ENEE236 & 241

Analog Electronics

L2 Semiconductor Diodes

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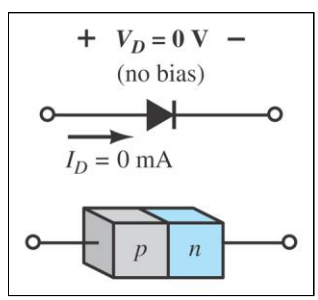
Diode Operating Conditions

No Bias

No external voltage is applied: $V_D = 0$ V

There is no diode current: $I_D = 0$ A

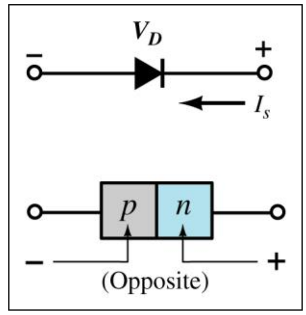
Only a modest depletion region exists



Diode Operating Conditions

Reverse Bias

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

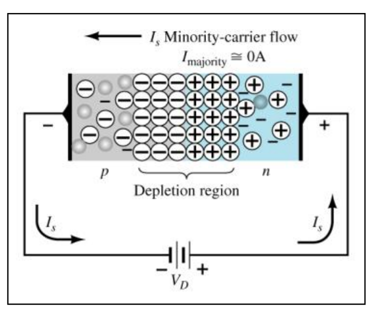


Diode Operating Conditions

Reverse Bias

The reverse voltage causes the depletion region to widen.

The electrons in the *n*-type material are attracted toward the positive terminal of the voltage source.

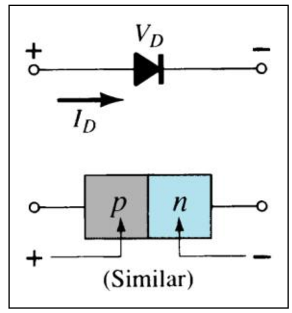


The holes in the *p*-type material are attracted toward the negative terminal of the voltage source.

Diode Operating Conditions

Forward Bias

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



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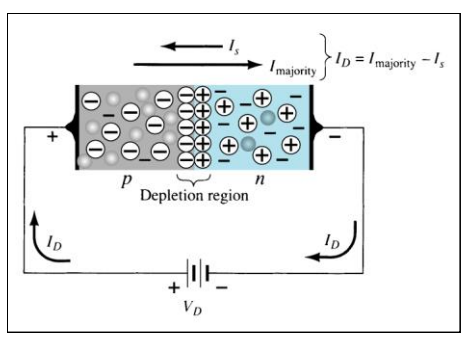
Diode Operating Conditions

Forward Bias

The forward voltage causes the depletion region to narrow.

The electrons and holes are pushed toward the *p-n* junction.



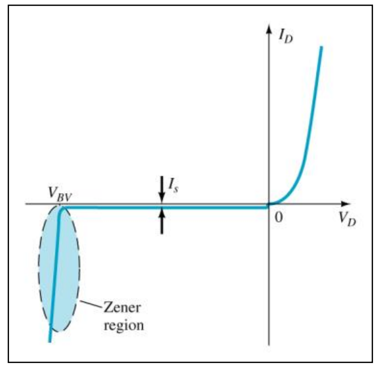
The electrons and holes have sufficient energy to cross the *p-n* junction.

Zener Region

The Zener region is in the diode's reverse-bias region.

At some point the reverse bias voltage is so large the diode breaks down and the reverse current increases dramatically.
The maximum reverse voltage that won't take a diode into the zener region is called the **peak inverse voltage** or **peak reverse voltage**.

The voltage that causes a diode to enter the zener region of operation is called the **zener voltage (V_Z).**



Forward Bias Voltage

The point at which the diode changes from no-bias condition to forward-bias condition occurs when the electrons 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:

gallium arsenide diode ≅ 1.2 V

silicon diode ≅ 0.7 V

germanium diode ≅ 0.3 V

Temperature Effects

As temperature increases it adds energy to the diode.

It reduces the required forward bias voltage for forward-bias conduction.

It increases the amount of reverse current in the reverse-bias condition.

It increases maximum reverse bias avalanche voltage.

Germanium diodes are more sensitive to temperature variations than silicon or gallium arsenide diodes.

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Resistance Levels

Semiconductors react differently to DC and AC currents.

There are three types of resistance:

DC (static) resistance

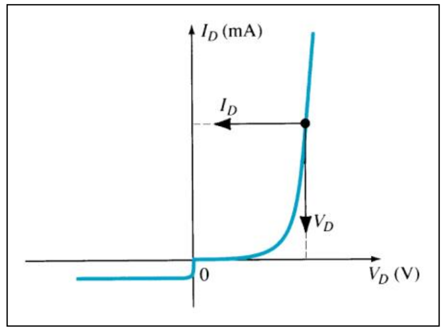
AC (dynamic) resistance

Average AC resistance

DC (Static) Resistance

For a specific applied DC voltage (V_D) the diode has a specific current (I_D) and a specific resistance (R_D).

$$R_D = \frac{V_D}{I_D}$$



AC (Dynamic) Resistance

In the forward bias region:

$$r'_d = \frac{26\text{ mV}}{I_D}$$

The resistance depends on the amount of current (I_D) in the diode.

The voltage across the diode is fairly constant (26 mV for 25°C).

In the reverse bias region:

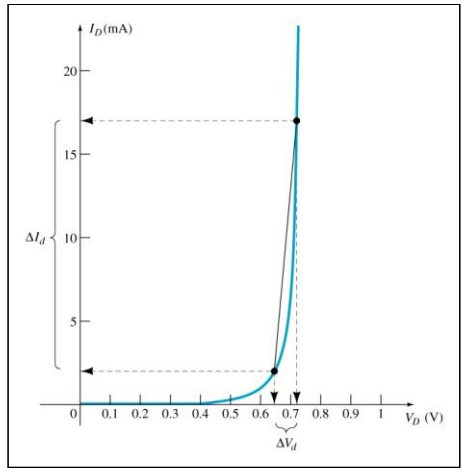
$$r'_d = \infty$$

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

Average AC Resistance

$$r_{av} = \frac{\Delta V_d}{\Delta I_d} \bigg| \; pt.\, to\, pt.$$

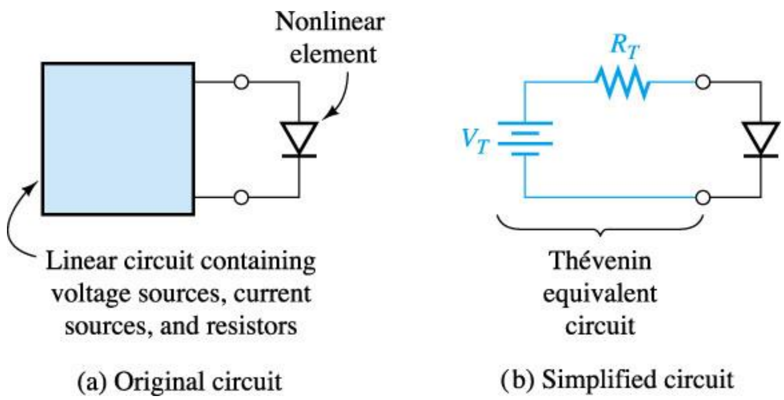
AC resistance can be calculated using the current and voltage values for two points on the diode characteristic curve.



Diode Analysis Methods:

1. **Using non-linear Math (not covered)**
2. **Using Diode Models (covered)**
3. **Using load line (covered)**

The Load Line Analysis



Analysis of a circuit containing a singular nonlinear element can be accomplished by "load-line analysis" of a simplified circuit.

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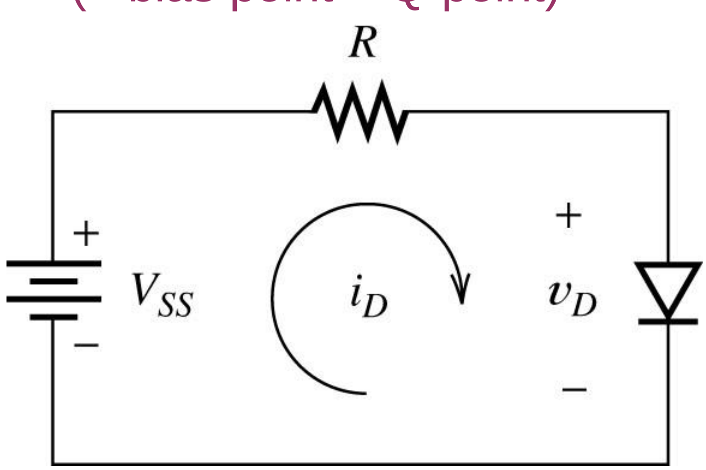
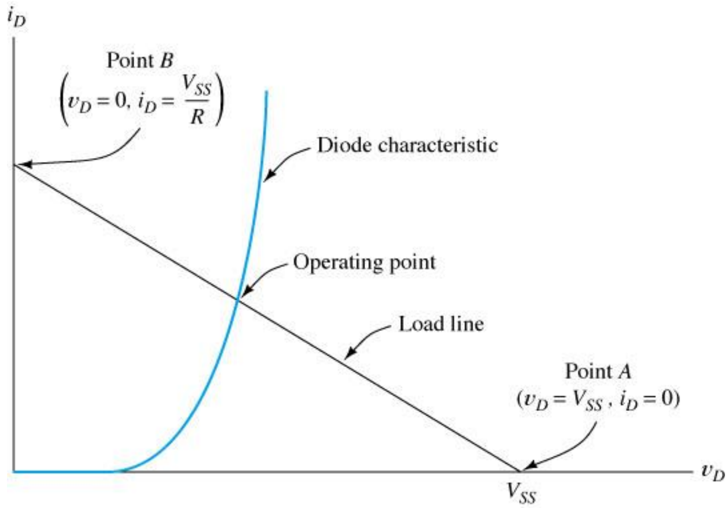
The device operating point (= bias point = Q-point)



Circuit for load-line analysis.

The load-line concept



Load-line analysis of the circuit

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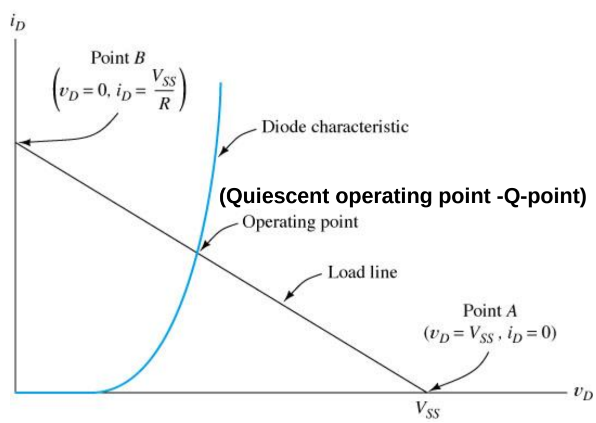
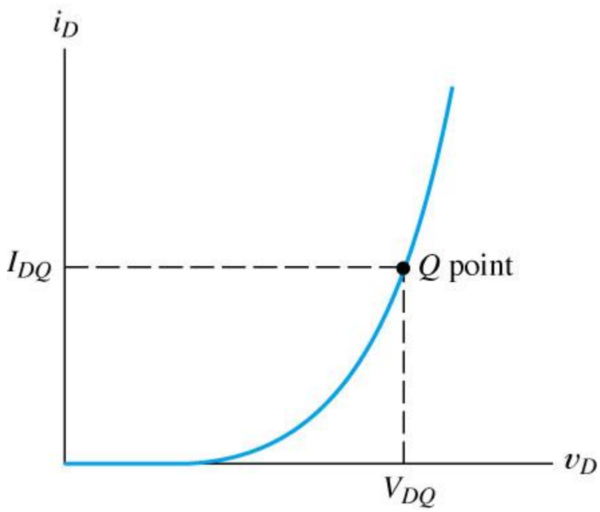
The load-line concept

Intersecting the two lines is the same as simultaneous solution of equations



Load-line analysis of the circuit

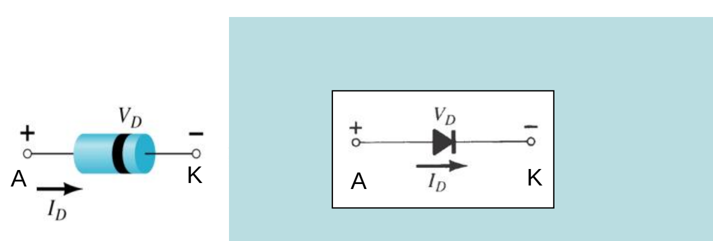
The device Q-point (quiescent)



Diode characteristic, illustrating the *Q*-point.

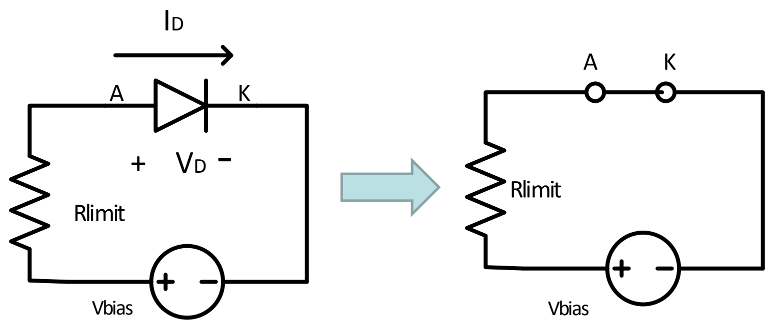
Diode (Models)

1) **Ideal Diode Model**
2) **Simplified/piecewise/ knee model**
3) **Complete diode model**



Ideal Diode Model

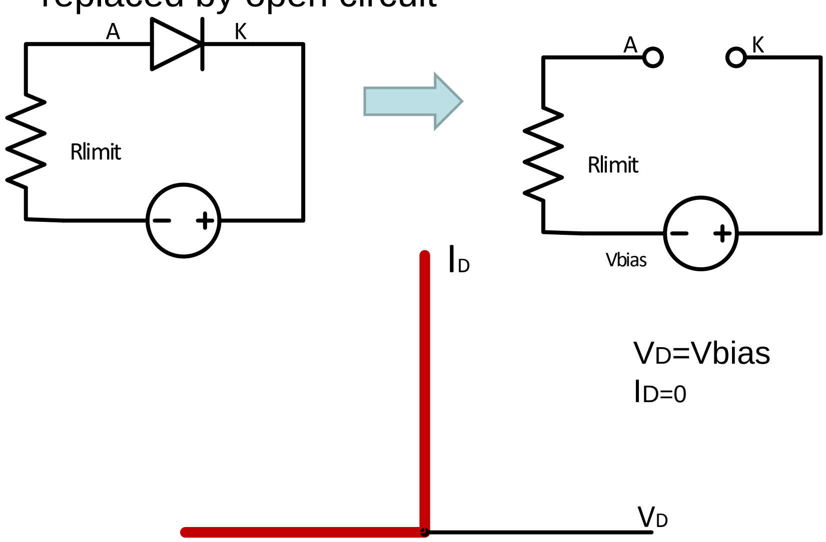
- 1) if the diode is forward biased ==> diode is replaced by short circuit



VD=0
ID=Vbias/Rlimit

Ideal Diode Model

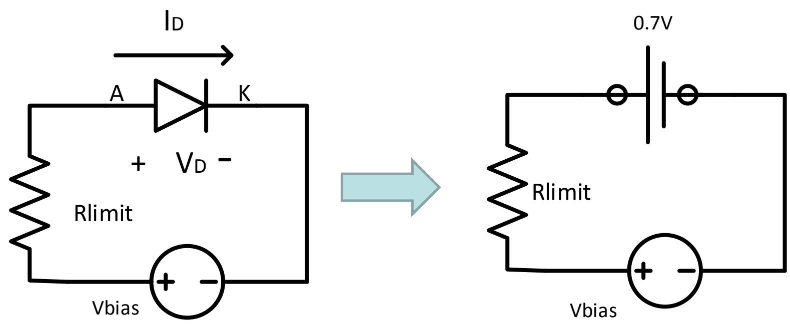
- 2) if the diode is Reverse biased ==> diode is replaced by open circuit



VD=Vbias
ID=0

Simplified/piecewise/ knee model

- 1) if the diode is forward biased ==> diode is replaced by a 0.7V battery (for Si)



V_D=0.7 V
I_D=(Vbias-0.7)/Rlimit

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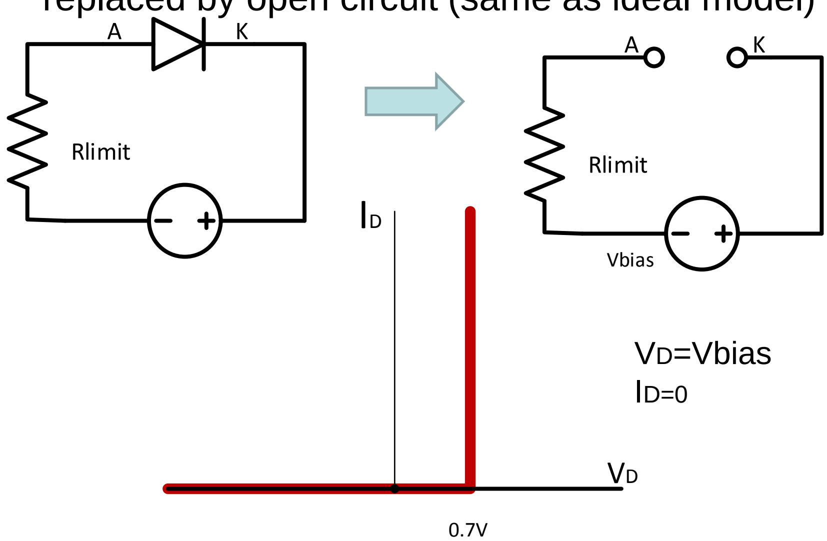
Simplified/piecewise/ knee model

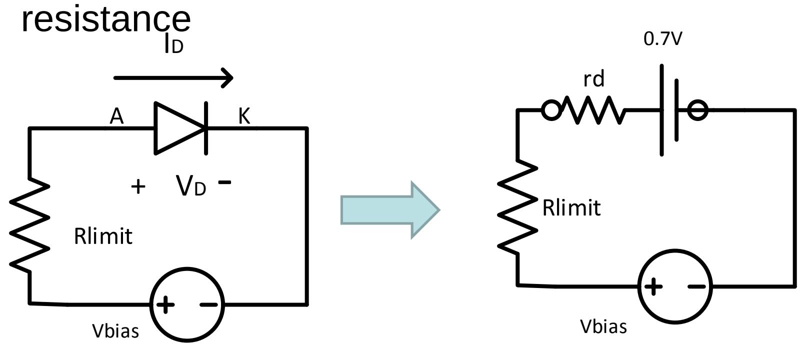
- 2) if the diode is Reverse biased ==> diode is replaced by open circuit (same as ideal model)



V_D=Vbias
I_D=0

Complete Diode model

- 1) if the diode is forward biased ==> diode is replaced by a 0.7V battery and forward dynamic resistance



$V_D = 0.7 + I_D \cdot rd$

$I_D = (Vbias - 0.7)/(Rlimit + rd)$

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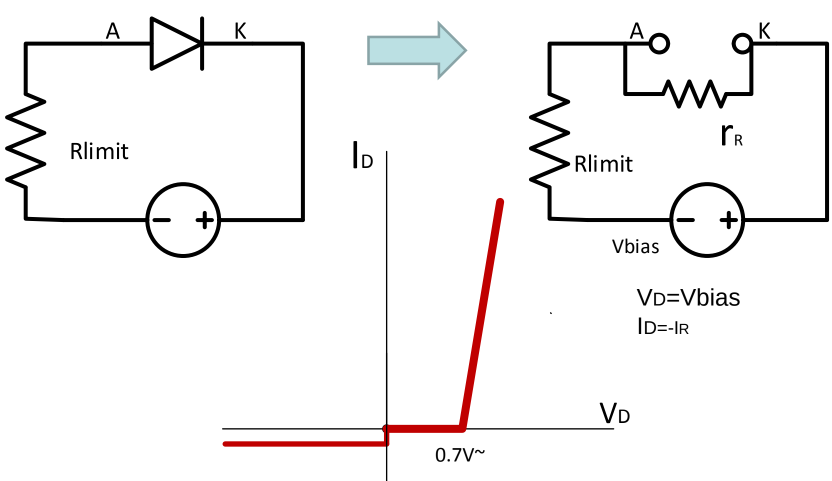
Complete Diode model

- 2) if the diode is Reverse biased ==> diode is replaced by open circuit // to reverse resistance r_R

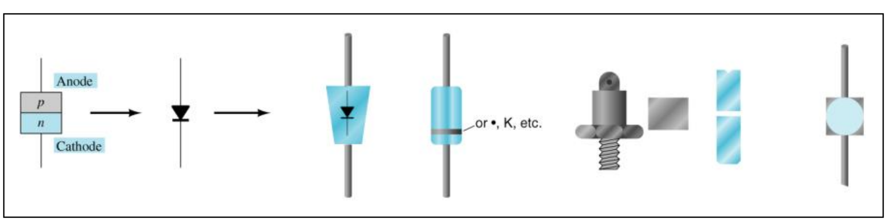


Diode Specification Sheets

Diode data sheets contain standard information, making cross-matching of diodes for replacement or design easier.

1. Forward Voltage (V_F) at a specified current and temperature
2. Maximum forward current (I_F) at a specified temperature
3. Reverse saturation current (I_R) at a specified voltage and temperature
4. Reverse voltage rating, PIV or PRV or $V_{(BR)}$, at a specified temperature
5. Maximum power dissipation at a specified temperature
6. Capacitance levels
7. Reverse recovery time, t_{rr}
8. Operating temperature range

Diode Symbol and Packaging



The anode is abbreviated A

The cathode is abbreviated K

Diode Testing

Diodes are commonly tested using one of these types of equipment:

Diode checker

Ohmmeter

Curve tracer

Diode Checker

Many digital multimeters have a diode checking function. The diode should be tested out of circuit.

A normal diode exhibits its forward voltage:

Gallium arsenide ≅ 1.2 V

Silicon diode ≅ 0.7 V

Germanium diode ≅ 0.3 V

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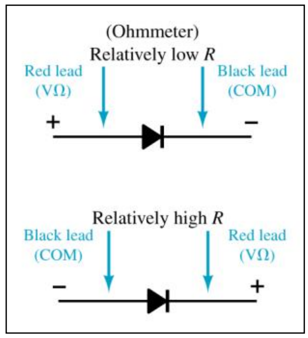
Ohmmeter

An ohmmeter set on a low Ohms scale can be used to test a diode. The diode should be tested out of circuit.



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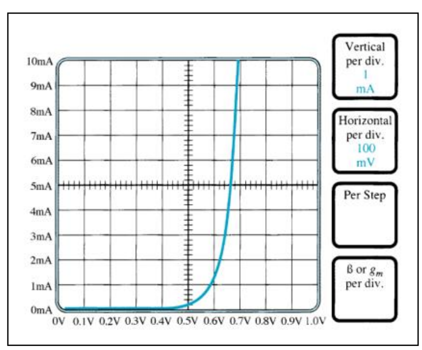
Curve Tracer

A curve tracer displays the characteristic curve of a diode in the test circuit. This curve can be compared to the specifications of the diode from a data sheet.



Other Types of Diodes

There are several types of diodes besides the standard *p-n* junction diode. Three of the more common are:

Zener diodes

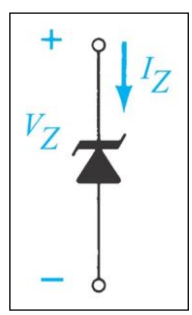
Light-emitting diodes

Diode arrays

Zener Diode

A **Zener diode** is one that is designed to safely operate in its zener region; i.e., biased at the Zener voltage (V_Z).

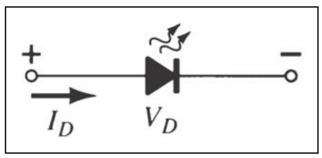
Common zener diode voltage ratings are between 1.8 V and 200 V



The **Zener diode** is used for voltage regulation, details will be discussed later

Light-Emitting Diode (LED)

An **LED** emits light when it is forward biased, which can be in the infrared or visible spectrum.



The forward bias voltage is usually in the range of 2 V to 3 V.

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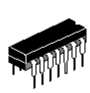
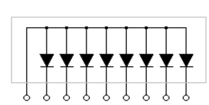
Diode Arrays

Multiple diodes can be packaged together in an integrated circuit (IC).

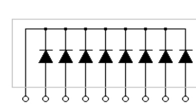


Common Anode



A variety of diode configurations are available.

Common Cathode



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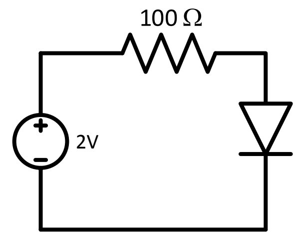
Example:

Find the Q-point (I_{DQ} and V_{DQ})

a) Use ideal diode model

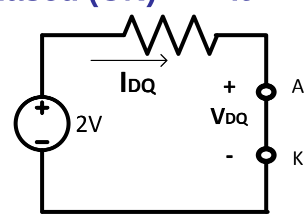
b) Use practical diode model

c) Use exact model



Solution

a) Since VA > VK , diode is forward biased (ON) ==> it can be replaced by a short circuit



V_{DQ}=V_{AK}=0 V

I_{DQ}= 2V/100 Ω=20 mA

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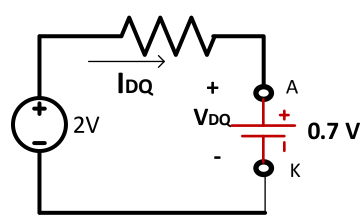
b) When using practical model , diode is replaced by a 0.7 V battery



V_{DQ}=V_{AK}=0.7 V

I_{DQ}= 2-0.7/100 = 13 mA

c) Exact solution yields

V_{DQ}=V_{AK}=0.786 V

I_{DQ} = 12.14 mA

Note: If applied voltage is much higher than VAK (at least 10 times) , then ideal diode model is recommended

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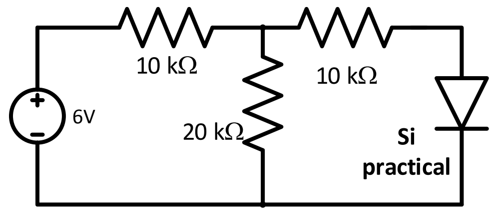
Example:

Find the Q-point

(I_{DQ} and V_{DQ})



Solution

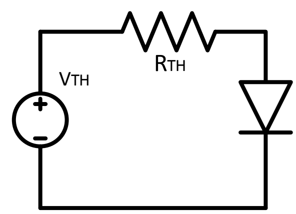
It is better to convert the two loop circuit to a single loop circuit by finding Thevenin's equivalent circuit

V_{TH}=6V. 20k/(20k+10k)=4 V

R_{TH}=(10k+20k//10k)=16.67 kΩ

V_{DQ}=V_{AK}=0.7 V

I_{DQ}= (4-0.7)/16.67 kΩ = 0.198 mA



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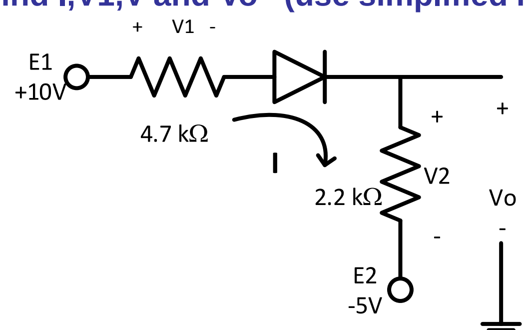
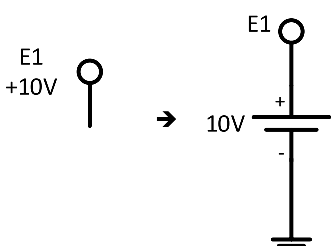
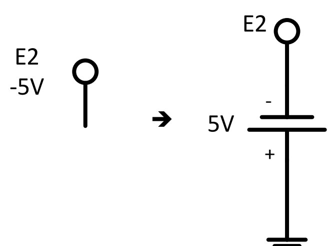
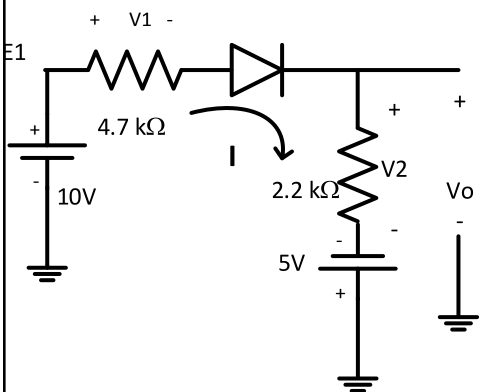
Example: **Find I,V1,V and Vo (use simplified model)**



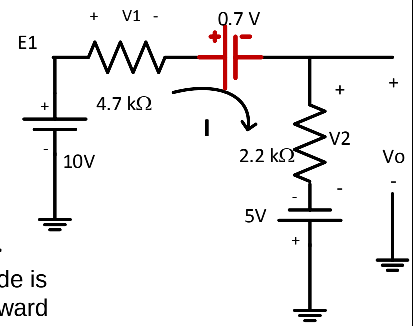
Solution:







==>
Diode is
Forward
biased



I=(10+5-0.7)V/(4,7+2.2) kΩ
=2.07 mA

V1=I . R1= 9.73 V

V2=I . R2= 4.55 V

Vo= V2- 5 = -0.45 V

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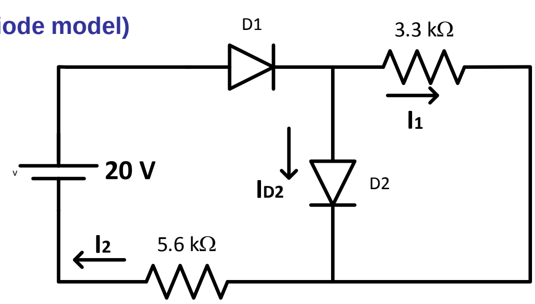
Find I_1, I_2, I_{D2} (use practical diode model)



Solution:

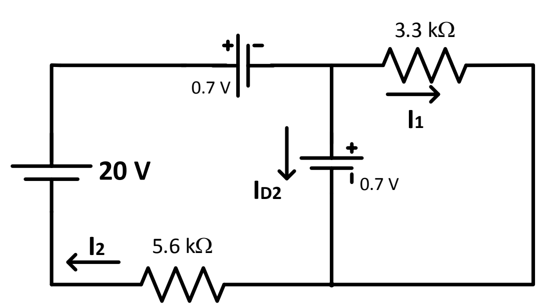
Applied voltage is suitable for forward biasing both diodes

I_1= 0.7 V/3.3 kΩ

=0.212 mA

I_2= (20-0.7-0.7)/5.6 kΩ

=3.32 mA



$I_2=I_1+I_{D2}$

$I_{D2}=I_2-I_1$= 3.32– 0.212

=3.11 mA