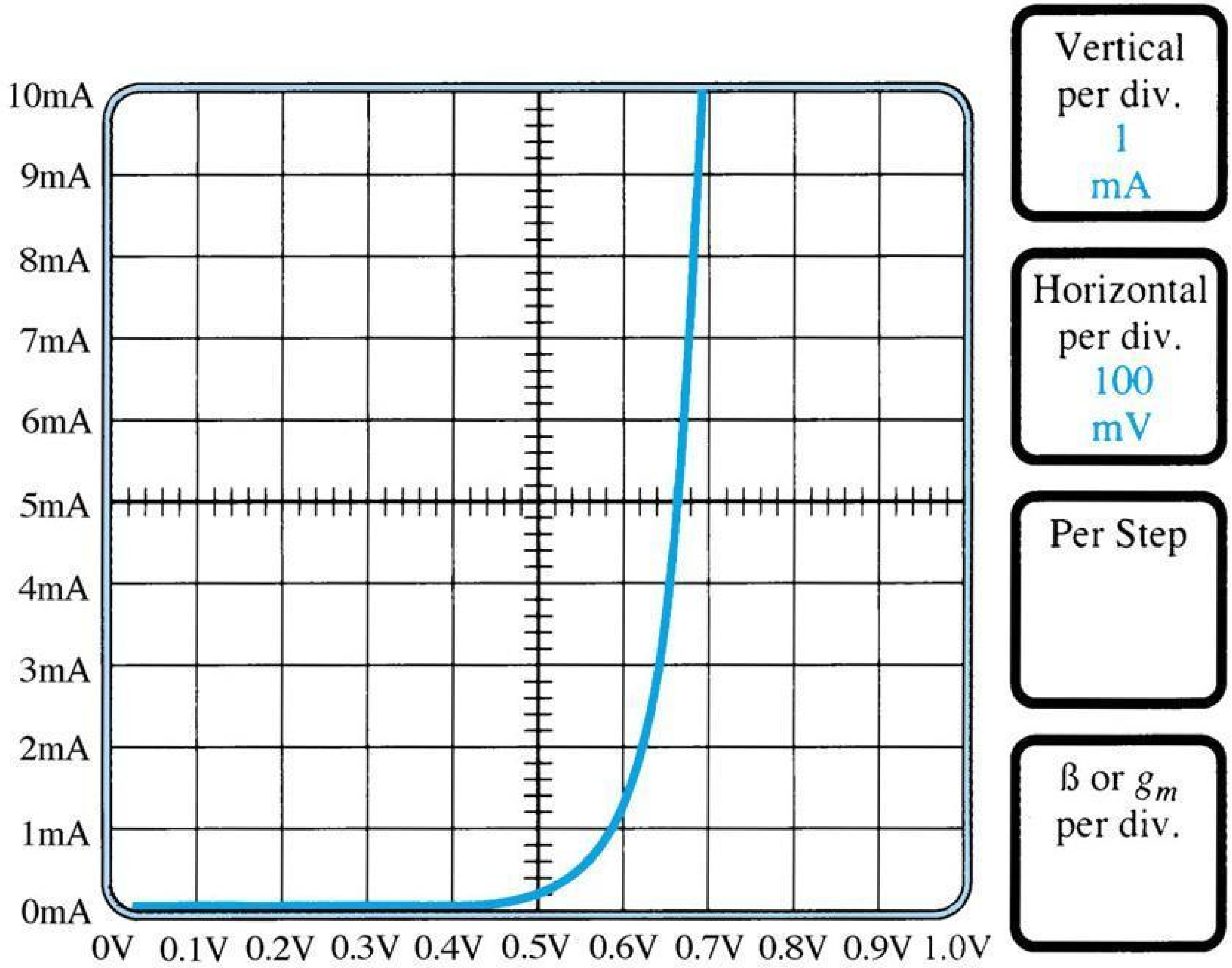
C. Curve Tracer

A curve tracer is a specialized type of test equipment. It will display the characteristic curve of the diode in the test circuit. This curve can be compared to the specifications of the diode from a data sheet.



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Other Types of Diodes

1. Zener Diode
2. Light Emitting Diode
3. Diode Arrays

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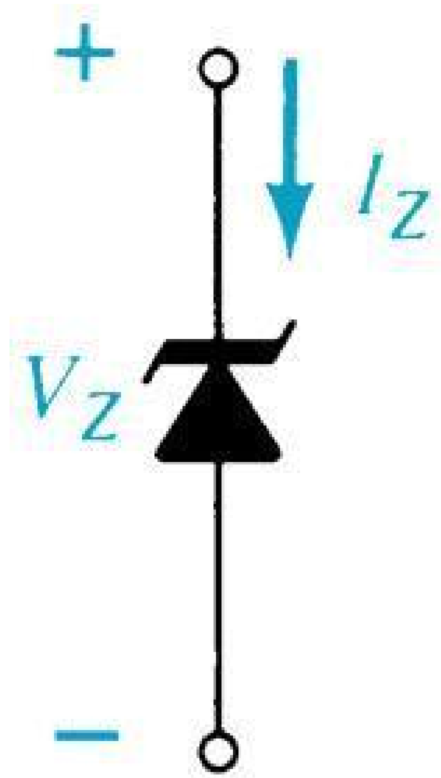
1. Zener Diode

A Zener is a diode operated in reverse bias at the Peak Inverse Voltage (PIV) called the Zener Voltage (V_Z).

Symbol



(a)

Common Zener Voltages: 1.8V to 200V

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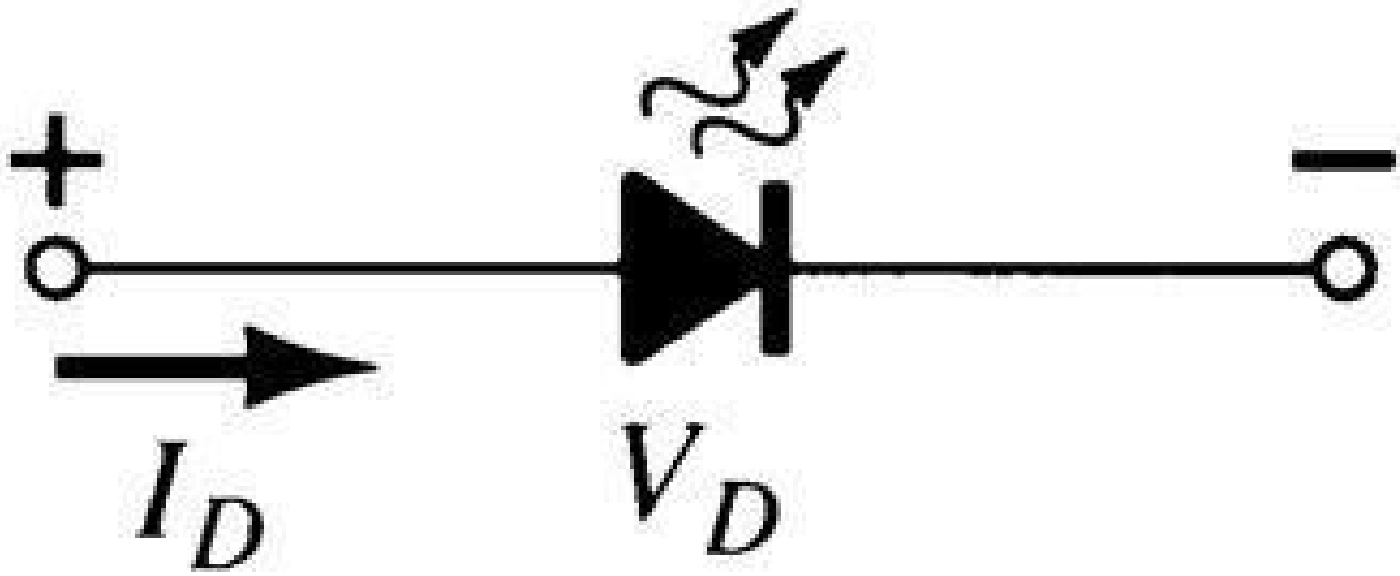
2. Light Emitting Diode (LED)

This diode when for

Symbol



The forward bias voltage is higher, usually around 2-3V.

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3. Diode Arrays

Multiple diodes can be packaged together in an integrated circuit (IC).
A variety of combinations exist.

Example of an array:

PLANAR AIR–ISOLATED MONOLITHIC DIODE ARRAY

- **C . . . 5.0 pF (MAX)**
- **ΔV_F . . . 15 mv (MAX) @ 10 mA**

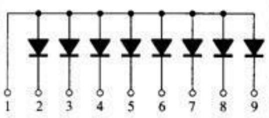
ABSOLUTE MAXIMUM RATINGS (Note 1)

Temperatures	
Storage Temperature Range	–55°C to +200°C
Maximum Junction Operating Temperature	+150°C
Lead Temperature	+260°C
Power Dissipation (Note 2)	
Maximum Dissipation per Junction at 25°C Ambient	400 mW
per Package at 25°C Ambient	600 mW
Linear Derating Factor (from 25°C) Junction	3.2 mW/°C
Package	4.8 mW/°C

Maximum Voltage and Currents

WIV	Working Inverse Voltage	55 V
I_F	Continuous Forward Current	350 mA
$i_{f(surge)}$	Peak Forward Surge Current	
	Pulse Width = 1.0 s	1.0 A
	Pulse Width = 1.0 μs	2.0 A

CONNECTION DIAGRAM



See Package Outline TO-96

ELECTRICAL CHARACTERISTICS (25°C Ambient Temperature unless otherwise noted)

SYMBOL	CHARACTERISTIC	MIN	MAX	UNITS	TEST CONDITIONS
B_V	Breakdown Voltage	60		V	I_R = 10 μA
V_F	Forward Voltage (Note 3)		1.5 1.1 1.0	V V V	I_F = 500 mA I_F = 200 mA I_F = 100 mA
I_R	Reverse Current Reverse Current (T_A = 150°C)		100 100	nA μA	V_R = 40 V V_R = 40 V
C	Capacitance		5.0	pF	V_R = 0, f = 1 MHz
V_{FM}	Peak Forward Voltage		4.0	V	I_f = 500 mA, t_r < 10 ns
t_{fr}	Forward Recovery Time		40	ns	I_f = 500 mA, t_r < 10 ns
t_{rr}	Reverse Recovery Time		10 50	ns ns	$I_f = I_r$ = 10 – 200 mA R_L = 100 Ω, Rec. to 0.1 I_r I_f = 500 mA, I_r = 50 mA R_L = 100 Ω, Rec. to 5 mA
ΔV_F	Forward Voltage Match		15	mV	I_F = 10 mA

NOTES
1 These ratings are limiting values above which life or satisfactory performance may be impaired.
2 These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operation.
3 V_F is measured using an 8 ms pulse.