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PDS

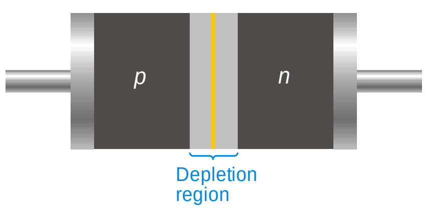
Electronics Basic

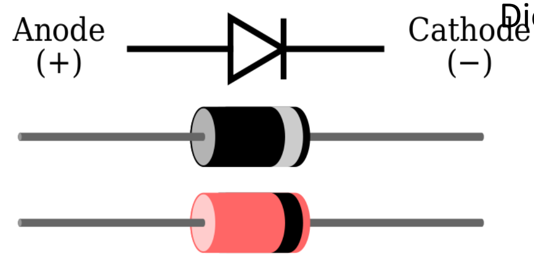
The Ideal Diode

Diodes

- Diode, semiconductor material, such as silicon, in which half is doped as p-region and half is doped as n-region with a pn-junction in between.

- The p region is called **anode** and n type region is called **cathode.**





Diode symbol

Diodes

- Diode, semiconductor material, such as silicon, in which half is doped as p-region and half is doped as n-region with a pn-junction in between.

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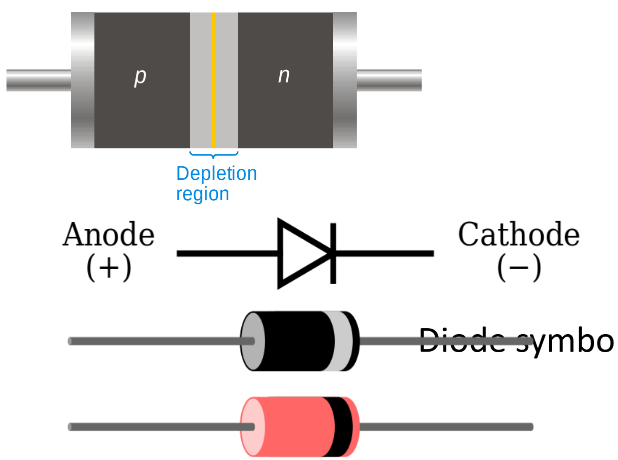


Bulk resistance = Positive R + negative Resistan

$$R_B = R_P + R_N$$ Rb = 0 , Rp, Rn <= 1 ohm

$$P_D = V_D I_D \tag{3-3}$$

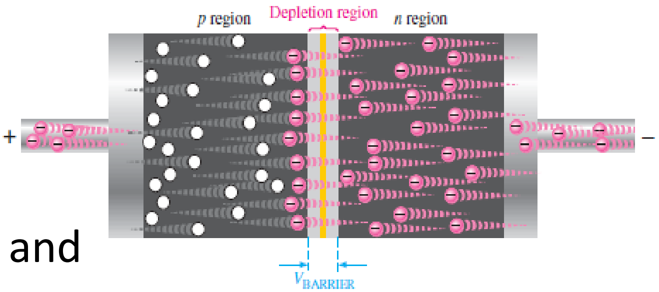
The **power rating** is the maximum power the diode can safely dissipate without shortening its life or degrading its properties. In symbols, the definition is:

$$P_{max} = V_{max} I_{max} \tag{3-4}$$

- It conducts current in one direction and offers high (ideally infinite) resistance in other direction.

Forward Biased

- Forward bias is a condition that allows current through pn junction.

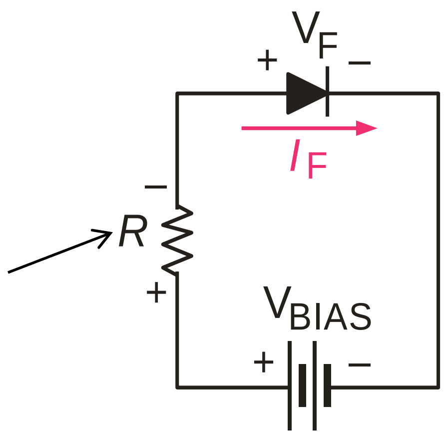


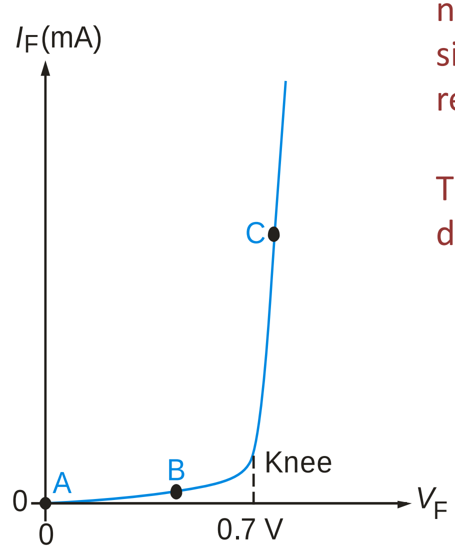
- A dc voltage (V_{bais}) is applied to bias a diode.
- Positive side is connected to p-region (anode) and negative side is connected with n-region.
- V_{bais} must be greater than 'barrier potential'

As more electrons flow into the depletion region reducing the number of positive ions and similarly more holes move in reducing the positive ions.

This reduces the width of depletion region.

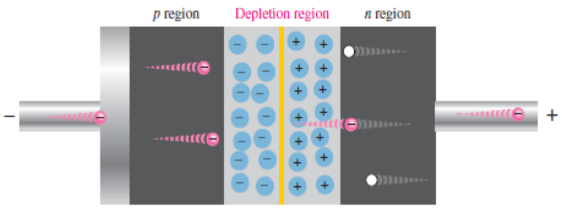
Current limiting resistance





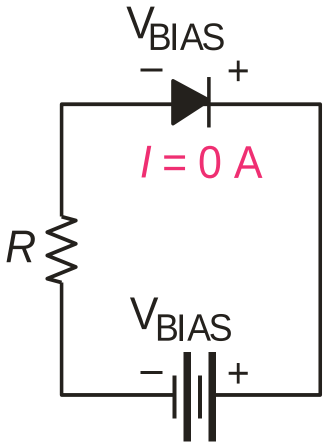
Reverse Biased

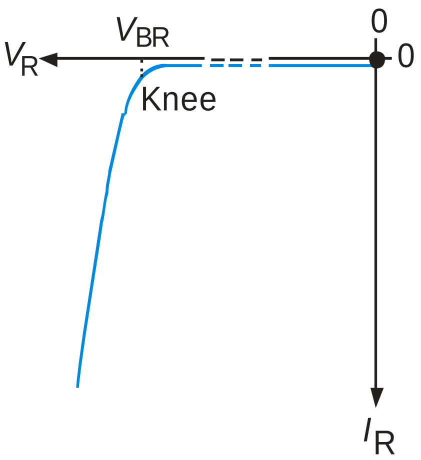
- Reverse bias is a condition that prevents current through junction.
- Positive side of V_{bias} is connected to the n-region whereas the negative side is connected with p-region.
- Depletion region get wider with this configuration.



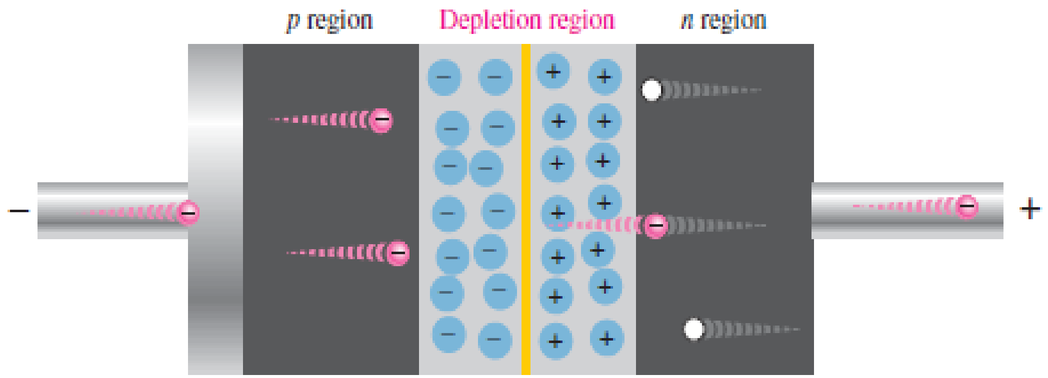
The positive side of bias voltage attracts the majority carriers of n-type creating more positive ions at the junction.

This widens the depletion region.



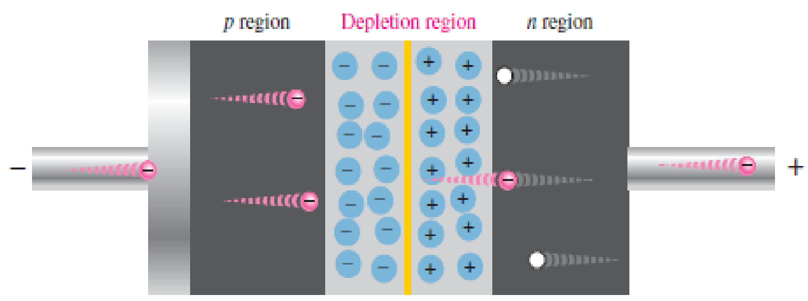


Reverse Current



- A small amount current is generated due to the minority carriers in p and n regions.
- These minority carriers are produced due to thermally generated hole-electron pairs.
- Minority electrons in p-region pushed towards +ve bias voltage, cross junction and then fall in the holes in n-region and still travel in valance band generating a hole current.

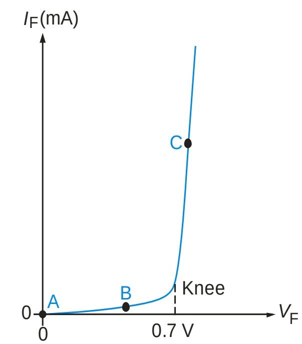
Reverse Breakdown

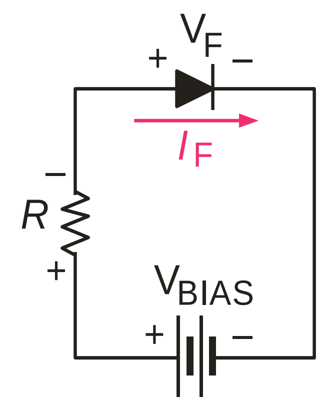


- If the external bias voltage is increased to a value call *breakdown voltage* the reverse current can increase drastically.
- Free minority electrons get enough energy to knock valance electron into the conduction band.
- The newly released electron can further strike with other atoms.
- The process is called ***avalanche effect.***

Diode V-I Characteristic

- **VI Characteristic for forward bias.**
  - The current in forward biased called *forward current* and is designated I_f.
  - At 0V (V_{bias}) across the diode, there is no forward current.
  - With gradual increase of V_{bias}, the forward voltage and forward current increases.
  - A resistor in series will limit the forward current in order to protect the diode from overheating and permanent damage.
  - A portion of forward-bias voltage drops across the limiting resistor.
  - Continuing increase of V_f causes rapid increase of forward current but only a gradual increase in voltage across diode.

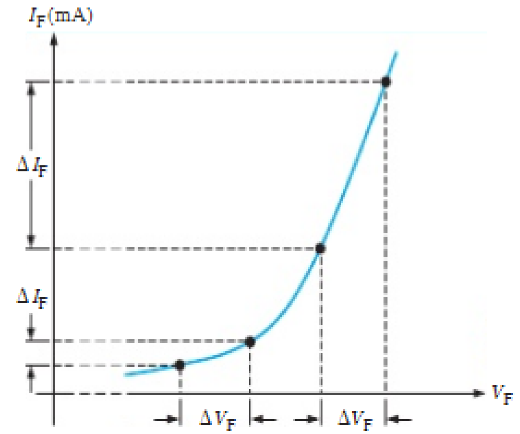




Diode V-I Characteristic

❖ **Dynamic Resistance:**

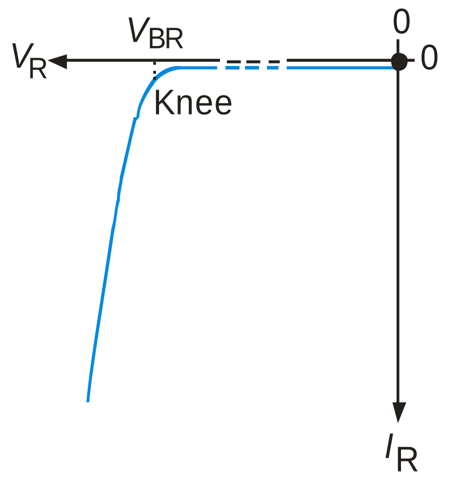
- The resistance of diode is not constant but it changes over the entire curve. So it is called dynamic resistance.



The dynamic resistance r'_d decreases as you move up the curve, as indicated by the decrease in the value of $\Delta V_F / \Delta I_F$.

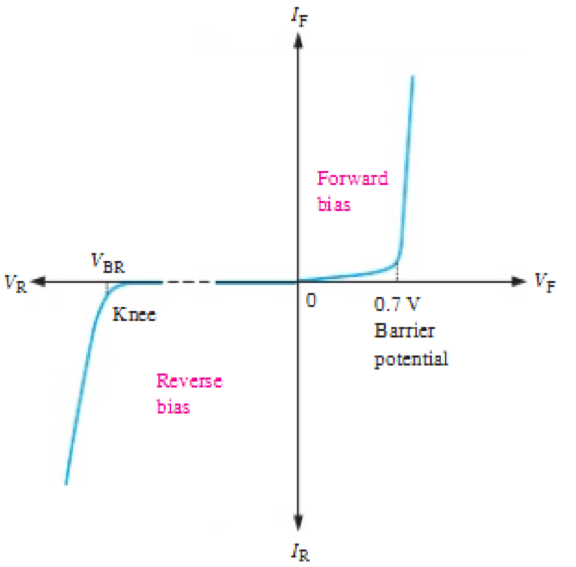
Diode V-I Characteristic

- **VI Characteristic for reverse bias.**
  - With 0V reverse voltage there is no reverse current.
  - There is only a small current through the junction as the reverse voltage increases.
  - At a point, reverse current shoots up with the break down of diode. The voltage called break down voltage. This is not normal mode of operation.
  - After this point the reverse voltage remains at approximately VBR but IR increase very rapidly.
  - Break down voltage depends on doping level, set by manufacturer.



Diode V-I Characteristic

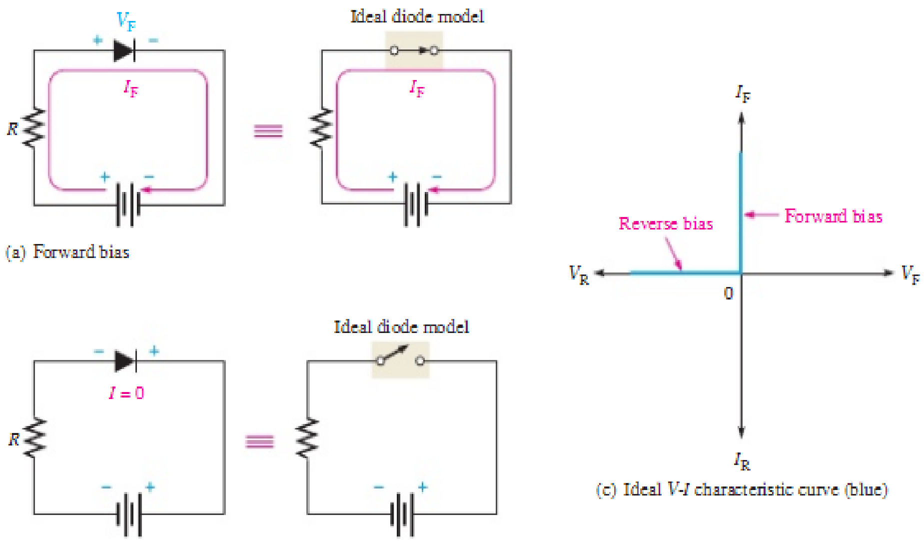
❖ The complete V-I characteristic curve



The complete *V-I* characteristic curve for a diode.

Diode models

- **Ideal Diode Model**



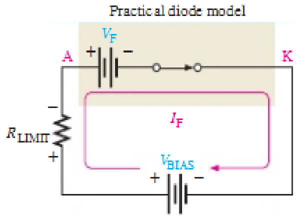
(a) Forward bias

(b) Reverse bias

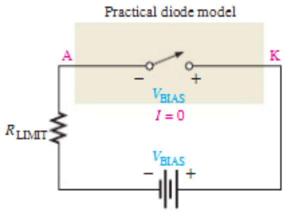
(c) Ideal V-I characteristic curve (blue)

- Barrier potential, the forward dynamic resistance and reverse current all are neglected.

Diode models



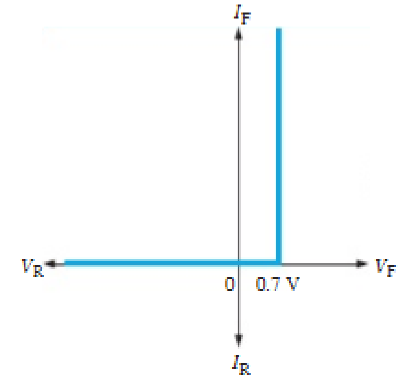
(a) Forward bias



(b) Reverse bias

$V_F = 0.7V$

- **Practical Diode Model**
- Barrier potential, the forward dyr resistance and reverse current all neglected.



(c) Characteristic curve (silicon)

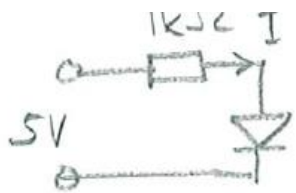
- Forward current I_F is determined using Kirchhoff's voltage as follows:

$$V_{BIAS} - V_F - V_{R_{LIMIT}} = 0$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT}$$

Substituting and solving for I_F,
$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}}$$

Ex)



$V > 0{,}7V \rightarrow$ Diode conducts $\rightarrow V_D = 0{,}7V$

$$I = \frac{V_R}{R} = \frac{5 - 0{,}7}{1k} = \frac{4{,}3}{1k} = 4{,}3\,mA$$

V_F = Knee Voltage = 0.7V

Ex 3-1

Example 3-1

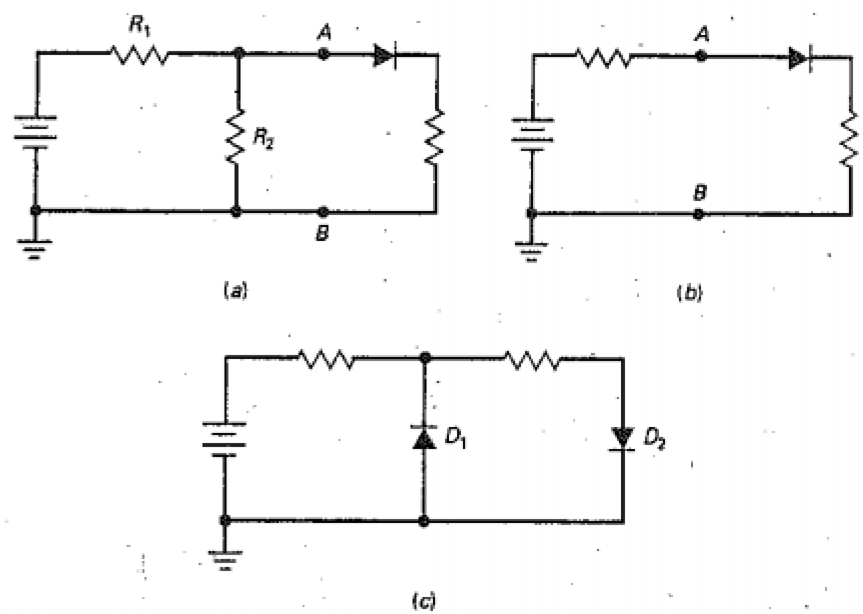
MultiSim

Is the diode of Fig. 3-3*a* forward biased or reverse biased?

SOLUTION The voltage across R_2 is positive; therefore, the circuit is trying to push current in the easy direction of flow. If this is not clear, visualize the Thevenin circuit facing the diode as shown in Fig. 3-3*b*. In this series circuit, you can see that the dc source is trying to push current in the easy direction of flow. Therefore, the diode is forward biased.

Whenever in doubt, reduce the circuit to a series circuit. Then, it will be clear whether the dc source is trying to push current in the easy direction or not.

Figure 3-3



PRACTICE PROBLEM 3-1 Are the diodes of Fig. 3-3*c* forward biased or reverse biased?

Example 3-2

Example 3-2

A diode has a power rating of 5 W. If the diode voltage is 1.2 V and the diode current is 1.75 A, what is the power dissipation? Will the diode be destroyed?

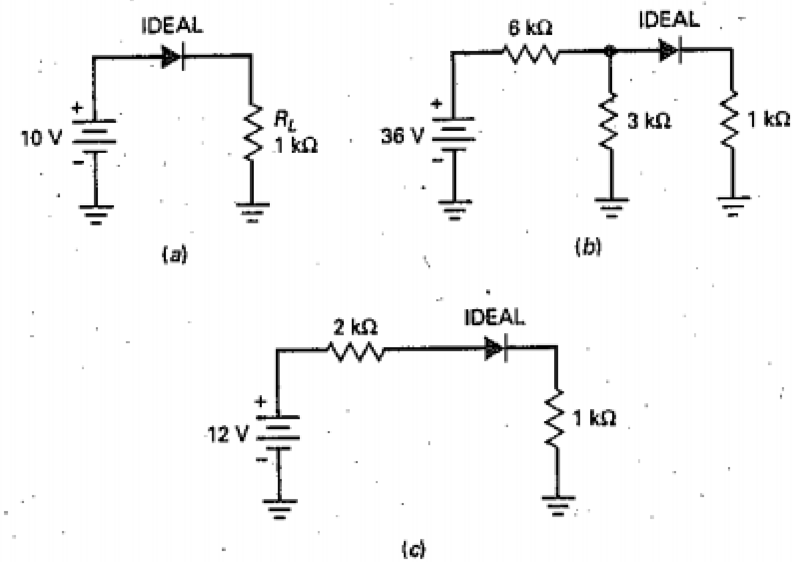
SOLUTION

$$P_D = (1.2\text{ V})(1.75\text{ A}) = 2.1\text{ W}$$

This is less than the power rating, so the diode will not be destroyed.

PRACTICE PROBLEM 3-2 Referring to Example 3-2, what is the diode's power dissipation if the diode voltage is 1.1 V and the diode current is 2 A?

Figure 3-6



Example 3-3

Use the ideal diode to calculate the load voltage and load current in Fig. 3-6*a*.

SOLUTION Since the diode is forward biased, it is equivalent to a closed switch. Visualize the diode as a closed switch. Then, you can see that all of the source voltage appears across the load resistor:

$$V_L = 10\text{ V}$$

With Ohm's law, the load current is:

$$I_L = \frac{10\text{ V}}{1\text{ k}\Omega} = 10\text{ mA}$$

PRACTICE PROBLEM 3-3 In Fig. 3-6*a*, find the ideal load current if the source voltage is 5 V.

Example 3-4

Calculate the load voltage and load current in Fig. 3-6*b* using an ideal diode.

SOLUTION One way to solve this problem is to Thevenize the circuit to the left of the diode. Looking from the diode back toward the source, we see a voltage divider with 6 kΩ and 3 kΩ. The Thevenin voltage is 12 V, and the Thevenin resistance is 2 kΩ. Figure 3-6*c* shows the Thevenin circuit

Now that we have a series circuit, we can see that the diode is forward biased. Visualize the diode as a closed switch. Then, the remaining calculations are:

$$I_L = \frac{12\text{ V}}{3\text{ k}\Omega} = 4\text{ mA}$$

and

$$V_L = (4\text{ mA})(1\text{ k}\Omega) = 4\text{ V}$$

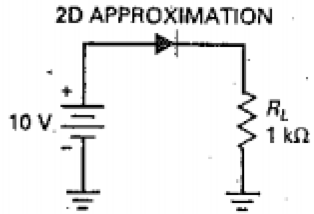
You don't have to use Thevenin's theorem. You can analyze Fig. 3-6*b* by visualizing the diode as a closed switch. Then, you have 3 kΩ in parallel with 1 kΩ, equivalent to 750 Ω. Using Ohm's law, you can calculate a voltage drop of 32 V across the 6 kΩ. The rest of the analysis produces the same load voltage and load current.

PRACTICE PROBLEM 3-4 Using Fig. 3-6*b*, change the 36 V source to 18 V and solve for the load voltage and load current using an ideal diode.

Example 3-5

Use the second approximation to calculate the load voltage, load current, and diode power in Fig. 3-8.

Figure 3-8



SOLUTION Since the diode is forward biased, it is equivalent to a battery of 0.7 V. This means that the load voltage equals the source voltage minus the diode drop:

$$V_L = 10\text{ V} - 0.7\text{ V} = 9.3\text{ V}$$

With Ohm's law, the load current is:

$$I_L = \frac{9.3\text{ V}}{1\text{ k}\Omega} = 9.3\text{ mA}$$

The diode power is

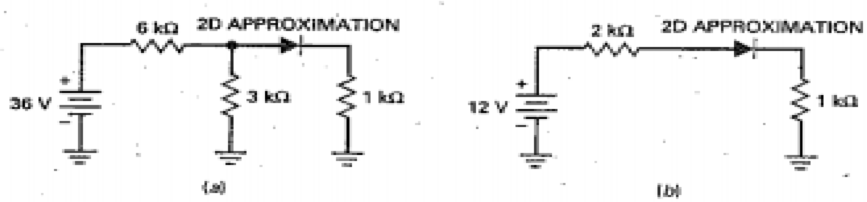
$$P_D = (0.7\text{ V})(9.3\text{ mA}) = 6.51\text{ mW}$$

PRACTICE PROBLEM 3-5 Using Fig. 3-8, change the source voltage to 5 V and calculate the new load voltage, current, and diode power.

Example 3-6

Calculate the load voltage, load current, and diode power in Fig. 3-9*a* using the second approximation.

Figure 3-9 (*a*) Original circuit; (*b*) simplified with Thevenin's theorem.



SOLUTION Again, we will Thevenize the circuit to the left of the diode. As before, the Thevenin voltage is 12 V and the Thevenin resistance is 2 kΩ. Figure 3-9*b* shows the simplified circuit.

Since the diode voltage is 0.7 V, the load current is:

$$I_L = \frac{12\text{ V} - 0.7\text{ V}}{3\text{ k}\Omega} = 3.77\text{ mA}$$

The load voltage is:

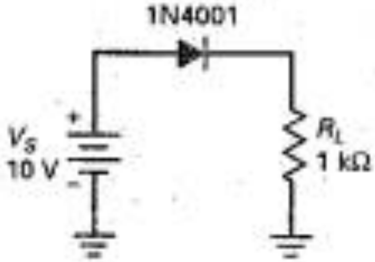
$$V_L = (3.77\text{ mA})(1\text{ k}\Omega) = 3.77\text{ V}$$

and the diode power is:

$$P_D = (0.7\text{ V})(3.77\text{ mA}) = 2.64\text{ mW}$$

PRACTICE PROBLEM 3-6 Repeat Example 3-6 using 18 V as the voltage source value.

Figure 3-14 Troubleshooting a circuit.



the diode to burn out. What kind of symptoms will you get?

SOLUTION When a diode burns out, it becomes an open circuit. In this case, the current drops to zero. Therefore, if you measure the load voltage, the voltmeter will indicate zero.

Example 3-10

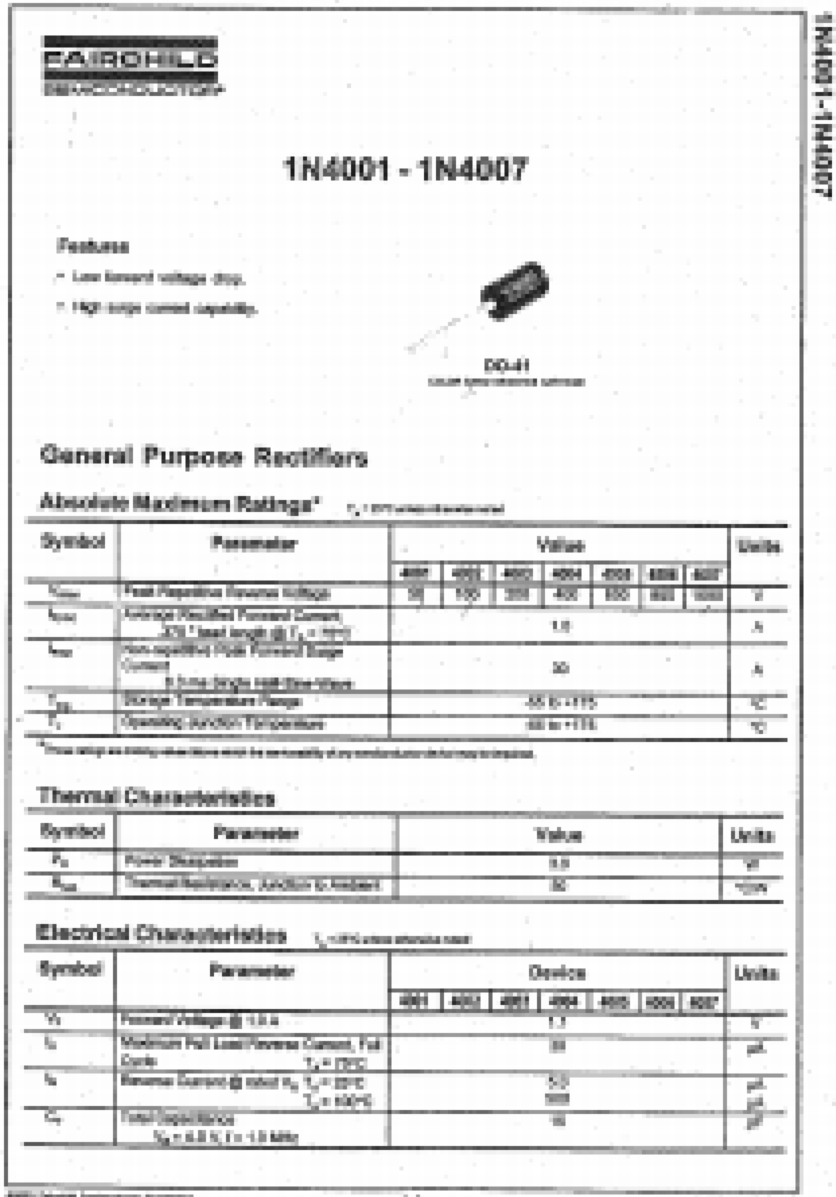
Suppose the circuit of Fig. 3-14 is not working. If the load is not shorted, what is the trouble?

SOLUTION Many troubles are possible. First, the diode could be open. Second, the supply voltage could be zero. Third, one of the connecting wires could be open.

How do you find the trouble? Measure the voltages to isolate the defective component. Then disconnect any suspected component and test its resistance. For instance, you could measure the source voltage first and the load voltage second. If there is source voltage but no load voltage, the diode may be open. An ohmmeter or DMM test will tell. If the diode passes the ohmmeter or DMM test, check the connections because there's nothing else to account for having source voltage but no load voltage.

If there is no source voltage, the power supply is defective or a connection between the supply and the diode is open. Power-supply troubles are common. Often, when electronics equipment is not working, the trouble is in the power supply. This is why most troubleshooters start by measuring the voltages out of the power supply.

Figure 3-16 Data sheet for 1N4001–1N4007 diodes.


FAIRCHILD
SEMICONDUCTOR

1N4001 - 1N4007

Features
- [illegible]
- [illegible]

DO-41

General Purpose Rectifiers

Absolute Maximum Ratings*

Symbol	Parameter	4001	4002	4003	4004	4005	4006	4007	Units
[illegible]	Peak Repetitive Reverse Voltage	50	100	[illegible]	400	[illegible]	[illegible]	1000	V
[illegible]	Average Rectified Forward Current, [illegible]	1.0							A
[illegible]	Non-repetitive Peak Forward Surge Current [illegible]	30							A
T_{stg}	Storage Temperature Range	[illegible]							°C
T_J	Operating Junction Temperature	[illegible]							°C

*[illegible]

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	[illegible]	W
[illegible]	Thermal Resistance, Junction to Ambient	[illegible]	[illegible]

Electrical Characteristics

Symbol	Parameter	4001	4002	4003	4004	4005	4006	4007	Units
V_F	Forward Voltage @ 1.0 A	[illegible]							V
[illegible]	Maximum Full Load Reverse Current, Full Cycle [illegible]	[illegible]							µA
I_R	Reverse Current @ rated V_R [illegible]	[illegible]							µA
C_T	Total Capacitance [illegible]	[illegible]							pF

Again, a designer looks upon 1 A as the absolute maximum rating of the 1N4001, a level of forward current that should not even be approached. This is why a safety factor would be included—possibly a factor of 2. In other words, a reliable design would ensure that the forward current is less than 0.5 A under all operating conditions. Failure studies of devices show that the lifetime of a device decreases the closer you get to the maximum rating. This is why some designers use a safety factor of as much as 10:1. A really conservative design would keep the maximum forward current of the 1N4001 at 0.1 A or less.

Forward Voltage Drop

Under "Electrical Characteristics" in Fig. 3-16, the first entry shown gives you these data:

Characteristic and Conditions	Symbol	Maximum Value
Forward Voltage Drop		
$(I_F) = 1.0$ A, $T_A = 25$°C	V_F	1.1 V

As shown in Fig. 3-16 on the chart titled "Forward Characteristics," the typical 1N4001 has a forward voltage drop of 0.93 V when the current is 1 A and the junction temperature is 25°C. If you test thousands of 1N4001s, you will find that a few will have as much as 1.1 V across them when the current is 1 A.

Maximum Reverse Current

Another entry on the data sheet that is worth discussing is this one:

Characteristic and Conditions	Symbol	Typical Value	Maximum Value
Reverse Current	I_R		
$T_A = 25$°C		0.05 µA	10 µA
$T_A = 100$°C		1.0 µA	50 µA

This is the reverse current at the maximum reverse dc rated voltage (50 V for a 1N4001). At 25°C, the typical 1N4001 has a maximum reverse current of 5.0 µA. But notice how it increases to 500 µA at 100°C. Remember that this reverse current includes thermally produced saturation current and surface-leakage current. You can see from these numbers that temperature is important. A design that requires a reverse current of less than 5.0 µA will work fine at 25°C with a typical 1N4001, but will fail in mass production if the junction temperature reaches 100°C.

How to Calculate Bulk Resistance

$$R_b = \frac{V_2 - V_1}{(I_2 - I_1)}$$

$$R_B = \frac{V_2 - V_1}{I_2 - I_1}$$

where V_1 and I_1 are the voltage and current at some point at or above the knee voltage; V_2 and I_2 are the voltage and current at some higher point on the diode curve.

For instance, the data sheet of a 1N4001 gives a forward voltage of 0.93 V for a current of 1 A. Since this is a silicon diode, it has a knee voltage of approximately 0.7 V and a current of approximately zero. Therefore, the values to use are $V_2 = 0.93$ V, $I_2 = 1$ A, $V_1 = 0.7$ V, and $I_1 = 0$. Substituting these values into equation, we get a bulk resistance of:

$$R_B = \frac{V_2 - V_1}{I_2 - I_1} = \frac{0.93\text{V} - 0.7\text{ V}}{1\text{ A} - 0\text{ A}} = \frac{0.23\text{ V}}{1\text{ A}} = 0.23\ \Omega$$

Incidentally, the diode curve is a graph of current versus voltage. The bulk resistance equals the inverse of the slope above the knee. The greater the slope of the diode curve, the smaller the bulk resistance. In other words, the more vertical the diode curve is above the knee, the lower the bulk resistance.

DC Resistance of a Diode

Forward Resistance

Because the diode is a nonlinear device, its dc resistance varies with the current through it. For example, here are some pairs of forward current and voltage for a 1N914: 10 mA at 0.65 V, 30 mA at 0.75 V, and 50 mA at 0.85 V. At the first point, the dc resistance is:

$$R_F = \frac{0.65\ \text{V}}{10\ \text{mA}} = 65\ \Omega$$

At the second point:

$$R_F = \frac{0.75\ \text{V}}{30\ \text{mA}} = 25\ \Omega$$

And at the third point:

$$R_F = \frac{0.85\ \text{mV}}{50\ \text{mA}} = 17\ \Omega$$

Notice how the dc resistance decreases as the current increases. In any case, the forward resistance is low compared to the reverse resistance.

Reverse Resistance

Similarly, here are two sets of reverse current and voltage for a 1N914: 25 nA at 20 V; 5 μA at 75 V. At the first point, the dc resistance is:

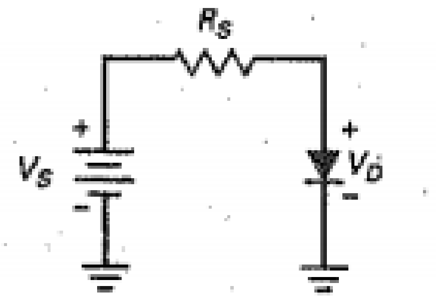
$$R_R = \frac{20\ \text{V}}{25\ \text{nA}} = 800\ \text{M}\Omega$$

At the second point:

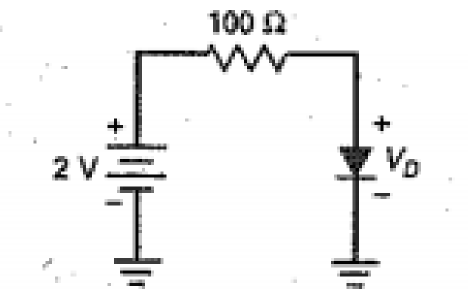
$$R_R = \frac{75\ \text{V}}{5\ \mu\text{A}} = 15\ \text{M}\Omega$$

Notice how the dc resistance decreases as we approach the breakdown voltage (75 V).

Load Lines of a Diode



(a)



(b)

Equation for the Load Lines of a Diode

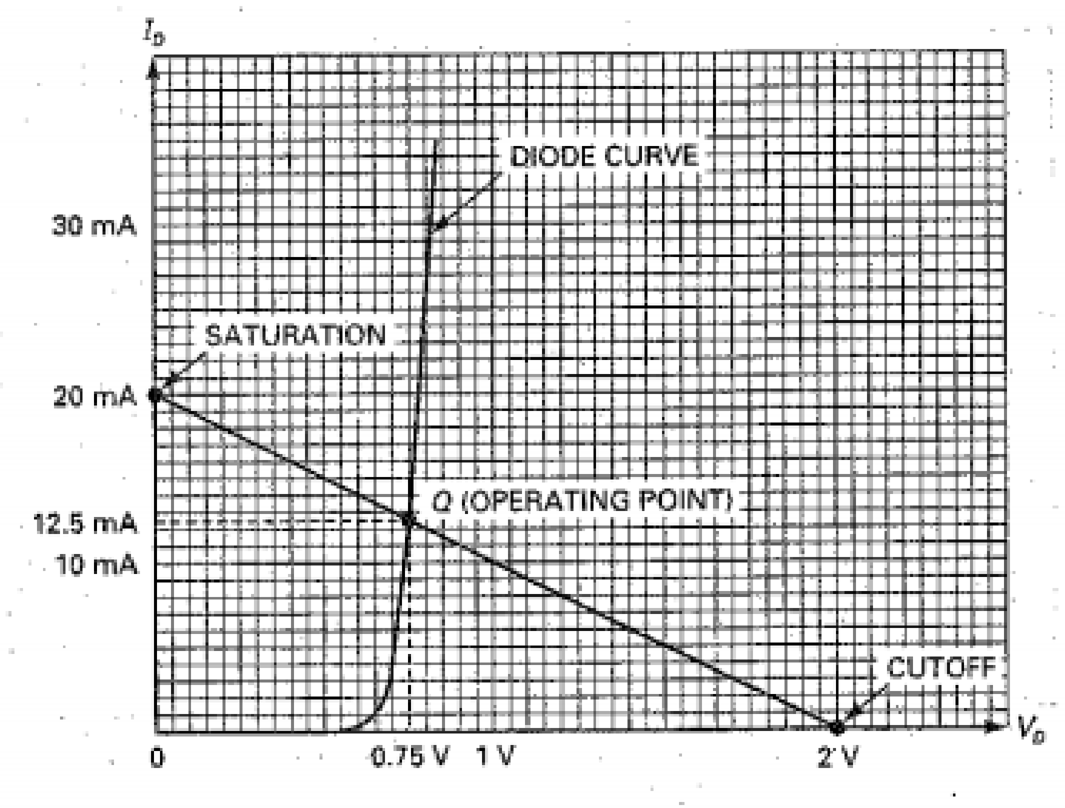
$$I_D = \frac{V_s - V_D}{R_s}$$

$$I_D = \frac{2 - V_D}{100}$$

If VD equal zero $$I_D = \frac{2-0}{100} = 0mA$$

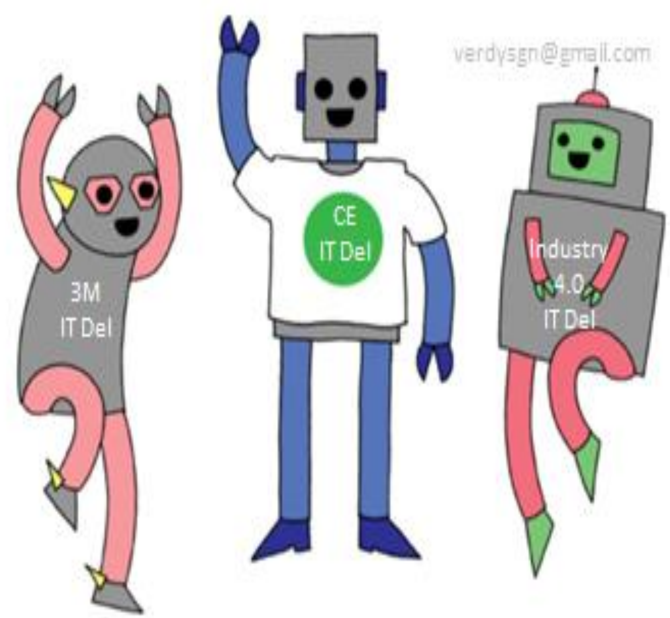
If VD equal 2 V $$I_D = \frac{2-2v}{100} = 0$$

The Q Point



I_D
DIODE CURVE
30 mA
SATURATION
20 mA
Q (OPERATING POINT)
12.5 mA
10 mA
CUTOFF
V_D
0
0.75 V
1 V
2 V


Thanks!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